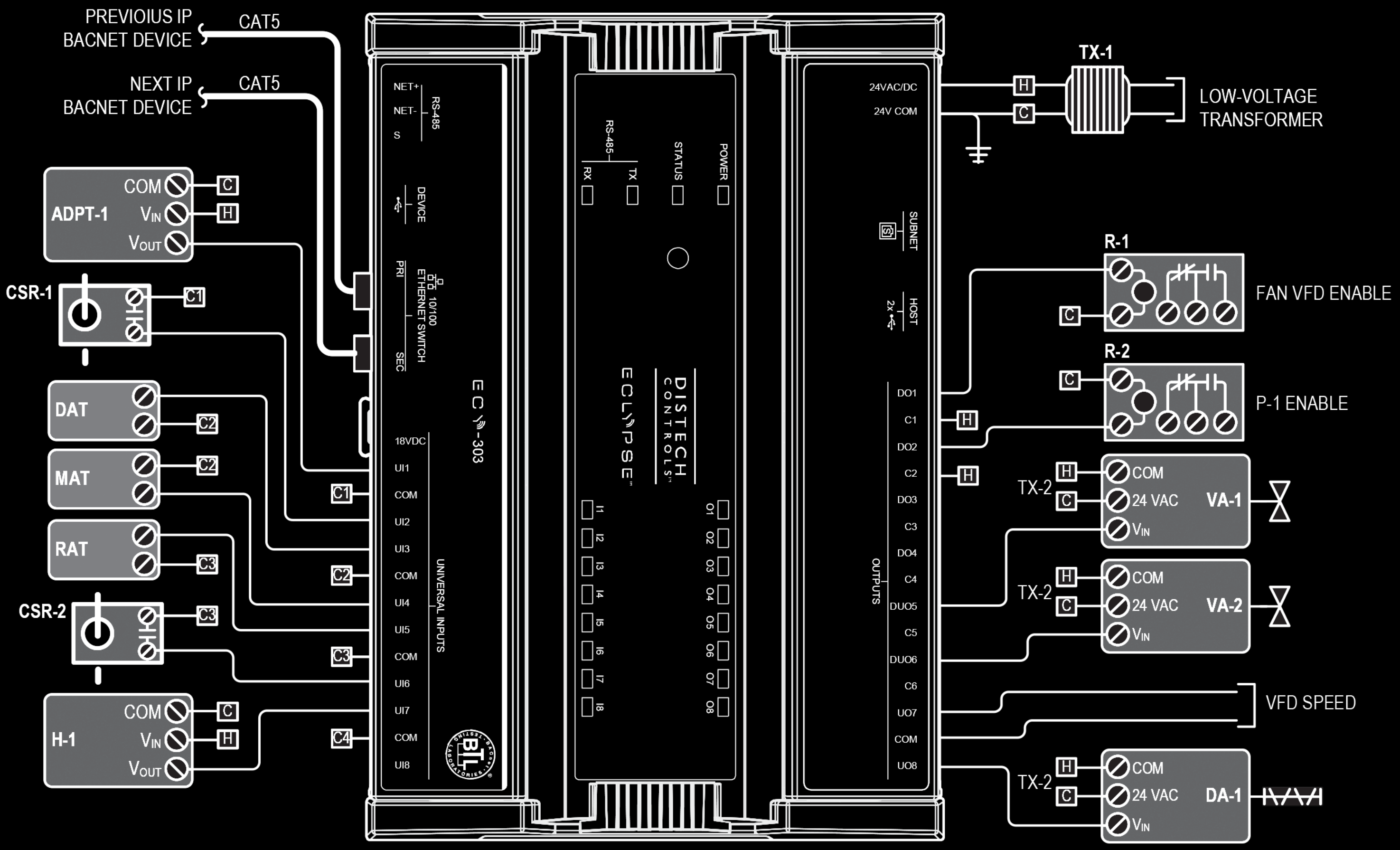
Fruit Cove Commissioning Series:

BAS Input and Output Devices

Third Edition

Francisco Valentine, PE



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PREFACE

This book provides a description of the field-testing methods that I have employed in the commissioning of Direct Digital Control (DDC) systems [also called Building Automation Systems (BAS), Building Management System (BMS), Energy Management Systems (EMS), or Energy Management & Control Systems (EMCS)] for Heating, Ventilation, and Air Conditioning (HVAC) system control. It was written to serve as a guide, reference, or training manual for those just beginning their BAS career as well as those who already have significant knowledge, training, and experience. The primary focus of this book is on the testing and verification of the typical input and output devices of a BAS and the creation of standardized testing protocols for each device.

I have had the opportunity to work with many Controls Technicians, Programmers, and their installation subcontractors. Because of the myriad of education, training, and experience levels of the people performing the building automation system work, the methods used to install, test, troubleshoot, calibrate, and verify proper operation are equally varied. To the extent possible, we should all be testing and calibrating BAS input and output devices using the same means and methods. Likewise, we should all have a common knowledge base, terminology, tools, and methods. Standards create consistency and consistency creates confidence. This book is an attempt to achieve common ground or a foundation among the people that install, test, troubleshoot, commission, calibrate, and service the BAS input and output devices and the systems they control.

It has been my experience that a significant portion of the issues identified during the commissioning of building automation systems are related to the installation, setup, configuration, and calibration of the input and output devices. As a result, system level functional performance testing is not recommended until you have thoroughly reviewed, verified, tested, and calibrated the BAS input and output devices or you have documentation that someone (typically the Controls Contractor) has done the same. Once the inputs and output devices have been verified, the information they provide can be trusted and used during the system and intersystem level tests. Countless hours can be wasted investigating, troubleshooting, documenting, testing, retesting, back checking, and updating documentation of failed system level tests only to find that the root cause of the issue was at the component level.

Environmental control is a major cost of doing business throughout the world and building automation systems are typically tasked with this objective. Like a chain, the BAS is only as good as its most poorly performing components. Identifying and correcting the poorly performing components restores the BAS and the controlled systems and equipment (HVAC, domestic water heating, renewable energy systems, lighting, electrical meters, etc.) to optimum efficiency and reliability while also improving occupant comfort. Therefore, more emphasis needs to be placed on education and training of the installation, setup, and configuration of the input and output components and this book is a small step in that direction.

The availability and proper use of the appropriate tools, equipment, and test instrumentation is a critical factor that is too-often overlooked and undervalued. The BAS input and output components cannot be properly tested and calibrated without these items. Many input/output devices are installed without testing or calibration because the installer may not be properly equipped or they rely on the fact that the installed components are new and therefore must be accurate. However, testing is required to verify its operation and determine its current accuracy. Without initial testing at installation, we will not know if the devices are performing adequately. Field test data is powerful, objective, and it always tells the truth. We just need to learn how to find it, collect it, and use it.

It took many years of education, field experience, training, and perseverance to acquire this body of knowledge and experience contained within this book. I feel a duty to share what I have learned and experienced in the world of Building Automation Systems through the writing and publication of this book. It summarizes the tools, equipment, and instruments that are required to do the testing and calibration work. It also conveys the insights, procedures, and techniques that I have acquired and developed over the years. Hundreds of tables, diagrams, and photos were included as visual aids to better understand the content. In addition, it provides procedures for testing and calibrating the typical BAS input and output devices. Review questions are also provided to test your understanding of the content. I hope that the readers find this book to be as useful, informative, and valuable as I believe it to be.

Take Me Home, Country Roads

By Bill Danoff, Taffy Nivert, and John Denver

Almost heaven, West Virginia
Blue Ridge Mountains, Shenandoah River
Life is old there, older than the trees
Younger than the mountains, growin' like a breeze

Country roads, take me home
To the place I belong
West Virginia, Mountain Mama
Take me home, country roads

All my memories gather 'round her
Miner's lady, stranger to blue water
Dark and dusty, painted on the sky
Misty taste of moonshine, teardrops in my eyes

Country roads, take me home
To the place I belong
West Virginia, Mountain Mama
Take me home, country roads

I hear her voice, in the mornin' hour she calls me
Radio reminds me of my home far away
Drivin' down the road, I get a feelin'
That I should have been home yesterday, yesterday

Country roads, take me home
To the place I belong
West Virginia, Mountain Mama
Take me home, country roads, everybody sing

Country roads, take me home
To the place I belong
West Virginia, Mountain Mama
Take me home, country roads

Take me home, down country roads
Take me home, down country roads

The Bridge Builder

By Will Allen Dromgoole

An old man going a lone highway,
Came, at the evening cold and gray,
To a chasm vast and deep and wide.
Through which was flowing a sullen tide
The old man crossed in the twilight dim,
The sullen stream had no fear for him;
But he turned when safe on the other side
And built a bridge to span the tide.

“Old man,” said a fellow pilgrim near,
“You are wasting your strength with building here;
Your journey will end with the ending day,
You never again will pass this way;
You’ve crossed the chasm, deep and wide,
Why build this bridge at evening tide?”

The builder lifted his old gray head;
“Good friend, in the path I have come,” he said,
“There followed after me to-day
A youth whose feet must pass this way.
This chasm that has been as naught to me
To that fair-haired youth may a pitfall be;
He, too, must cross in the twilight dim;
Good friend, I am building this bridge for him!”

ORGANIZATION OF THE BOOK

Section 1 consists of Chapters 1 through 7 which provide background information and preliminary data which are applicable to all of the chapters that follow. These topics include general BAS configuration, calibration of inputs and output devices, safety device wiring, and the required tools, instruments, and equipment. This minimizes the amount of data that will be repeated throughout the subsequent chapters.

Section 2 consists of Chapters 8 through 18 which are associated with various Binary Input devices.

Section 3 consists of Chapters 19 through 31 which are associated with various Analog Input devices.

Section 4 consists of Chapters 32 through 36 which are associated with various Binary Output devices.

Section 5 consists of Chapters 37 through 41 which are associated with various Analog Output devices.

Section 6 consists of Chapters 42, 43, and 44. Chapter 42 provides the testing protocol for Variable Frequency Drives (VFDs). VFDs were given a dedicated chapter because they require multiple points (binary inputs, analog inputs, binary outputs, and analog outputs) and a good understanding of their operation is required to properly test them. Chapter 43 provides the answers to the chapter review questions. Chapter 44 provides a summary of the abbreviations used in the book.

TABLE OF CONTENTS

Section 1: Preliminary/Common Information

Chapter 1 - Building Automation Systems (BAS)

1.1 General

Building Automation Systems (BAS) automate the control and monitoring of the Heating, Ventilation, and Air Conditioning (HVAC) equipment found in most commercial buildings. These include, but are not limited to, Air-Handling Units (AHUs), Fan Coil Units (FCUs), Unit Ventilators (UVs), Roof-Top Units (RTUs), Dedicated Outdoor Air Systems (DOAS) units, Terminal Units (TUs), boilers, chillers, pumps, cooling towers, Energy Recovery Ventilators (ERVs), Heat Recovery Ventilators (HRVs), etc. The BAS provides central monitoring, sophisticated control strategies, graphics, alarming, trending, scheduling, notification, and other diagnostic tools that conventional line-voltage and low-voltage controllers cannot provide. Building automation systems accept setpoints, schedules, and input signals (binary and analog) from input devices (temperature, static pressure, humidity, status contacts, etc.), they process these signals based on its programmed logic, and they provide output signals (binary and analog) which are used to control output devices (valves, dampers, relays, etc.) and equipment. The programmed control logic resides within the BAS controllers.

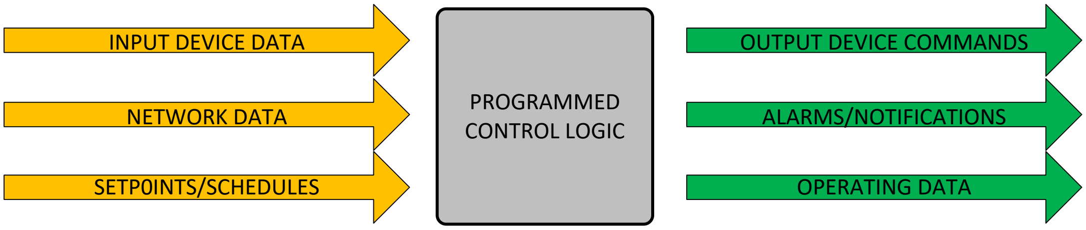


Figure 1 - Typical Controller Configuration

HVAC systems are logical collections of equipment that provide a specific function – conditioning the occupied environment or parts thereof. The BAS allows us to monitor and control the various functions of the HVAC systems and it follows the same topology as the HVAC systems. Central heating and cooling plants typically have dedicated controllers. Their purpose is to provide the chilled water, hot water, steam, and condenser water required by the HVAC equipment distributed throughout the building. Air-handling units and terminal units generally have dedicated controllers because they have specific purposes and condition specific areas. In other words, all input and output devices necessary to control the air-handing unit are connected to the same controller. It is considered poor control system design to use multiple controllers to control a system. The selected BAS controller should have enough input and output points to accommodate the required point density and control strategy.

1.2 ATC Submittal

The ATC (Automatic Temperature Controls) Submittal is prepared by the Controls Contractor to demonstrate how they plan to satisfy the design and performance requirements of the project. It typically contains the BAS system architecture, wiring strategies, naming conventions, bill of materials, component data sheets, sequences of operation, valve and damper schedules, system schematics, input/output device locations, and panel locations. Once the ATC submittal is approved, the control system components are purchased, installed, powered, programmed, and tested. After construction, this document is updated to reflect the actual construction, operations and maintenance data added, and it is resubmitted as an "As-Built" ATC submittal. The ATC submittal is the best data available for use in control system testing, troubleshooting, calibration, commissioning, and balancing. The approved ATC submittal is typically the starting point from which to generate pre-functional checklists and functional performance checklists. There are typically issues when equipment that is not the basis of design has been selected. Occasionally, the differences are so drastic that the sequences of operation must be substantially modified to accommodate the capabilities of the installed equipment. Issues are also encountered when the control system design is based on the design documents instead of the approved equipment submittals.

1.3 BAS Sequences of Operation

Sequences of Operation (SOO) are typically provided in the contract documents and detail how the associated equipment/systems will operate, what modes of operation they will provide, what input and output devices are to be provided, fail-safe positions of dampers and valves, what conditions constitute alarms, and what happens during the alarm conditions. If equipment with packaged controls is purchased, the SOO may be provided by the equipment manufacturer. Packaged controls are typically configurable, so the SOO is actually variable and dependent on the programmed settings. It is not uncommon to find that the packaged controls cannot satisfy the SOOs. It may lack physical components, appropriate input/output points, or required programming. There typically is no remedy because additional components cannot be added, there are no spare input/output points, and the programmed logic cannot be accessed and modified.

Industry best practices often dictate the required sequences of operation. If a mechanical design is missing SOO that should be included or has SOO that should be excluded, the Controls Contractor should submit a Request for Information. It is an industry best practice to include discharge air temperature sensors on terminal equipment because it helps immensely with troubleshooting and performance monitoring. When the installed equipment is different from the basis of design, there may be differences in the equipment that the SOO did not address or foresee. If the omission requires a significant amount of material, labor, or programming time to provide, then a Change Order Request may be submitted for consideration. In other cases, a credit may be due.

The sequences of operation should be simple and concise. Some Engineers have bad experiences with a particular control sequence and overcorrect on subsequent projects by making the SOOs long-winded, overly intricate, and convoluted. It is typically best to explain the modes of operation included in the SOO once to avoid unnecessary repetition and contradiction. If the modes of operation are mentioned in multiple places and they are not all coordinated, it is very possible that there will be conflicts. Long-winded and overly complicated SOOs make it difficult to understand what is required. Without clear direction, it is difficult to program the required control logic. This difficulty translates to the drafting of testing and verification checklists. It is best to keep it simple. Clear and concise SOOs reduce cost and time requirements for all related tasks.

1.4 BAS Controller Types

1.4.1 Supervisory Controllers

There are three types of controllers that will typically be encountered in a building automation system. They are Supervisory controllers, programmable controllers, and application specific controllers. Supervisory controllers, like the JACE or NAE, provide central access, control, monitoring, troubleshooting, programming, maintenance, upgrades of all connected controllers. They integrate the data points provided by the connected controllers and make the data available for use by any controller. For example, an outdoor air temperature sensor connected to a controller may be used by any other controller whose programmed control logic requires it. This is typically done for economizer, supply air temperature reset, hot water supply temperature reset, freeze pump control, etc. This precludes the unnecessary inclusion and cost of multiple outdoor air temperature sensors that are connected to various controllers. In addition, their readings may differ significantly because of the various installation conditions. Supervisory controllers typically have the ability to execute programmed logic and accept input and output devices via onboard Input/Output (I/O) terminals or expansion modules. Supervisory controllers are connected to the field controllers (Programmable and Application Specific Controllers) through either Ethernet or serial communication wiring and communicate using one of many available communication protocols (BACnet, Modbus, Lonworks, etc.).

Photo 1 - Distech Controls EC-BOS-8 JACE

Photo 2 - Honeywell WEB-8000 JACE

Photo 3 - Building Logix JACE

1.4.2 Programmable Controllers

Programmable controllers provide system control through custom programming which can be modified at any point to suit field conditions or changing design and/or performance standards. Like supervisory controllers, programmable controllers may also accept I/O expansion modules to increase its point capacity. They may also have outputs that are equipped with manual overrides (potentiometers and Hand-Off-Auto switches) which make testing and verification very easy for the installation personnel. The manual overrides allow them to verify control before the BAS Technician/Programmer arrives which saves valuable time. Many programmable controllers come with user interface which allows the input and output data points to be viewed and modified without requiring any additional devices or adapters. The greatest advantage of a programmable controller becomes supremely evident when troubleshooting, control verification, or functional performance testing is required on equipment with extensive and complicated sequences of operation. With open access to the programmed logic (line code or logic blocks), it is easy to verify that the required control logic has been provided. In addition, it allows us to verify the presence of control logic that should not be present so that it may be removed. When the programmed control logic is accessible for review and testing, it is much easier to verify that the equipment or system is operating in accordance with the design requirements. If it is not, then it can be modified.


Photo 4 - Distech ECB-410 Programmable Controller

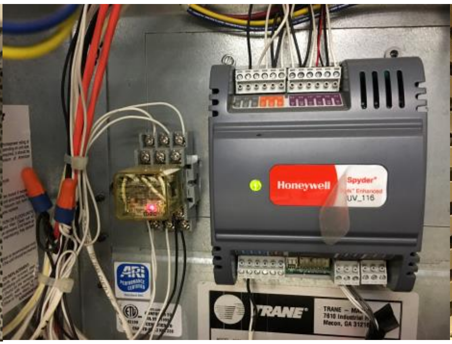


Photo 5 - Honeywell Spyder PUB4024S Programmable Controller


Photo 6 - Distech ECY-303 Programmable Controller

1.4.3 Application Specific Controllers

Application Specific Controllers (ASCs) are controllers that are pre-loaded with "canned" control logic. They are typically used in applications that require a low number of input/output points and very simple control strategies with very little variation. For example, Variable-Air-Volume (VAV) Terminal units, fan coil units, and unit ventilators are often controlled with ASCs. The programmed control logic is typically not accessible for viewing by field personnel. Field personnel typically only see a set of input and output points or parameters that control how the ASC operates. The sequences of operation typically accompany the ASC and explains the control logic and how the various parameters affect its operation. Because the sequences of operation are limited, it is typically easy to perform functional performance testing. ASCs may use a hand-held device to provide access to its settings or a small user interface screen and buttons. Many have a built-in web server that allow users to access the program settings through a web browser. Others require proprietary software running on a laptop and an adapter to connect to the ASC for configuration, testing, and calibration. The previous generation of Siemens TEC VAV controllers were a favorite among balancing professional because of the WCIS software. It made access to the controller's configuration simple, quick, and reliable.

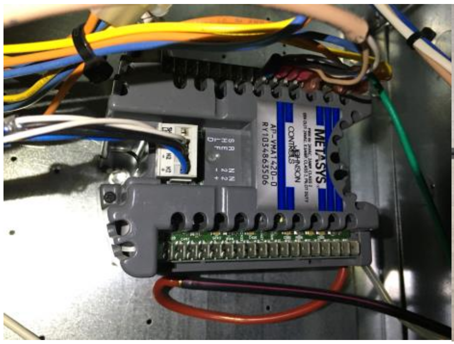


Photo 7 - Johnson Controls Metasys VMA1420 VAV Controller


Photo 8 - Honeywell TB7200 BACnet Air-Handling Unit Thermostat

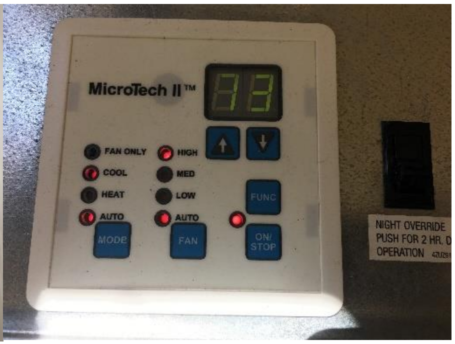


Photo 9 - Microtech II Controller in a Fan Coil Unit

1.5 BAS System Configuration

It is important to have an idea of how the typical BAS is configured. The approved controls submittal typically provides a BAS riser diagram that shows the overall layout of the control system. The simplest building automation systems will resemble the following diagram which will typically include: a supervisory controller (network adapter), BAS field controllers, input devices, output devices, and a communication bus. The typical network adapter is called a JACE which stands for Java Application Control Engine and is the component that integrates all BAS controllers into a "system." In this particular example, there is no onsite head-end computer (or supervisor) for the staff to access the BAS, so all environmental control-related issues (hot calls, cold calls, equipment operating failures, special events scheduling, etc.) are communicated to the Controls Contractor who must visit the site to assess the situation, troubleshoot, modify schedules, and make any necessary adjustments, calibrate, review trend data, make repairs, and provide recommendations. Remote access for the Controls Contractor may be an option.

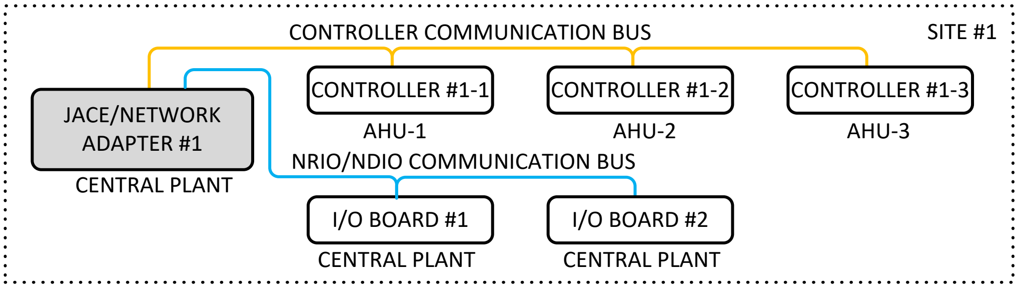


Figure 2 - Simple BAS Configuration

The supervisory controller (JACE or its equivalent) is the brain of the building automation system. Every manufacturer of building automation controls has an equivalent supervisory controller that integrates their BAS controllers into a single cohesive system. The supervisory controller is typically located in the main mechanical equipment room in a Local Control Panel (LCP). Without a supervisory controller and a fully functional communication bus, access to each BAS controller is established by physically connecting to each of them, one by one. This is a cumbersome and time-consuming prospect. Alternatively, through a properly configured supervisory controller and communication bus, the program of any BAS controller can be accessed, modified, tested, and reloaded from a single location. In addition, the data provided by any BAS controller is available for use by any other BAS controller in the system.

Programming specific to the equipment (AHU, FCU, UV, RTU, etc.) being controlled resides in each BAS controller. Programming can also reside in the supervisory controller and this logic can be pushed down to the BAS controllers or it can be used to provide direct control and monitoring through its Input/Output (I/O) modules. Because of the immense processing power of the supervisory controllers, compared to typical BAS controllers, it can be used to provide direct control and monitoring of equipment or central plants requiring a high input/output point count. The supervisory controller communicates with the I/O modules on a communication bus (represented by blue lines) separate from the communication bus used to pass data to and from the BAS controllers. A building's central plant equipment and sensors are typically connected to I/O modules and its programming resides in the supervisory controller. With this BAS configuration, the central plant is not dependent on the integrity of the BAS controller communication bus which is distributed throughout the facility.

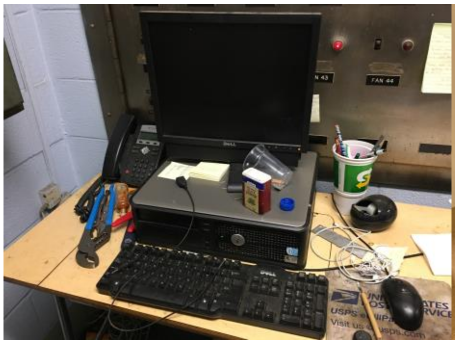


Photo 10 - BAS Supervisor Example #1

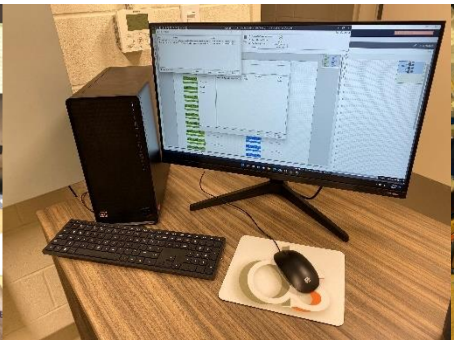


Photo 11 - BAS Supervisor Example #2


Photo 12 - BAS Supervisor Example #3

The supervisory controller permits the sharing of operating data across the BAS. Some data points are required by the programmed logic in various pieces of equipment. Outdoor air temperature, for example, is typically used by the central hot water plant, chilled water plant, most air-handling units, coil freeze protection pumps, and seasonal control valves to control aspects of their operation. It would be wasteful to install an outdoor air temperature sensor at each of these systems when only one is required. A "global" outdoor air temperature sensor is typically connected to the central plant supervisory controller, but it may also be connected to the closest BAS controller. This value can then be communicated to the rest of the BAS controllers that require it. With this strategy it is only necessary to install, configure, test, calibrate, program, bind, and maintain one outdoor air temperature sensor instead of numerous units. This outdoor air temperature sensor should be nearly perfect in terms of accuracy and location to qualify as a "global" sensor. The same strategy is used for all global data points (emergency shutdown, outdoor air humidity, outdoor air enthalpy, wet-bulb temperature, etc.).

The communication bus which typically utilizes the BACnet, Modbus, or Lonworks protocols is represented by orange lines in the diagram above. They originate at the supervisory controller and are typically connected to the BAS controllers in a daisy chain fashion, but other topologies are possible. The last controller typically has an end-of-line terminator or resistor. The controller communication bus is equivalent to the nervous system in the human body. It is responsible for transporting operating data between the supervisory controller and BAS controllers. If, for example, the outdoor air temperature sensor was connected to BAS controller 1-1 and the controller communication bus failed, then the outdoor air temperature reading would no longer be available for the other BAS controllers. Likewise, without the BAS controller communication bus it would not be possible to connect to this controller through the supervisory controller. BAS controller 1-1 is still fully functioning at the local level, but the outdoor air temperature reading will not be available to the other controllers until the failure in the controller communication bus is corrected.

Controls Contractors typically have maintenance and service contracts with Owners at many sites where they have installed control systems. Remotely accessing a BAS installation for troubleshooting, service, or program updates is a huge advantage for both the Controls Contractor and the Owner. This provides them quick initial response time to perform troubleshooting and analysis while minimizing travel costs. It also allows them to perform ongoing system maintenance activities such as software updates, programming changes, trend data review, and control logic review remotely. This system configuration will resemble the diagram shown in Figure 3. The dashed green line represents a temporary connection that the Control Technician makes to remotely access the BAS. The Control Technician can also access the BAS through the supervisory controller or switch while on site.

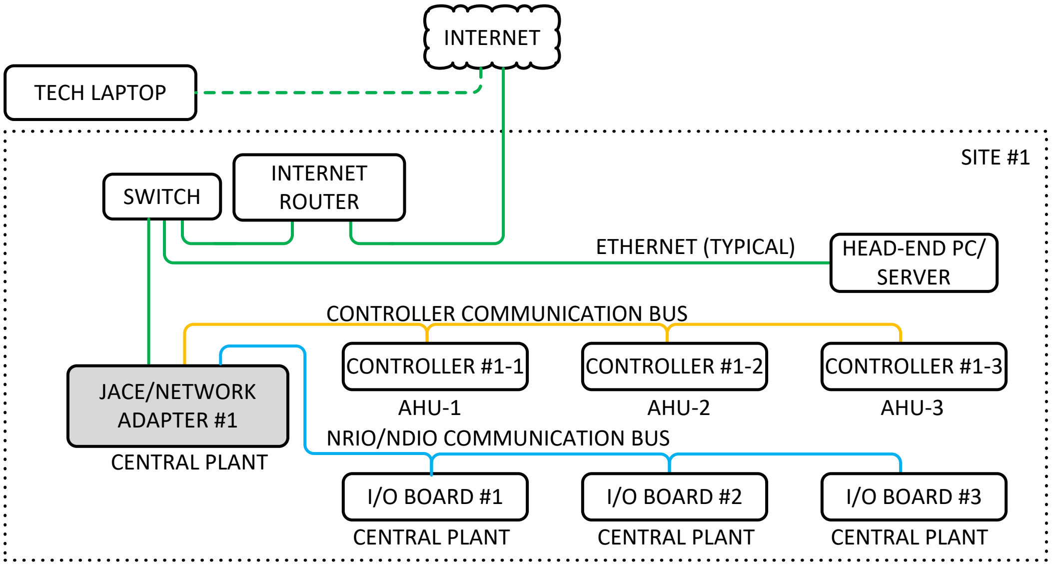


Figure 3 - Simple BAS Configuration with Remote Access

In larger installations, the BAS communications may utilize the Owner's Ethernet network upon which the internet, email, file server, and telephone services reside or it may utilize a totally separate Ethernet network dedicated to the BAS. When the BAS is on the same Ethernet network as the Information Technology (IT) services, a Virtual Private Network (VPN) is typically created for the BAS infrastructure. This effectively creates a private tunnel on the IT network through which the BAS information travels. Only those with the proper credentials to access the BAS VPN can access the BAS. It also prevents these people from accessing data beyond the BAS VPN. Even though they are both on the same physical network infrastructure, each one is oblivious to the other. The green lines represent the Ethernet communication bus. Some Owners choose to have a totally independent BAS Ethernet network to provide a physical barrier between the IT infrastructure and the BAS networks. This BAS system configuration is without a doubt the most secure, but it does require the additional cost to install the second network. The level of security required for each system must be weighed against the cost of security and risk level. Users can be given varying levels of access to the BAS. Most people may have view-only rights while others may be given the ability to change setpoints, modify schedules, and override valve and damper commands. A select few may be granted access to the control logic. However, this is only recommended if they are thoroughly familiar with the Niagara software (or equivalent) and its use.

As the buildings get larger and its HVAC infrastructure become more expansive, so does the BAS. Supervisory controllers have limitations on the number of devices that they can handle. Exceeding these limits reduces the reliability and stability of the BAS, so multiple supervisory controllers may be required. Larger sites will utilize a supervisory controller with I/O modules to control and monitor the central plant equipment. The plant supervisory controller may also have BAS controllers connected to its controller communication trunks. Additional supervisory controllers will be provided, as necessary, to integrate the remainder of the BAS field controllers into the BAS.

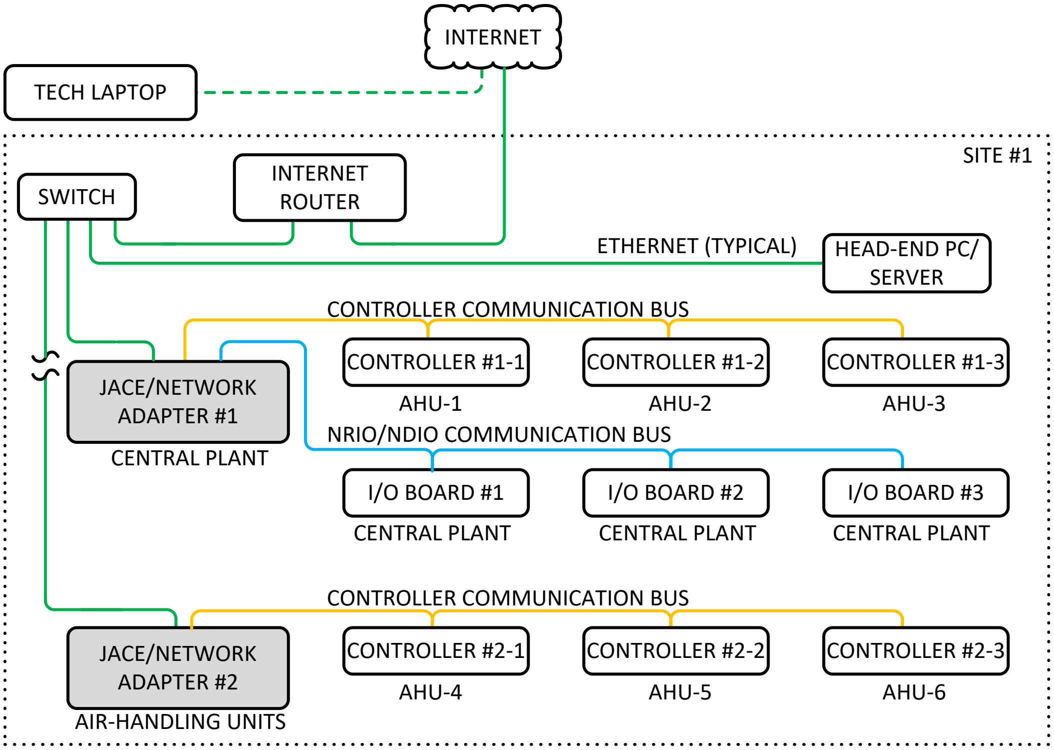


Figure 4 - Larger Building Automation System Configuration

Many BAS installations will have a head-end computer (also called a supervisor or server) where the maintenance and operating staff interface with the BAS. This desktop computer may have either browser access to the supervisory controller or it may be configured as a supervisor. If configured for browser access, the IP (Internet Protocol) address of the supervisory controller is entered in the address bar of an internet browser program to access the BAS graphics. This provides review of the system graphics, operating data, schedules, alarms, and trend data on the JACE. A valid user profile must exist that has been configured with the appropriate access.

A supervisor has the same software that the Control Technician has on their laptop, but the license is purchased to accommodate the expected point/device counts for the planned BAS. Through the supervisor, all of the programming tools are available and it is used to integrate with other JACE panels on this and/or other building or sites. This allows access to all configured systems through a single user interface. When a supervisor is included with the BAS design, the graphics are typically stored on it (as opposed to the supervisory controller) to speed the delivery of this data. BAS graphics stored on the supervisory controller (JACE) can be slow. The supervisor typically has additional storage capacity to store historical trend and alarm data. A supervisor is also advantageous when the BAS monitors and controls a large VRF (Variable Refrigerant Flow) system. The VRF panels typically include an Ethernet port which allows it to communicate over IP (Internet Protocol) directly to the supervisor rather than going through a JACE. It makes the processing of the VRF data more efficient and the graphics so much faster.

The size, configuration, and placement of the HVAC systems dictate the need for more complex BAS configurations. The layout of the HVAC control system follows the configuration of the HVAC system design. Large BAS Owners, such as college campuses or county/city school districts, and local governments centrally monitor their BAS-equipped buildings from a central monitoring site through a wide-area network.

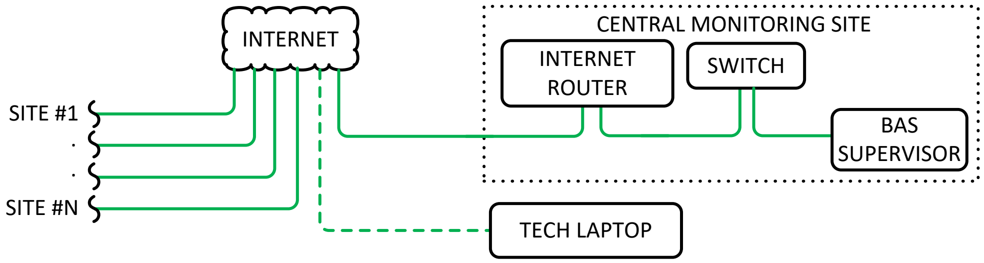


Figure 5 - Distributed Building Automation System Configuration

This BAS system configuration allows central scheduling, monitoring, control, trending, alarming, and notification. The Owner will typically have a person or group that monitors the HVAC system operation and changes schedules and setpoints to optimize the controlled environment for comfort and/or efficiency. Depending on their staffing levels and technical competency, the Owner may address hot calls, cold calls, and equipment failures directly or they may call the Controls Contractor to address them as they arise. Once a user logs into the BAS, they can access any site that their profile allows. It is also important to keep in mind that the BAS Owner may have multiple BAS supervisors representing the various BAS manufacturers used throughout their buildings.

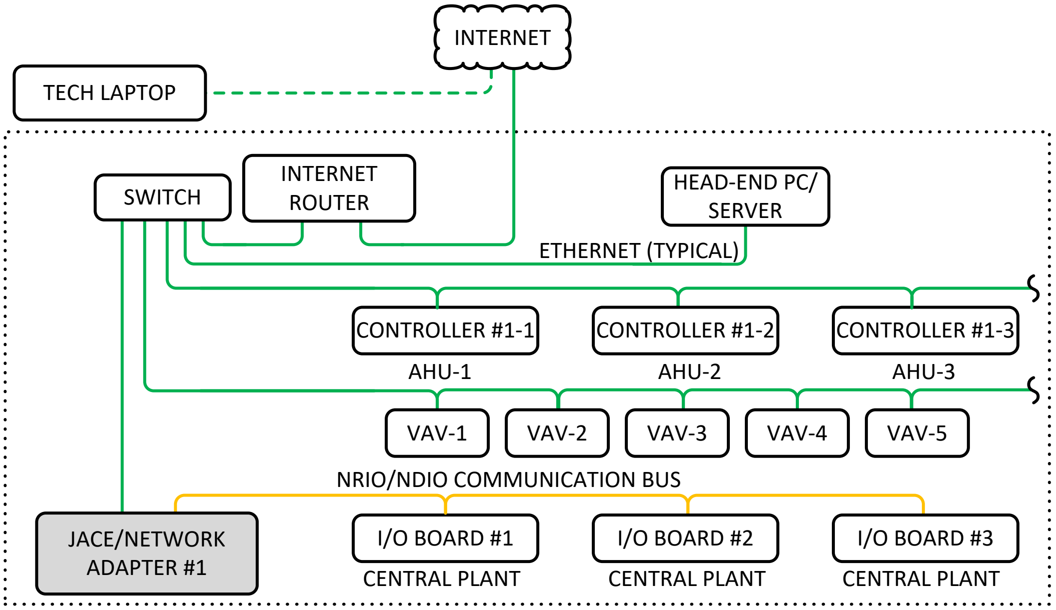


Figure 6 - Flat Network Topology of Ethernet-Connected Controllers

Distech Controls is a leader in the transition from TIA-485 (commonly referred to as RS-485) communications to Ethernet (four twisted pairs of wires) communications. Ethernet connectivity eliminates the often-immense amount of time that is expended to establish communication, identify connectivity issues, troubleshoot the issues, and correct the issues with the RS-485 communication trunks. Ethernet network testers are used to verify that the eight conductors are properly terminated. The eight wires have two possible termination standards that were determined by the Telecommunications Industry Association (TIA). The wires may be configured for either TIA 568A or TIA 568B. TIA 568B is typically used in building automation systems and networking applications in the United States and has a specific wiring sequence (Orange-White, Orange, Green-White, Blue, Blue-White, Green, Brown-White, Brown). Ethernet communication has already proven to be more flexible and faster in terms of data throughput, easier to establish system communication, and more reliable than the previous RS-485 communications. Data is served up on the BAS graphics very quickly now that the JACE does not have to wait as long for it to arrive. The Master-Slave/Token-Passing (MS/TP) baud rate is typically set to 38,400 Kilobits per Second (KBS) transfer speed and data requests are processed sequentially through the passing of a token. On the other hand, Ethernet communication operates at 100 Megabytes per Second (MBS) and allows the simultaneous transfer of data on multiple pathways and multiple protocols for dramatically improved data transfer rates (200-300 times faster). In addition, it facilitates a flat BAS system hierarchy where a high percentage of the controllers directly communicate with the JACE and each other through the Ethernet communication bus. As Figure 6 indicates, all of the devices connected with the solid green wires are on the same network level. With the JACE, supervisor, field controllers, and integrated equipment (boilers, chillers, packaged rooftop units, VFDs, etc.) on the same level in the communication network, this enhances the efficiency and throughput of the data and significantly reduces the wait times for the population of data-intensive equipment summary tables and graphics.

1.6 BAS System Construction

The installation of a building automation system typically requires the involvement and coordination of several parties. Each party is responsible for their portion of the installation process, but the execution of the work may occur in a serial fashion or may occur in parallel (or simultaneously). Recognizing these serial and parallel relationships is important to understanding the planning and execution of the required BAS construction work. Some parties simply cannot do their work until others have done theirs. For example, the installation of air-handling unit controls components (sensors, actuators, wiring, etc.) can occur at the same time that the electrical power is being run to this unit, but the point-to-point checkout of the BAS controller cannot occur until the electrical power, either permanent or temporary, has been established.

While we recognize that the participation of multiple parties is absolutely required to accomplish most BAS construction projects, we must also recognize that the addition of each new party introduces the potential for errors. This potential for errors is increased when we factor in communication, construction schedule, differences in interpretation, language barriers, staffing levels, training, funding, etc. Building automation systems typically require multiple contractors working in concert. Table 1 shows most of the construction tasks and the responsible parties typically required to execute a successful building automation system installation. It also makes it clear that there must be open lines of communication between the various participants. The participation of so many contractors and their subcontractors underscores the need and importance of BAS input and output testing and verification.

BAS Construction Tasks	Contractor
Equipment Survey	Controls
Controls Engineering/Submittal Generation	Controls and/or Subcontractor
Conduit/Wiring Installation for Electrical Power	Controls and/or Electrical Subcontractor
Conduit/Wiring Installation for Sensors and Actuators	Controls and/or Electrical Subcontractor
Conduit/Wiring Installation for Communication Bus	Controls and/or Electrical Subcontractor
Conduit/Wiring Installation for Network Communication Bus	Controls and/or Electrical Subcontractor
Construction/Installation of Local Control Panels	Controls and/or Electrical Subcontractor
Installation of Sensors and Actuators	Controls and/or Electrical Subcontractor
Landing of Wires in the Local Control Panels	Controls and/or Electrical Subcontractor
Labeling of Wires in the Local Control Panels	Controls and/or Electrical Subcontractor
Labeling of Field Devices (Space Sensors/Pressure Pickups, etc.	Controls and/or Electrical Subcontractor
Start-up and Load Control Programs	Control Technician
Point-to-Point Checkout	Controls and/or Electrical Subcontractor
Input/Output Device Calibration	Controls Contractor
Verification of Equipment Integrations	Controls Contractor
Verification of Fire Alarm System Interface	Controls Contractor & Fire Alarm
Variable Frequency Drive Installation	Electrical Subcontractor
Variable Frequency Drive Wiring & Start-up	Controls Contractor and/or Electrical Subcontractor
Airflow Measuring Station Installation	Mechanical & Controls Contractor
Airflow Measuring Station Calibration	Controls Contractor & TAB
Hydronic Flow Meter Installation	Mechanical & Controls Contractor
Hydronic Flow Meter Calibration	Controls Contractor & TAB
Air System Testing, Adjusting, and Balancing	Controls Contractor, TAB, Mechanical
Water System Testing, Adjusting, and Balancing	Controls Contractor & TAB
Programming of Control Logic	Controls Contractor and/or Electrical Subcontractor
BAS Graphics Generation	Controls Contractor and/or Subcontractor
Binding of Points to the Graphics	Controls Contractor
Programming of Alarms	Controls Contractor
Programming of Trends	Controls Contractor
BAS Commissioning	Mechanical, TAB, Controls, and Manufacturer's Rep.

BAS Construction Tasks	Contractor
BAS Training	Controls Contractor
As-Built Documentation Submission	Controls Contractor and/or Subcontractor
Warranty	Controls Contractor

Table 1 - BAS Construction Tasks by Contractor

In most Design-Bid-Build projects, the TAB (Testing, Adjusting, and Balancing) and Controls Contractors are contracted through the Mechanical Contractor. This antiquated model may have been appropriate during the glory days of pneumatic controls when Mechanical, TAB, and Controls Contractors could work on the controls systems. However, with the advent of Direct Digital Controls (DDC), the same three contractors now focus almost exclusively on their individual trades and there is much less overlap with regard to the controls system. No longer is it possible for the Mechanical or TAB Contractors to tinker with the control systems. If a building is equipped with a BAS, the TAB Contractor requires the assistance of the Controls Contractor to posture the system for testing and balancing. TAB contractor access to the BAS is typically limited to terminal unit controllers to facilitate airflow balancing and calibration work. The TAB contractor is also involved with the calibration of the airflow measuring station and hydronic flow meter readings.

A laptop or computer with the appropriate software and licenses is generally required to access today's building automation systems. In addition, specialized education, training, and experience are required to use the programming tools, define input/output configurations, and calibrate the device readings. The installation and configuration of building automation systems is a specialty that requires specialists. As such, it makes more sense today for the Controls Contractors to be contracted directly through the General Contractor or the Owner. They should participate as equals to the Mechanical Contractor instead of subordinate to them. This would facilitate more formal lines of communications with the Control Contactor and would drastically improve their awareness of the overall project. In addition, it would provide direct access to the Controls Contractor who provides the most critical component of HVAC system. The service that the Controls Contractors provides is too important to the success of any project where a BAS is installed to be relegated to the third tier of the contractor-subcontractor hierarchy.

The Controls and TAB contractors are typically the last to enter the construction site because their ability to execute their work is limited until the mechanical and electrical systems are installed and powered and all piping and duct systems are complete. Unfortunately, construction projects are often behind schedule or are struggling to maintain current schedule milestones when the TAB and Controls Contractors begin their field installation work. Undue pressure is typically placed on them to perform their work with less time than is required to do their work properly, accurately, and completely. Working under these conditions only increases the potential for missed, incomplete, and erroneous work.

Subcontractors are often used to augment the work force required to accomplish each project. Many Controls Contractors utilize Electrical Subcontractors to install all or parts of the control system. They then utilize their own Control Technicians to review the installation, load programs, perform point-to-point checkouts, calibrate input/outputs, verify the control sequences, and complete the BAS graphics. Some larger Controls Contractors subcontract their BAS graphics generation, control logic programming, and controls submittal generation to smaller companies or their foreign subsidiaries. The introduction of each new party into the BAS construction process increases the possibility of errors and omissions if the prime contractor and their subcontractors are not very closely coordinated. Installation errors are also committed when the installer is not familiar with the controls components being installed or the HVAC systems in which they are installed. It is easy for them to install the BAS sensors in the wrong locations or install the incorrect controls devices. If the Controls Contractor has not invested the prerequisite time and detail in their controls submittal, then the installing Electrical subcontractor will be more likely to make installation errors that will have to be identified and corrected.

Some Controls Contractors have licensed electricians on staff that can perform high voltage (>50 VAC) as well as the low-voltage electrical work. In these companies, many of the Control Technicians are themselves Electricians. This business model brings value and efficiency to the Owner. The Controls Contractors with in-house electricians typically provide a higher quality installation because the Control Technicians and installing Electricians are on the same team and work together consistently. The close coordination between them ensures that errors from previous projects are identified, remembered, and corrected so that they are not repeated in future projects. This collective history and knowledge base grows with each project and fosters an environment of continuous improvement, comradery, and trust. Therefore, the quality of their work is typically higher than controls providers that use electrical subcontractors for the installation work.

A common problem with the building automation system construction projects is the lack of involvement of the Controls Contractor with the equipment submittal process. As previously mentioned, the Controls Contractor typically is contracted through the Mechanical Contractor. The Mechanical Contractor prepares equipment submittals in response to the mechanical design and specification requirements. The specifications indicate which alternate equipment manufacturers are acceptable and the Mechanical Contractor submits either the basis of design or an allowable alternate. Their submitted equipment is often different from the basis-of-design equipment that is provided on the mechanical plans and specifications. The configuration, capabilities, and accessories of the alternates may be vastly different from the basis-of-design equipment and this could substantially affect the controls system design. Meanwhile, the Controls Contractor is also preparing their controls submittal to submit to the Mechanical Contractor, but the Mechanical Contractor may not have shared the fact that they intend to submit something other than the basis of design equipment. As a result, the control system design, component selection, and installation are based on the basis of design equipment instead of the selected alternate. A lot of time and expense can be incurred to correct the resulting errors. This tends to happen most frequently with air-handling units (AHUs, RTUs, DOASs, ERVs, HRVs, etc.) because they can have so many possible variations in their design and configuration.

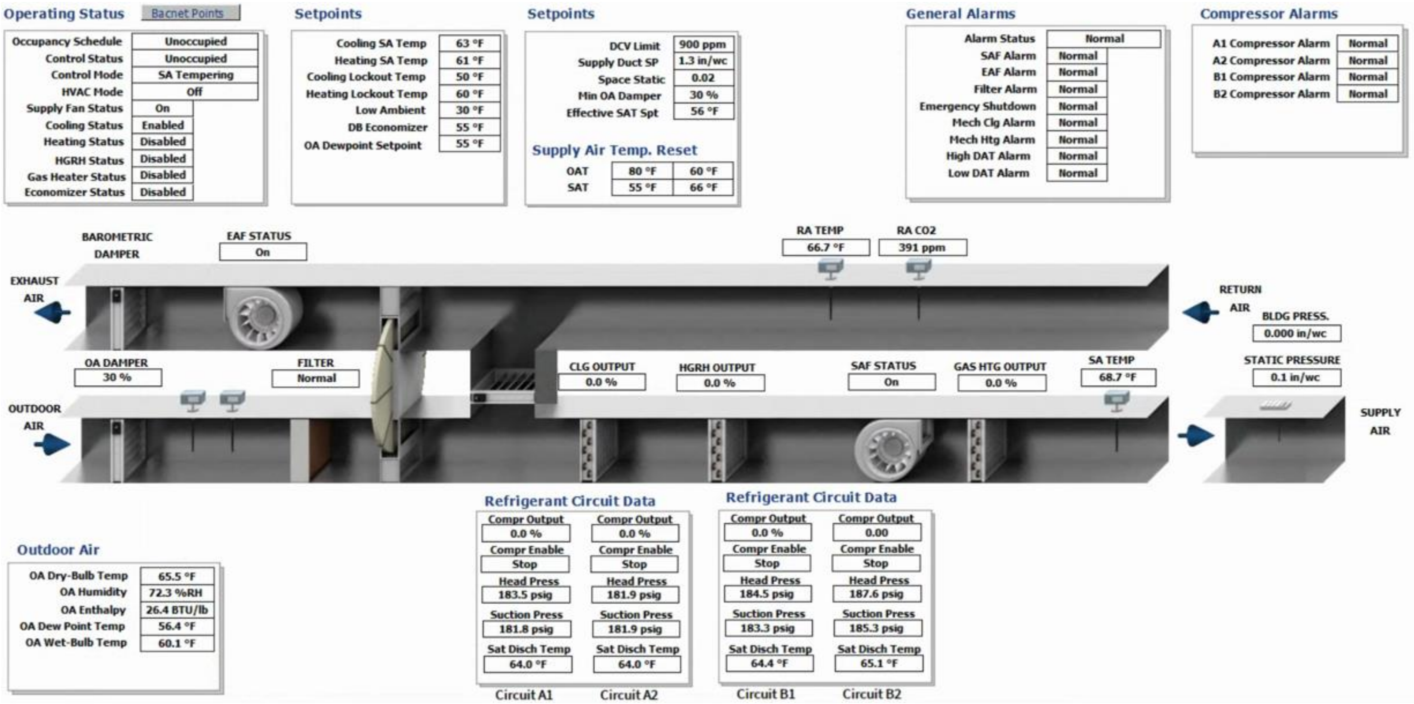
After the control components have been ordered and the installation process has begun, either the Controls Contractor or their installation subcontractor discovers that there are differences between the control drawings and the installed equipment. Some equipment differences often require modifications of the control components and sequences of operation. Had the Controls Contractor been aware that the submitted mechanical equipment differed from the basis-of-design, these issues could have been identified and avoided. This issue has a very simple solution – communication. Unfortunately, this scenario plays out regularly and leads to a host of installation errors and the unnecessary waste of time, money, and resources to perform remedial work. The controls submittal should always be based on the approved mechanical submittals to ensure that it satisfies the project requirements in the most economical fashion. However, it can be difficult to do this when the controls submittal is submitted at the same time that the mechanical equipment submittals are submitted.

1.7 BAS Graphics

The BAS graphics are a very important part of the BAS. This is especially true for those Owners, Operators, and users that rely on the BAS graphics to test, adjust, monitor, troubleshoot, and operate their buildings. It provides a window or Graphical User Interface (GUI) into the BAS and allows them to monitor and adjust the system control settings and schedules with a few mouse clicks rather than programming. If the BAS has equipment graphics and you are responsible for testing them, this will significantly increase the amount of commissioning effort required. The BAS graphics can be thought of as web pages with embedded BAS data points that provide a graphical representation of the actual equipment, its configuration, and its operation. BAS graphics are very tedious to generate and rely heavily on consistent point naming conventions. A point naming convention is a valuable tool that increases consistency, minimizes point naming errors, and facilitates quick and easy point name searches for implementing global changes and overrides when required.

There is no guarantee that the controller data points bound to the BAS graphics are correct (Figure 7). Just as the point-to-point checkout of each input and output device is required for each BAS controller, the binding of each data point displayed on the BAS graphic also requires a graphical point-to-point checkout. Errors and omissions in the BAS graphics are very common. To minimize the time and cost of verifying the BAS graphics, it should be done while the BAS controller point-to-point checkout is occurring. This is the ideal time to verify that each data point is properly bound to the BAS graphics. The BAS graphics are often not complete at the time of point-to-point checkout or functional performance testing. As a result, additional time is required to test and verify the accuracy, completeness, and relevancy of the points bound to the BAS graphics. Many of the same steps performed during the point-to-point checkout will have to be repeated to verify the BAS graphic bindings.

It is important to know as soon as possible in the BAS construction process whether the BAS installation will have a graphical user interface. Testing and verification of this user interface is vital to ensuring that the data it displays is accurate and complete. In some installations, the Owner or Operator may not have or want full BAS graphics. The decision often comes down to cost and competency of the staff. Some Owners feel that their staff's expertise is high enough that the BAS graphics are an unnecessary expense. They may only have lists of data points and/or summary tables of BAS points as shown in Figure 8. In this case, review of the BAS user interface consists of verifying whether the reported data is complete, correctly configured, and accurate.



Operating Status

Occupancy Schedule	Unoccupied
Control Status	Unoccupied
Control Mode	SA Tempering
HVAC Mode	Off
Supply Fan Status	On
Cooling Status	Enabled
Heating Status	Disabled
HGRH Status	Disabled
Gas Heater Status	Disabled
Economizer Status	Disabled

Setpoints

Cooling SA Temp	63 °F
Heating SA Temp	61 °F
Cooling Lockout Temp	50 °F
Heating Lockout Temp	60 °F
Low Ambient	30 °F
DB Economizer	55 °F
OA Dewpoint Setpoint	55 °F

Setpoints

DCV Limit	900 ppm
Supply Duct SP	1.3 in/wc
Space Static	0.02
Min OA Damper	30 %
Effective SAT Spt	56 °F

Supply Air Temp. Reset

OAT	80 °F	60 °F
SAT	55 °F	66 °F

General Alarms

Alarm Status	Normal
SAF Alarm	Normal
EAF Alarm	Normal
Filter Alarm	Normal
Emergency Shutdown	Normal
Mech Clg Alarm	Normal
Mech Htg Alarm	Normal
High DAT Alarm	Normal
Low DAT Alarm	Normal

Compressor Alarms

A1 Compressor Alarm	Normal
A2 Compressor Alarm	Normal
B1 Compressor Alarm	Normal
B2 Compressor Alarm	Normal

EAF STATUS	On
RA TEMP	66.7 °F
RA CO2	391 ppm
BLDG PRESS.	0.000 in/wc
OA DAMPER	30 %
FILTER	Normal
CLG OUTPUT	0.0 %
HGRH OUTPUT	0.0 %
SAF STATUS	On
GAS HTG OUTPUT	0.0 %
SA TEMP	68.7 °F
STATIC PRESSURE	0.1 in/wc

Refrigerant Circuit Data

	Circuit A1	Circuit A2
Compr Output	0.0 %	0.0 %
Compr Enable	Stop	Stop
Head Press	183.5 psig	181.9 psig
Suction Press	181.8 psig	181.9 psig
Sat Disch Temp	64.0 °F	64.0 °F

Refrigerant Circuit Data

	Circuit B1	Circuit B2
Compr Output	0.0 %	0.00
Compr Enable	Stop	Stop
Head Press	184.5 psig	187.6 psig
Suction Press	183.3 psig	185.3 psig
Sat Disch Temp	64.4 °F	65.1 °F

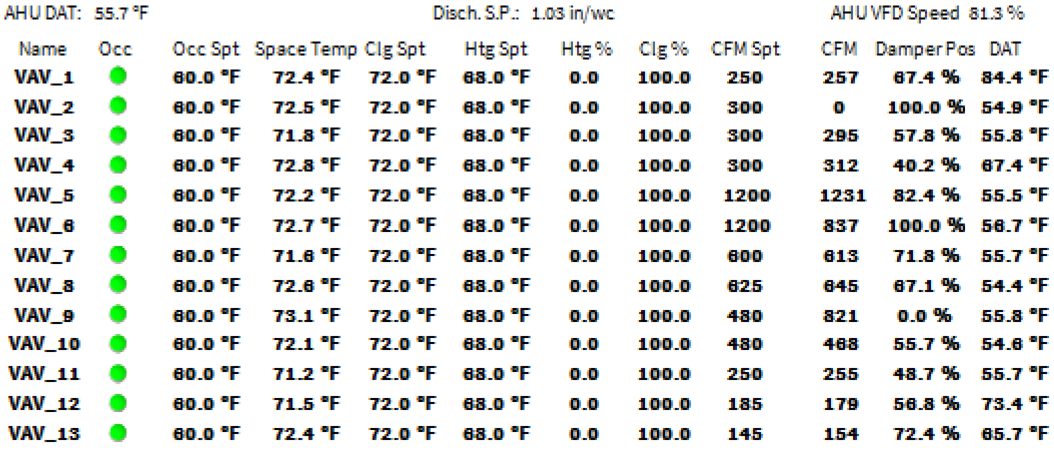
Outdoor Air

OA Dry-Bulb Temp	65.5 °F
OA Humidity	72.3 %RH
OA Enthalpy	26.4 BTU/lb
OA Dew Point Temp	56.4 °F
OA Wet-Bulb Temp	60.1 °F

Figure 7 - Example BAS Graphic of a Rooftop Air-Handling Unit

1.8 Equipment Summary Screens

Equipment summary screens are a very useful tool for the Owners, Operators, Control Technicians, TAB Contractors, and Commissioning Agents because they provide a quick overview of the status and performance of similar pieces of equipment (air-handling units, Variable-Air-Volume (VAV) boxes, fan coil units, unit ventilators, etc.) simultaneously without having to click into several individual pages. Summary screens are also very useful for testing and calibration of the inputs and outputs. They allow us to confirm and to view the results of global overrides (enable/disable, setpoint, and actuators commands). Temperature sensor calibrations can be initially evaluated from the equipment summary screens. The odd readings stand out when displayed in a summary table because there are other readings to compare it to without making hundreds of mouse clicks. The supply air temperature from the air-handling unit may be used to evaluate the calibration of VAV terminal unit discharge air temperature sensors. With summary screens, there is no excuse for commissioning a sampling of units. With global overrides and summary screens, it is easy and efficient to test the fundamental functions of all terminal units, unit ventilators, fan coil units, exhaust fans, etcetera that are typically sampled at a low rate (5%-25%). If a sampling protocol had been applied to the terminal units shown in Figure 8, several issues would never have been identified.



AHU DAT: 55.7 °F　Disch. S.P.: 1.03 in/wc　AHU VFD Speed 81.3 %

Name	Occ	Occ Spt	Space Temp	Clg Spt	Htg Spt	Htg %	Clg %	CFM Spt	CFM	Damper Pos	DAT
VAV_1	●	60.0 °F	72.4 °F	72.0 °F	68.0 °F	0.0	100.0	250	257	67.4 %	84.4 °F
VAV_2	●	60.0 °F	72.5 °F	72.0 °F	68.0 °F	0.0	100.0	300	0	100.0 %	54.9 °F
VAV_3	●	60.0 °F	71.8 °F	72.0 °F	68.0 °F	0.0	100.0	300	295	57.8 %	55.8 °F
VAV_4	●	60.0 °F	72.8 °F	72.0 °F	68.0 °F	0.0	100.0	300	312	40.2 %	67.4 °F
VAV_5	●	60.0 °F	72.2 °F	72.0 °F	68.0 °F	0.0	100.0	1200	1231	82.4 %	55.5 °F
VAV_6	●	60.0 °F	72.7 °F	72.0 °F	68.0 °F	0.0	100.0	1200	837	100.0 %	56.7 °F
VAV_7	●	60.0 °F	71.6 °F	72.0 °F	68.0 °F	0.0	100.0	600	613	71.8 %	55.7 °F
VAV_8	●	60.0 °F	72.6 °F	72.0 °F	68.0 °F	0.0	100.0	625	645	67.1 %	54.4 °F
VAV_9	●	60.0 °F	73.1 °F	72.0 °F	68.0 °F	0.0	100.0	480	821	0.0 %	55.8 °F
VAV_10	●	60.0 °F	72.1 °F	72.0 °F	68.0 °F	0.0	100.0	480	468	55.7 %	54.6 °F
VAV_11	●	60.0 °F	71.2 °F	72.0 °F	68.0 °F	0.0	100.0	250	255	48.7 %	55.7 °F
VAV_12	●	60.0 °F	71.5 °F	72.0 °F	68.0 °F	0.0	100.0	185	179	56.8 %	73.4 °F
VAV_13	●	60.0 °F	72.4 °F	72.0 °F	68.0 °F	0.0	100.0	145	154	72.4 %	65.7 °F

Figure 8 - Terminal Unit Summary Report

This non-graphical data is useful and efficient for identifying poorly performing sensors, actuators, and programming. For example, the equipment summary in Figure 8 is based on a global space temperature setpoint override which enables maximum cooling. The zero airflow reading for VAV_2 indicates that its differential pressure transmitter is not functioning properly or possibly its pneumatic tubes are not connected. The low airflow reading for VAV_6 indicates that its tubing connections may be loose or its airflow reading requires calibration. It is also possible that the duct static pressure is too low. It appears that the terminal reheat of VAV_1 may be energized as indicated by its elevated discharge air temperature and the discharge air temperature readings for VAV_4 and VAV_13 may require calibration. It is likely that the discharge air temperature sensor for VAV_12 has either fallen from its mounted position or was never mounted and is sensing the temperature of the ceiling plenum (not the supply duct). The terminal unit heat can be enabled to verify whether the discharge air temperature rises. Terminal unit VAV_9 likely has its binary outputs reversed as indicated by high airflow flow but closed damper position command. Terminal unit VAV_2 may have the same issue as indicated by its high damper command and low airflow. The binary output wires for its floating damper actuator likely need to be reversed or its damper action reversed. It is also possible that the actuator is not secured to the damper shaft. There are a lot of good observations that can be made from equipment summary tables and used to improve the performance of the system and occupant comfort.

1.9 Typical Errors in BAS Graphics

It is natural to assume that the displayed equipment configuration and data accurately match the actual equipment configuration and sequences of operation. The accuracy of the BAS graphic impacts operational decisions and adjustments made to the system. Each data point displayed on the BAS graphic is individually bound to a BAS controller data point. This binding relies on the accurate referencing of the controller's data point values. The point names are like addresses and are unique. Defining data point bindings is a very tedious, monotonous, and repetitive process, so there is always a potential for making mistakes. Any lapse in concentration by a phone call, text message, voice mail, conversation with a coworker, email, etc. can lead to errors. The following items are some of the common errors typically found on BAS graphics:

1. Coil arrangement or order of the heating, cooling, and reheat coils in an air-handling unit is incorrect. This is critical for dehumidification control because the air must first be cooled and then reheated using either an air-handling unit reheat coil, duct-mounted reheat coil, or terminal unit reheat coils.
2. System arrangement or configuration not accurately indicated.
3. Arrangement of the supply fan relative to the coils (Blow-through versus Draw-Through).
4. Valve types not accurately represented: Two-way versus Three-way control valves.
5. Valve arrangements (diverting versus mixing configuration)
6. Missing modes of operation and/or their status.
7. Missing interlock data. The status of interlock points (safety devices, end switches, etc.) is required to confirm their status and know they are not preventing a unit from operating.
8. Missing setpoints. Setpoint provides the viewer with an indication of what the system is trying to achieve.
9. Damper actuators indicated where barometric dampers exist and vice versa.
10. Broken BAS graphics bindings. Point names may be changed which breaks the binding to the BAS graphics.
11. Incorrect/missing navigation links.
12. Incorrect graphic bindings (links to incorrect data points).
13. Data points incorrectly placed.
14. Unnecessary or extraneous data on BAS graphics resulting in clutter.
15. Animations not linked or not linked to the correct data points.
16. Incorrect flags.
17. Incorrect or missing facets.
18. Missing data on BAS graphics.
19. Missing override and alarm indications.
20. Architectural errors (missing or incorrect walls)
21. Missing/incorrect operating schedule, trend data, and alarm links
22. Incorrect room identification tags (rooms number typically correspond with the original architectural plans, but they are often renumbered wholly or partially when the Owner takes occupancy).

An as-built air-handling unit sketch showing the actual system arrangement and the location of all sensors, actuators, coils, dampers, etc. should be drawn and used to confirm that the BAS graphics accurately represent the installed system. This as-built sketch should also be the basis of an as-built controls submittal. This becomes especially important when the basis of design equipment has not been selected and installed. There may be many changes that require documentation.

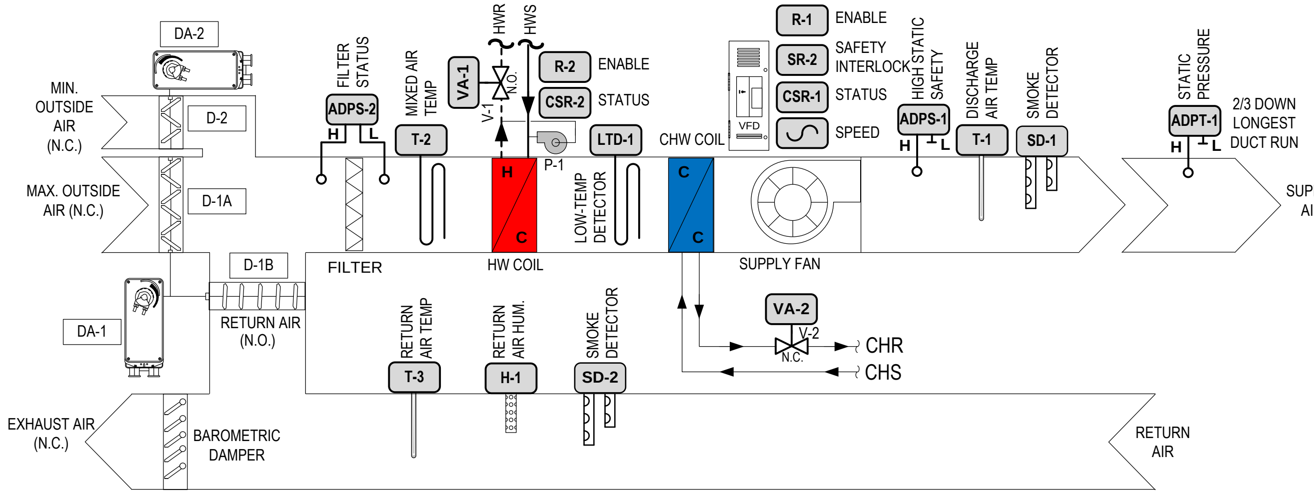


Figure 9 - Schematic of a Typical Air-Handling Unit with Maximum and Minimum Outdoor Air Dampers

1.10 State Tables

The BAS graphics provide an indication of what the system is doing, but what is not always evident is WHY it is doing what it is doing. Inclusion of current setpoints and active modes of operation on the BAS graphics is advantageous and highly recommended because they provide an indication of what the system is trying to achieve. Most systems have been programmed to operate according to the sequences of operations included in the design documents. The BAS graphics are most useful to Owners and Operators when the modes of operation and their status are included. This provides the BAS Operator and Controls Contractor with valuable operating data and troubleshooting information when the system is not performing as it should. A state table is a tool that summarizes the various modes of operation for which the system has been designed to provide. It also lists the system components and what they should be doing while each state or mode of operation is enabled.

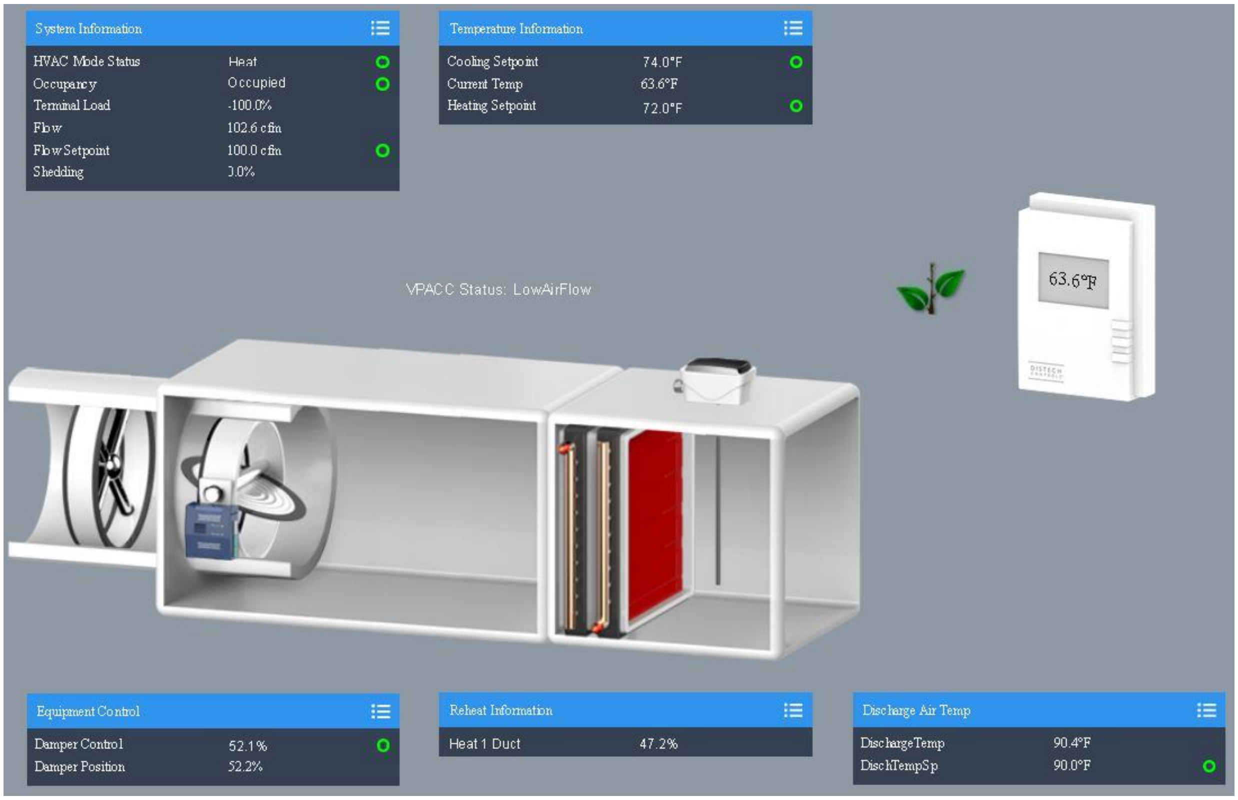
States	Fan	P-1	VA-1	VA-2	D-1A	D-1B	D-2
Unoccupied	Off	Off	100%	0%	0%	100%	0%
Low-Temp. Alarm	Off	On	100%	0%	0%	100%	0%
Smoke Detector Alarm	Off	Off	100%	0%	0%	100%	0%
MAT Low Limit	On	Off	0%	0%	0%	100%	Mod.
Heating Night Cycle	Cycle	Off	Mod.	0%	0%	100%	0%
Cooling Night Cycle	Cycle	Off	0%	Mod.	0%	100%	0%
Morning Warm-up	On	Off	Mod.	0%	0%	100%	0%
Morning Cool-down	On	Off	0%	Mod.	0%	100%	0%
Occupied Heating (Min OA)	On	Off	Mod.	0%	0%	100%	Min.
Occupied Cooling (Min OA)	On	Off	0%	Mod.	0%	100%	Min.
Economizer	On	Off	0%	0%/Mod.	Mod.	Mod.	100%

Table 2 - State Table Example (Based on Air-Handling Unit in Figure 9)

Simple pieces of equipment like unit heaters, reheat coils, electric resistance heaters, humidifiers, and exhaust fans typically have only two or three states or modes of operation. However, air-handling units are very well known for having many different modes of operation and their state tables can be large. State tables is often used as a basis to determine which modes of operation are included on the BAS graphics. The main operating modes should be clearly indicated on the BAS graphics so that the viewer can quickly understand what the equipment is doing and why. For example, if the Economizer Cycle is enabled, there should be an icon or text indicating that this mode is active (Figure 7). In addition, we would expect to see the outdoor air dampers open beyond their minimum position or minimum outdoor airflow setpoint and maximum outdoor air damper open (if equipped). Likewise, operating modes such as night cycle, morning warm-up, morning cool-down, heating, cooling, and dehumidification should also be displayed on the BAS graphics. Without indications of active operating modes on the BAS graphics, the viewer is left to wonder what the displayed system is trying to accomplish.

1.11 BAS Commissioning Time Requirement

The time required to commission a control system is always minimized when the input and output devices have been properly selected, located, wired, installed, calibrated, and bound to the BAS graphics. This will eliminate an untold amount of time troubleshooting failed system level functional performance tests. It also facilitates a familiarity with the control system and its components that only the installers ever have. At the same time, test and verify that the BAS graphic bindings and the ability to override the binary and analog outputs. Once you gain a comfort level with the BAS installation, its performance, and its graphics, they become tools for testing, troubleshooting, and functional performance testing.



System Information		
HVAC Mode Status	Heat	○
Occupancy	Occupied	○
Terminal Load	-100.0%	
Flow	102.6 cfm	
Flow Setpoint	100.0 cfm	○
Shedding	0.0%	

Temperature Information		
Cooling Setpoint	74.0°F	○
Current Temp	63.6°F	
Heating Setpoint	72.0°F	○

Equipment Control		
Damper Control	52.1%	○
Damper Position	52.2%	

Reheat Information	
Heat 1 Duct	47.2%

Discharge Air Temp		
DischargeTemp	90.4°F	
DischTempSp	90.0°F	○

Figure 10 - Single-Duct VAV Terminal Unit BAS Graphic Example

1.12 Packaged Equipment Controls

When equipment with manufacturer-provided controls or "packaged" controls is involved, the BAS construction process varies slightly. Rooftop air-handling units, energy recovery units, boilers, and chillers are examples of HVAC equipment that often incorporate packaged controllers. Since the equipment arrives with its controls (controllers, sensors, actuators, etc.) in place and programming already completed, these steps are not required at the construction site. Equipment with packaged controls can operate independently of the BAS. To be included in the BAS, a data connection is required. Prior to establishing the communications link, the Controls Contractor may have already constructed the graphics for the equipment, programmed supplemental logic (in the JACE or equivalent), and defined operating schedules, alarms, and trends. After the communication link is made, select control and monitoring data points are added to the proxy points list in the Niagara station and bound to the BAS equipment graphics. This process is commonly referred to as "integration." Through the established communication link, the Controls Contractor can see the input and output data points that have been exposed by the equipment manufacturer. The point names are often cryptic and difficult to interpret without additional documentation from the equipment manufacturer. Even with this information, it can still be difficult to interpret because the descriptions are so brief that their meaning cannot be accurately discerned. In addition, there are often various versions and the correct version may not have been provided.

The main disadvantage of integrated equipment is the inability to view the programmed control logic. Proprietary software is typically required to access the programmed logic. Most technicians and manufacturer's representatives who install and service these units cannot even see the control logic. Contrary to popular belief, the Controls Contractor has no access to the programmed logic. They only have access to the exposed points. While it is true that the packaged controller is typically programmable, the control logic is only accessible and visible by the manufacturer. The Controls Contractor cannot view the programmed control logic. For equipment with very simple control strategies like chillers, boilers, VFDs, humidifiers, VRF (Variable Refrigerant Flow) systems, split system air-handling units, fan coil units, unit vents, etc., the lack of control logic access is not a huge issue because there are only a limited number of modes of operation that they provide. As a result, there are only a limited number of tests to perform. However, large air-handling units can have many sensors, actuators, and numerous operating modes which make them much more difficult to test and verify. Each project has design requirements that are detailed in the construction documents and controls submittal. Reviewing and testing the programmed logic at the core of any commissioning effort. Yet, it is not possible with packaged controls.

Without access to the programmed control logic, we cannot fully verify that the programmed logic performs as required nor can we verify whether there is additional control logic that should not exist. Air-handling units tend to have lots of "behaviors" that cannot be explained without review of the programmed logic. Without access to the control logic, these behaviors will never be diagnosed or corrected. The programmed logic can only be inferred from the observed reactions to signal simulations, point overrides, and setpoint changes on points that have been exposed. Some sequences of operation cannot be proven with the available points and observed reactions. As a result, the quality and depth of the commissioning effort significantly reduces. This is not good for the industry or the building occupants. In addition, the specificity of the commissioning tests are typically reduced to more general tests (i.e. setpoint changes). All we can do is verify what we can and document the sequences of operations that could not be verified.


Photo 13 - Air-Cooled Chiller


Photo 14 - High Efficiency Modular Boiler Plant


Photo 15 - Rooftop Air-Handling Unit

With regard to air-handling units with packaged controls, the Owner is often condemned to a lifetime of equipment problems and contractor finger-pointing. Design Engineers allow and even promote packaged controls based on the rationale of lower first cost (based on equipment and controls), but there are other ongoing costs (Contractor denials of responsibility, aggravation, lost productivity, lack of environmental control, lost production, prices gouging, poor response time, equipment downtime, etc.) that the Owner must bear over the equipment life time. First cost should not preclude consideration of flexibility, convenience, and the cost of operating and maintaining the BAS and the controlled HVAC equipment over its life time. It is difficult to estimate the cost of Owner aggravation and inconvenience, but it should not be ignored. Equipment manufacturers are more than happy to get into the controls business because it ensures at least 10-15 years of work for their service department. Several public school districts in Maryland that have learned this expensive and aggravating lesson and specifically exclude packaged controls from their air-handling unit equipment specifications to avoid the various problems that their proprietary controls cause.


Photo 16 - Variable Frequency Drive


Photo 17 - Water-Source Heat Pump Air-Handling Unit


Photo 18 - LG Variable Refrigerant Flow (VRF) Condensing Units

In buildings or sites where a building automation system is used, the Controls Contractor is typically the first called when there is an environmental controls issue, but they can offer only minimal assistance because they cannot access the programmed logic that would explain the observed behavior or failure. It could be argued that higher first cost of separate equipment and controls is a very worthwhile investment in the long run. When the Controls Contractor provides the control system, the Owner has maximum flexibility to make control logic and hardware changes when they are required.

The control logic can be fully reviewed and tested because full access is available. In addition, the Controls Contractor can immediately respond and resolve the operational issues that arise with minimal cost to the Owner, minimal disruption of service, and minimal discomfort for the building occupants. Packaged controls are perfect for non-critical applications, designs requiring only a few modes of operation, or where the occupants will not be in the conditioned zone for an extended period of time. However, if the sequences of operations are complex, the occupants are present for extended periods of time, the system will be commissioned, or where the application is of a critical nature, packaged controls should be selected and used with extreme caution.

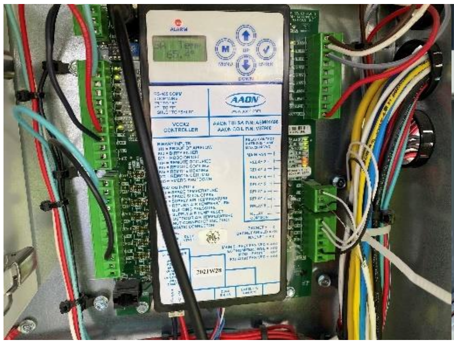


Photo 19 - Aaon Rooftop Air-Handling Unit Controller


Photo 20 - Diakin Rooftop Air-Handling Unit Controller

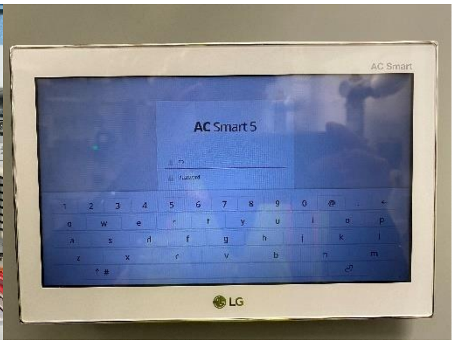


Photo 21 - LG AC Smart 5 BAS Gateway Panel

If equipment with complicated sequences of operation (large air-handling units) and packaged controls are to be installed, it is recommended that you secure written correspondence (emails, letters, guarantee, warranty letter, etc.) from the equipment manufacturer and/or their representative stating that they have reviewed all of this project's construction documents and that the submitted equipment, its controllers, its input and output devices, and its programming satisfy all design requirements. In addition, this document should state that they will make any and all hardware and software modifications necessary, including total replacement with a design-capable unit, in order to comply with the project's design requirements. It is further recommended that the onus rest on the Architect and/or Engineer-of-Record to review and provide final acceptance of every instance where the packaged controls, that they specified during the design phase and accepted during submittal review phase, does not satisfy the design requirements (especially the sequences of operation). This is the only way that they will realize that packaged controls have many limitations and they need to recognize the position that the Owner/Operator is placed when they specify equipment with packaged controls. Packaged controls are great in the correct applications, but they can easily be misapplied. In the end, packaged controls are here to stay and we have to learn to manage the associated issues, risks, and limitations. Equipment manufacturers can help by providing more complete documentation and more user-friendly user interfaces.

1.13 Review

1. The Controls Contractor is typically contracted through the ________________________ on new construction and major renovation projects.
2. JACE stands for ______________________________________.
3. A ______________________ is a tool that helps visualize how the parts of a system function while in each mode of operation.
4. A ______________________ is a visual aid that helps to quickly review several pieces of similar equipment simultaneously by displaying key operating data (modes of operation, commands, status, operating points, alarms, etc.) in a tabular format.
5. True or False: The JACE integrates all BAS controllers into a cohesive system. Answer: ________
6. With the addition of ______________________ a JACE can also be used as a controller.
7. True or False: Equipment with packaged controls provides open access to the programmed logic as well as the operating data and setpoints. Answer: ________
8. Packaged controls are typically selected because of ____________________________ and the lack of understanding of the problems that Owner face following the initial construction and warranty period.

1.14 References

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Chapter 2 - BAS Calibration

2.1 General

Calibration is the process of verifying the requirements, installation, configuration, and performance of the input/output devices so that they may be corrected or "calibrated" to match the results from reference instruments or field observations under steady-state conditions. The reference readings are typically provided by instruments that have been calibrated to a national standard which ensures proper function and accuracy. This comparison allows us to evaluate the accuracy of the Unit Under Test (UUT). Once the error is known, it is compared to the calibration tolerance. If the observed error is within the calibration tolerance, nothing more has to be done. If the error is beyond the calibration tolerance, then the reading of the UUT must be corrected or "calibrated" to restore the accuracy to within the calibration tolerance. If the UUT cannot be field-calibrated, then it must be replaced. This process is what allows input and output devices to operate accurately so that the systems to which they are part of can operate at maximum efficiency.

> "I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind."
>
> Lord Kelvin (William Thompson)

BAS controllers and their input and output devices are manufactured in large quantities and sent all over the globe for installation. In addition, they are manufactured to industry standards so that the sensor/sensor transmitter manufactured by Company A performs as well as the same unit manufactured by Company B. Because of these manufacturing and quality standards, components of building automation systems are interchangeable. However, any mass-produced device will have minor variations in its materials, manufacturing process, composition, quality control, etc. that affect its final operation. This means that there will be variations in the sensor signals and transmitter output signals and this is where calibration comes into play.

When the topic of calibration is discussed, we are generally referring to binary and analog input devices (temperature sensors, humidity transmitters, current sensing relays, air differential pressure switches, pressure switches, carbon dioxide transmitters, etc.) which are typically more numerous than output devices. However, output devices (relays, valves, dampers, VFD speed, etc.) also need to be calibrated. Calibration of BAS output devices is typically performed with a digital multimeter or continuity tester to verify that the signals generated by the BAS controller outputs provide control of the end device or equipment. BAS output calibration work is typically easier to implement than input devices.

For many, calibration is thought of as the process of verifying that the input and output device parameters in the BAS controller are configured to match the nominal ratings of the corresponding devices. While it is true that this step is necessary, it falls far short of qualifying as calibration. When calibration begins, the correct configuration of the device parameters is assumed. The test readings confirm whether this assumption was correct and whether the UUT provides accurate readings. Therefore, configuration of the BAS controller is the starting point – not the end. For input devices, calibration verifies the performance of the sensor/transmitter under ambient and simulated conditions to verify that it produces the appropriate signals across its operating range. For output devices, calibration verifies that the BAS controller produces the correct signals and the controlled actuator, variable frequency drive, or system responds appropriately. Verification of input and output device performance requires instrument readings, measurements, and field observations. If the input/output signals are determined to be accurate, nothing more is required. When a correction is required, the performance of the devices must be modified (zero and span adjustment) or replaced to provide the required accuracy and the BAS input/output parameters must be modified to match the actual or observed performance. There is no calibration without comparison of the BAS readings to reference readings from calibrated instruments or observations.

2.2 Reference Instruments

The reference instruments used for BAS input/output calibration are themselves calibrated to standards defined by the National Institute of Standards and Technology (NIST) or other similar entities. NIST is a United States government organization that develops and maintains national standards and methods of measurement to ensure national conformance among the various equipment calibration laboratories. When the reference instruments have been calibrated to NIST-traceable standards, they have been calibrated to a national calibration standard using accurate equipment, standard test conditions, and uniform calibration methods. This ensures that the reference instruments properly function and provide accurate reference readings. Most project specifications require that the reference instruments be calibrated to NIST-traceable standards within a year of use. Occasionally, a specification that requires calibration within six months or less of use may be encountered.

2.3 Characteristic Curves

Sensors and transmitters sample the media (air, water, gases, steam, light, electrical power, etc.) and produce a corresponding signal that is monitored by an analog input of a BAS controller. The signal may be a resistance, voltage, or a current reading. Each sensor/sensor transmitter is manufactured according to international standards that ensure that they produce standardized output signals for a given sensor condition. Sensors are generally categorized as devices whose output signal requires no power and are directly read by the BAS controller. Thermistors are a prime example. Sensor transmitters are devices that include a sensor, but they also have additional circuitry that requires electrical power to process the sensor signal and produce standard output signals (0-10 VDC, 4-20 mA, etc.) that are proportional to the sensor reading. Chapter 3: BAS Inputs and Outputs will explain this in greater detail.

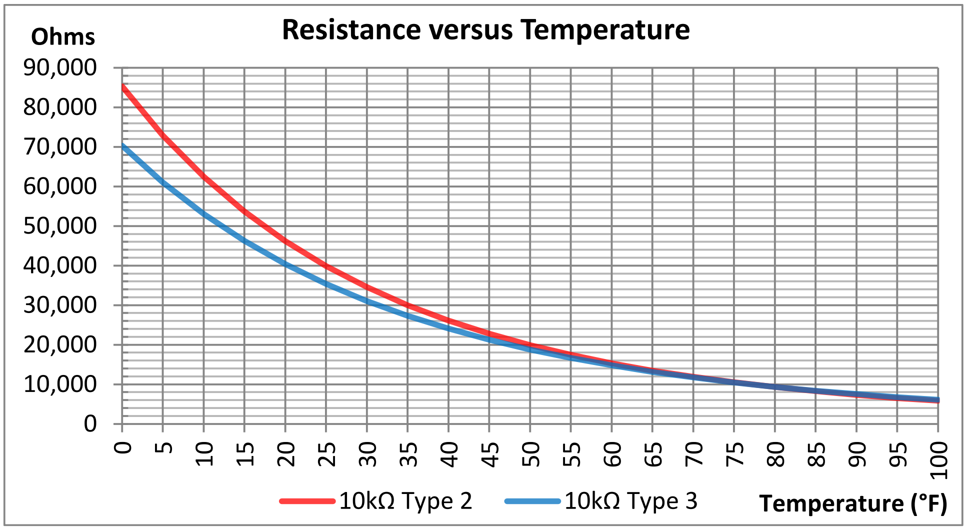


Figure 11 - 10k Ohm Type 2 & 3 Thermistor Characteristic Curves

Characteristic curves are a graphical way to represent the change in sensor or sensor transmitter output signal per unit change in sensor signal. When an analog input of a BAS controller is initially configured, it is typically based on the nominal sensor/transmitter ratings provided by the manufacturer. After testing and collecting calibration data, the programmed sensor/transmitter parameters should be updated to reflect the actual performance results. The form in which they are updated is based on whether they are a sensor or a sensor transmitter.

2.3.1 Temperature Sensor Characteristic Curves

Temperature sensors (Thermistors and RTDs) are resistance-based measurement devices that are directly read by an analog input of a BAS controller. Each temperature sensor type is manufactured to produce a standard resistance versus temperature profile. The BAS then takes the resistance signal and calculates the temperature reading based on the resistance versus temperature table for the specific thermistor or RTD. Table 3 provides example data points for some commonly-used resistance temperature sensors.

Temperature sensors are not interchangeable. It is important to correctly configure the analog input to the specific temperature sensor type(s) connected to the BAS controller. As the data (Table 3) and the characteristic curves (Figure 11) show, 10kΩ Type 2 and Type 3 thermistors are not the same. They produce the same resistance reading at the reference temperature, but they diverge from that point. The difference in the resistance values increases slightly as the temperature increases beyond the reference temperature, but it increases significantly as the temperature reduces from the reference temperature. If the installed and programmed temperature sensor types do not agree, the resulting temperature indication will be incorrect. Standardizing the sensor types used in a BAS construction project is a good practice. It minimizes confusion and reduces installation and configuration errors. Calibration verifies the temperature sensor installation as well as its performance, so that errors may be identified and corrected.

	Thermistors			
Temperature (°F)	10kΩ Type 2	10kΩ Type 3	20kΩ	Platinum 1kΩ RTD
0.0	85346	70317	195197	930.3
10.0	62464	53063	140223	952.2
20.0	46222	40411	101882	973.9
30.0	34563	31046	74831	995.7
32.0	32651	29481	70175	1000
40.0	26104	24051	57189	1017.4
50.0	19903	18782	41621	1039
60.0	15313	14780	31488	1060.7
70.0	11884	11717	24037	1082.2
77.0	10000	10000	20000	1097.6
80.0	9298	9353	18508	1103.8
90.0	7333	7517	14367	1125.3
100.0	5826	6080	11241	1146.8

Table 3 - Abbreviated Table of Resistance versus Temperature Values

Figure 12 shows the ideal characteristic curve (black dashed line) for a 10kΩ Type 2 thermistor in the 40°F to 80°F range. The analog input of the BAS controller has been configured to interpret the analog resistance signal based on the resistance temperature table for a 10kΩ Type 2 thermistor. The red line indicates the characteristic curve for the actual thermistor performance. As previously stated, there will be minor variations in the performance of mass-produced thermistors. This is why temperature sensor testing and calibration is required. In this example, the actual thermistor characteristic curve is slightly higher than the actual characteristic curve. It is also possible that it may exactly coincide with it or may be below it. In some cases, the two curves may cross one another.

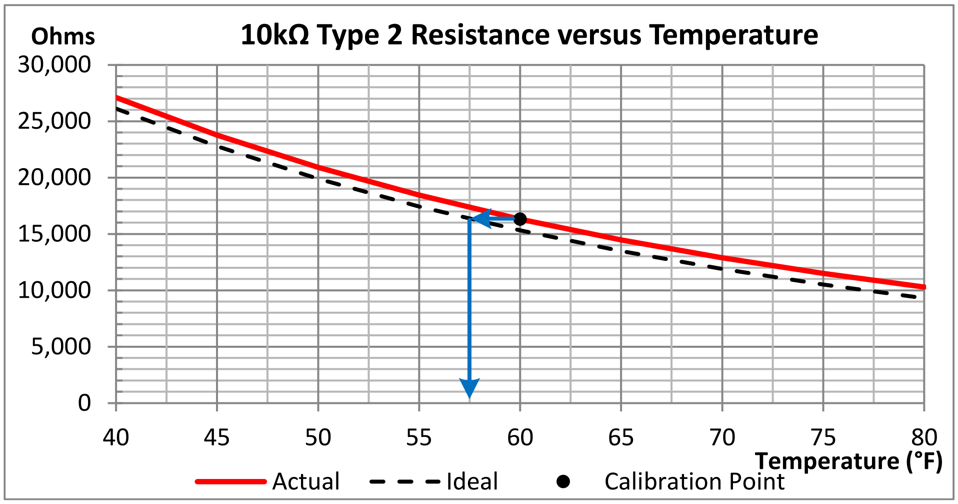


Figure 12 - Thermistor Characteristic Curve Example

At 60°F, as indicated by calibrated temperature meter readings, the BAS analog input measures a resistance of 16,313 Ohms. However, 16,313 Ohms is interpreted by the BAS as 57.6°F per the programmed resistance temperature tables. If the performance of the thermistor does not match the programmed resistance temperature tables, the temperature indication may require calibration. If the error is high, replacement is recommended. In this case, a +2.4°F offset is required to calibrate the BAS-indicated temperature to the reference temperature reading. This offset is applied to all temperature readings, so it is critical that the calibration readings be performed at the temperatures it will experience during normal operations. Therefore, it will be most accurate where it is required.

2.3.2 Transmitter Characteristic Curves

Each transmitter also has a characteristic curve which represents the linear relationship between its output signal and its sensor signal. A perfect transmitter generates an actual characteristic curve that exactly matches the ideal characteristic curve as indicated by its performance. However, there are no perfect transmitters. They always have differences in their sensor and output signals which necessitate testing and calibration. Therefore, each transmitter must be tested to determine its actual performance. This data is then used to update the BAS controller's analog input configuration so that it matches the actual transmitter performance. Errors in BAS-indicated transmitter readings are typically caused by the fact that they have not been tested and calibrated. All too often, newness is equated to accuracy and proper function. As a result, new input and output devices are often not tested or calibrated. At a minimum, sensor transmitters should be tested to verify that the analog input parameters of the BAS controller match its performance so that it accurately produces its sensor readings.

Reading	Sensor Transmitter (PSIG)	Transmitter Signal (VDC)
Minimum	0	2
Maximum	100	10

Table 4 - Ideal Transmitter Configuration for a Hydronic Differential Pressure Transmitter (HDPT)

The following figure shows the ideal characteristic curve (black dashed line) for a 0-100 PSIG differential pressure transmitter that produces a 2-10 VDC output signal. The connected analog input of the BAS controller has been configured to interpret the analog signal provided by the HDPT input based on the ideal characteristic curve parameters provided Table 4. Therefore, when 2 VDC is measured, the indicated pressure is zero PSIG. When the 10 VDC is measured, the indicated pressure is 100 PSIG. Voltages between these two points are used to calculate the pressure reading. The red line depicts the actual characteristic curve which represents the actual transmitter performance. Based on its performance, this transmitter will not provide accurate pressure readings. At 0, 50, and 100 PSIG applied test pressures, a perfect pressure transmitter produces 2.0, 6.0, and 10.0 VDC signals, respectively. However, when the same test pressures (0, 50, and 100 PSIG) are applied to this HDPT, it produced 2.0, 5.5, and 9.0 VDC signals, respectively (red line). This indicates that this differential pressure transmitter has a span of only 7.0 VDC instead of the full 8.0 VDC (10 VDC-8 VDC). Consequently, the BAS then indicates 0, 43.75, and 87.5 PSIG readings because its interpretation (blue arrows) of the transmitter signal is based on the ideal characteristic curve data – not its actual performance.

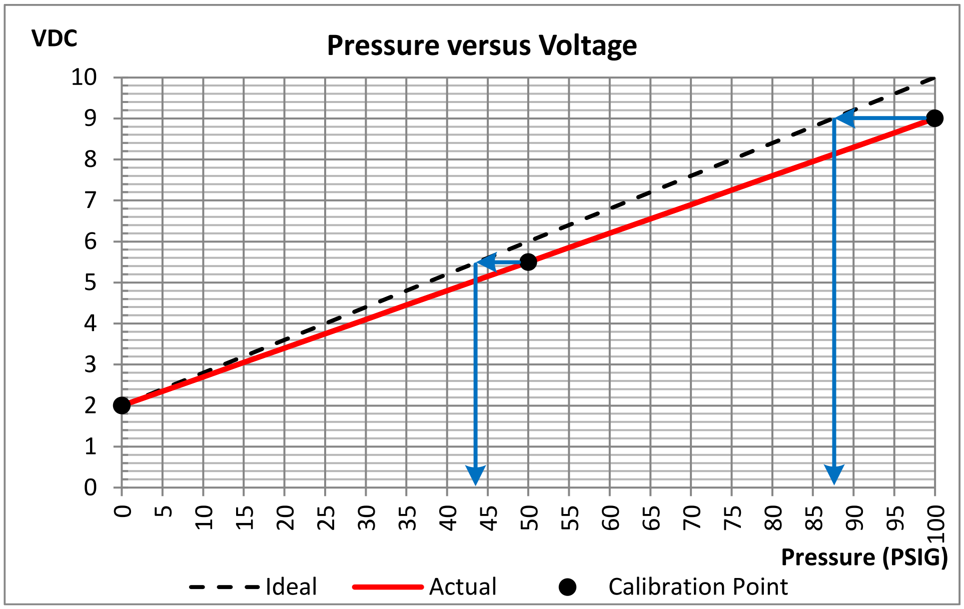


Figure 13 - Differential Pressure Transmitter Characteristic Curve Example

We have confirmed that the transmitter does not produce an accurate reading. We also have confirmed that the programmed characteristic curve for the installed HDPT does not match its actual performance. At this point, we can either calibrate the HDPT reading to more closely match the programmed analog input parameters or we can update the analog input parameters to match the actual HDPT performance. Which should be done? The correct answer is both. If the transmitter produces a signal that is within the calibration tolerance, then only update of the analog input would be required. If the transmitter signal exceeds the calibration tolerance, then the transmitter would be calibrated (zero and span adjustment) to more closely match the ideal characteristic curve and the analog input updated to reflect the actual performance of the sensor transmitter. If the sensor transmitter cannot be field-calibrated or it exhibits high levels of error or does not function across its sensor and/or signal range, replacement is recommended. Like temperature sensors, it is impossible to mass produce transmitters with perfect characteristic curves. Calibration verifies the transmitter's actual performance and corrects for deviations from the ideal characteristic curve.

2.3.3 Energy Impact

Each input/output device that is out of calibration produces a parasitic loss in system operating efficiency. When considered individually, each device may not produce a significant loss in efficiency or comfort. However, when all input and output devices are tested and calibrated, there is typically a significant increase in system efficiency and occupant comfort. Retro-commissioning projects typically produce much improved energy efficiency and occupant comfort because of the elimination of a significant portion of the parasitic energy penalties. This process identifies the input and output devices that are not performing or are out of calibration. In the process, many failed BAS, mechanical, electrical, and plumbing system components are typically identified and corrected (or scheduled for correction). Calibration of BAS input and output devices can also cause an increase in energy use. For example, if a space temperature sensor is reading lower than actual, calibrating the temperature sensor will increase energy use because the system requires more energy to maintain the corrected space temperature at setpoint during cooling mode. There will also be energy savings during the heating season because less energy is required to maintain the corrected space temperature at setpoint.

Targeted testing and calibration work can produce significant energy savings with minimal effort. Sensors and transmitters that affect the load of downstream control loops have a higher value or impact on the system energy use than others. For example, if an air-handling unit is discharging supply air at 53°F (instead of 55°F), then all associated terminal units will require additional reheat energy to maintain the space temperature at setpoint should heat be required. Likewise, if the air-handling unit supply duct static pressure transmitter is reading 0.20 inches W.C. lower than actual, then the duct static pressure will be maintained at 1.70 inches W.C. instead of the 1.50 inches W.C. setpoint. This means that the supply fan Variable Frequency Drive (VFD) operates at higher speeds than would be necessary had the Air Differential Pressure Transmitter (ADPT) been calibrated. These examples of strategic sensor and transmitter calibrations produce significant improvement in system energy efficiency and comfort with minimal effort. Testing and calibrating the high value sensors and transmitters should be part of an ongoing commissioning strategy and should happen at a higher frequency to maintain the system at peak efficiency.

Calibration of the airflow indications in pressure-independent terminal units is a mostly untapped energy conservation opportunity because of a lack of understanding of its full impact. Airflow indications drift with continued operation and they tend to indicate airflow rates below the actual airflow. As a result, they provide more cooling airflow than is required. Most of the terminal units will be at their minimum cooling load and consequently minimum airflow setpoint at some point in a typical day and will require reheat energy (if equipped) to maintain the space temperature at setpoint. Terminal Units servings zones with variable occupancy (conference rooms, classrooms, lobbies, corridors, waiting rooms, etc.) can operate for extended periods of time in heating mode, so increased energy savings is expected. These terminal units will expend more reheat energy than would be required had the correct airflow been provided. Because the terminal units are providing more airflow than is actually required, the supply fan (and return fan) VFD operates at a higher speed consuming energy at a higher rate. The cooling and heating energy savings also extend to the central plant or central station air-handling unit because it provides less cooling, heating, and pumping capacity to satisfy the loads. Calibrating the terminal unit airflow indications recovers the cooling, heating, and fan energy that is unnecessarily wasted because of erroneous airflow indications. Simply put, airflow calibration ensures that 500 Cubic Feet per Minute (CFM) of indicated airflow is equal to 500 CFM of actual airflow. However, the benefits of airflow calibration extend far beyond the terminal unit.

2.4 Calibration Terminology

In order to more fully understand the calibration process, a review of several related terms is recommended:

1. **Accuracy** describes how well the BAS sensor or sensor-transmitter reading agrees with the actual or true value. Comparisons with a reference value are the basis of evaluating accuracy and these reference readings are typically provided by calibrated instruments. From Equation 1, it is evident that high accuracy readings have low percent error values and the closer the percentage error is to zero the more accurate the reading. Accuracy is a qualitative property of an instrument because it does not represent a value (like error).

$$\text{(Equation 1)} \qquad \%\ \text{Error} = \frac{|ERROR|}{Reading_{Reference}} * 100\% = X\ \%$$

$$\text{(Equation 2)} \qquad \%\ \text{Error} = \frac{|X_{Reference} - X_{BAS}|}{X_{Reference}} * 100\% = X\ \%$$

Suppose the BAS reading for a humidity transmitter is 62.0% RH and the humidity reading from a calibrated meter shows 60.5% RH. This effectively indicates that the error between the BAS reading and the reference reading is 2.48% of the reference reading.

(Equation 3) $$\%\ \text{Error} = \frac{|60.5-62.0|\ \%RH}{60.5\ \%RH} X100\% = 2.48\ \%$$

Target practice provides us with a very good visual aid to understand the concepts of accuracy and precision. The goal of target practice is to place your shots in the center of the target or the "bull's eye" (red dot in the center). The following figures show increasing levels of accuracy from the left to right. The spread of the five shots gets tighter and tighter indicating improved levels of accuracy with each series of shots.

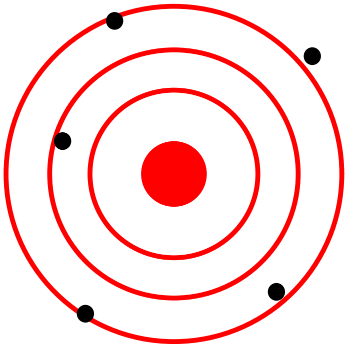


Figure 14 - Less Accurate Pattern

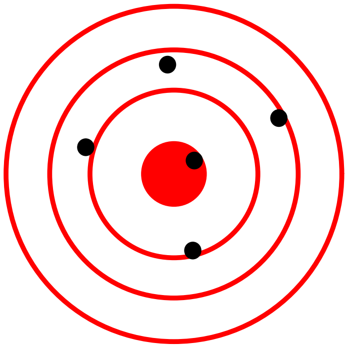


Figure 15 - More Accurate Pattern

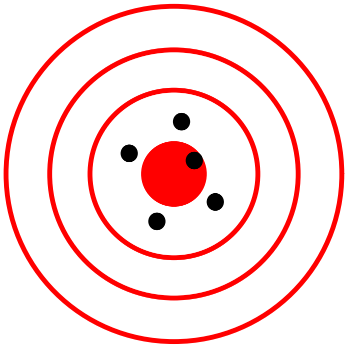


Figure 16 - Most Accurate Pattern

2. **As-Found Calibration** refers to the initial test results where the sensor or sensor transmitter readings are compared to reference readings at 0%, 25%, 50%, 75%, and 100% of the sensor range (when possible). If the results satisfy the calibration tolerance, nothing more is required and the "As-Found" calibration results are recorded in the As-Left calibration fields of the calibration form. If the as-found accuracy exceeds the calibration tolerance, then the unit under test must be calibrated or replaced.

3. **As-Left Calibration** refers to the final test results of the calibration process. If the initial test results did not satisfy the calibration tolerance, the sensor/sensor transmitter was either replaced or its zero and/or span were adjusted so that the calibration tolerance is satisfied. The final set of calibration readings is recorded in the As-left fields of the calibration form.

4. **Base Resistance** refers to the resistance (in Ohms) of thermistors and RTDs at which the indicated temperature reading is equal to a standard reference temperature. Thermistors use 77°F for the reference temperature while RTDs typically use 32°F as the reference temperature. For example, a BAS controller with a 10k Ohm thermistor connected to its analog input will indicate a temperature of 77°F when the thermistor resistance is equal to its base resistance of 10k Ohm. Likewise, a 1k Ohm RTD will indicate 32°F when its resistance is equal to its base resistance of 1 kOhm. Refer to Table 3 to view example resistance versus temperature data.

5. **Calibration** is the process of verifying the installation, configuration, and performance of the input/output devices so that they may be corrected or "calibrated" to match the results of reference instruments or field observations under steady-state conditions.

6. **Calibration Range** refers to the range of values utilized to perform the field sensor/transmitter calibration. The sensor/transmitter type and the available reference instruments dictate the calibration range in the field. The calibration range may be reduced because the full instrument range of the sensor/transmitter cannot be observed or simulated in the field. Air and water differential pressure transmitters are more easily simulated with calibration pumps, so their calibration range may be equal to the instrument range. Current transmitters are limited by the current source available in the field which is typically the load itself.

Reading	Amps (Amps)	Signal (VDC)
Minimum	0	0
Maximum	100	10

Table 5 - Calibration Range Example for a Current Transmitter

If a current transmitter capable of 100 amps and output signal of 0-10 VDC is installed on a fan that will only produce 50 amps of current draw, then the calibration range will be 0-50 amps. In this example, the indicated current reading is 42.5 Amps and the transmitter output signal is 4.25 VDC. Figure 17 shows the characteristic curve for the current transmitter where two calibration points define the calibration range. Reducing the calibration range to that which is available in the field makes sense because this is where it actually operates and where it should be most accurate. In this case, we can update the analog input to the values provided in Table 5. However, this would limit the maximum possible current reading to 50 Amps because the maximum transmitter signal is 4.25 VDCV.

Reading	Actual Current (Amps)	Transmitter Signal (VDC)	BAS-Indicated Current (Amps)
Minimum	0	0.0	0.0
Maximum	50	4.25	42.5

Table 6 - Calibration Range Example for a Current Transmitter

If it is required that we maintain the ability to read the full range of the installed current transmitter, then we would have to determine the maximum possible current reading based on the calibration data. This is done by extrapolating the current reading at 10 VDC and this procedure assumes that the sensor transmitter performs linearly across its full sensor range. The dashed line beyond the calibration points consists of the extrapolated data points.

Reading	Actual Current (Amps)	Transmitter Signal (VDC)	BAS-Indicated Current (Amps)
Minimum	0	0	0.0
Maximum	117.6	10	100.0

Table 7 - Calibration Range Example for a Current Transmitter

Based on the current analog input configuration, the 8.5 VDC signal produced at 100 Amps would be interpreted as 85.0 Amps by the BAS controller. This error indicates a need for update of the analog input configuration. At 10 VDC signal, the indicated current will be 117.6 Amps (10 VDC * 50Amps/4.25 VDC). Therefore, the analog input of the BAS controller is configured for a current range of 0-117.6 Amps and a signal range of 0-10 VDC (Table 7).

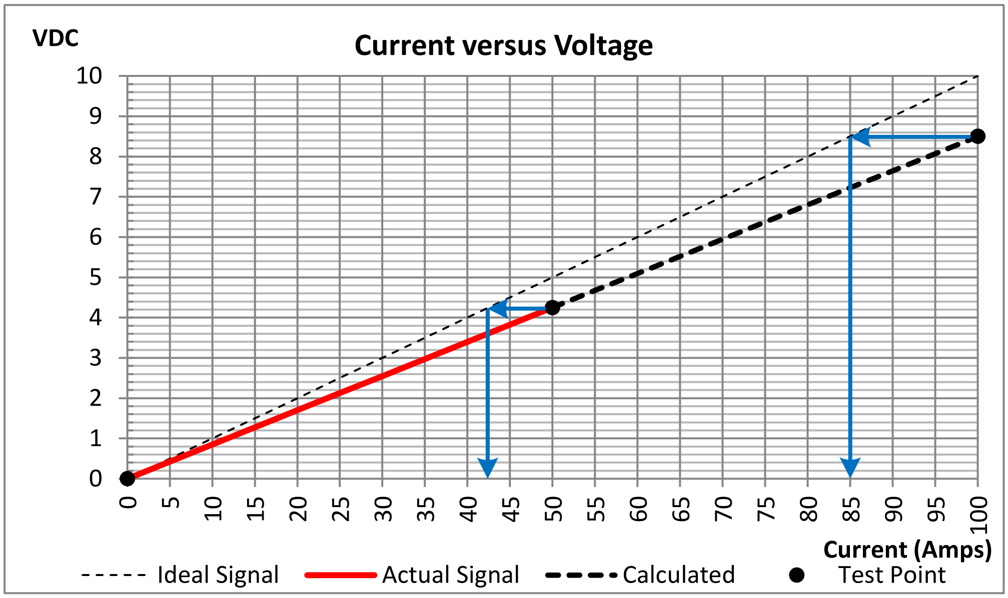


Figure 17 - Limited Calibration Range Example of a Current Transmitter

7. **Calibration Tolerance** refers to the maximum permissible deviation that the BAS reading may exhibit when compared to the reference reading by a calibrated instrument and still be considered acceptable. Calibration tolerances are typically expressed as a ± value from the reference reading. If the sensor/transmitter readings obtained during the testing are within the established calibration tolerances, then no corrections are required. If the readings exceed the calibration tolerance but are within the service tolerance, calibration is required which typically requires adjustment of the analog input configuration or its zero and span settings.
8. **Characteristic Curve**. This term describes the graphical representation of a sensor and sensor transmitter output signal versus its input or sensor signal. The term "curve" generically describes all linear or nonlinear lines that are formed by their corresponding data points.
9. **Configuration Error** describes the error that results when the input or output of the BAS controller is not configured

for the actual operating parameters of the connected device. For example, the voltage range for analog outputs is often configured for 0-10 VDC when the valve or damper actuator is set up to operate on a 2-10 VDC signal and vice versa. This results in a control damper or valve that either does not move until the control signal reaches 20% or it always remains at least 20% open. Alternatively, the signal ranges may be correct but the sensor ranges do not match. Supply duct static pressure transmitters may be configured for a 0-10 inches W.C. range when a 0-6 inches W.C. is actually installed. In both examples, the sensor transmitters will function, but they will not provide an accurate indication of the static pressure due to the errors in their configuration.

10. **Design Error** describes the signal error caused by the mechanical design's lack of provisions for the proper installation and operation of control system input and output components. This can have a significant effect on the control system operation, accuracy, and stability. Design error is often encountered with Airflow Measuring Stations (AFMSs). The mechanical designs require AFMSs, but often the duct design does not provide the minimum required straight duct lengths to properly install them or access doors to inspect and maintain them. This typically results in unstable airflow indications and the inability to inspect and maintain them. In many cases, the AFMSs are rendered useless because the noise signal generated by the turbulence exceeds the signal we are trying to measure. As a result, the readings may so erratic, pulsing, and unstable that they cannot provide usable airflow readings.

    Ventilation (outdoor air) codes and standards are typically concerned with the monitoring and control of the minimum ventilation airflow rate. Mechanical designs typically require the installation of a single full-sized outdoor air opening rather than minimum and maximum outdoor air openings. While operating at the minimum airflow, the maximum outdoor air damper remains closed and the minimum outdoor air damper either opens to a minimum position or modulates to maintain the minimum outdoor airflow rate at setpoint. In addition, it is typically much easier to install a minimum outdoor air duct and airflow measuring station with the required straight duct lengths. Only when the Economizer, Demand-Controlled Ventilation, or Purge/Flush modes of operation are enabled does the maximum outdoor air damper open. A single large outdoor air opening ensures very low air velocities while operating at the minimum ventilation airflow setting. If the air velocities are too low (<150 Feet Per Minute), this can result in poor or no airflow control. If duct fittings, louvers, dampers, etc. are in close proximity to the AFMS, then the situation is exacerbated by the turbulence that they cause.

    Perimeter rooms served by pressure-independent, Variable-Air-Volume (VAV) terminal units with reheat (electric or hot water) capacity often experience temperature control problems during heating season. Controls Contractors are often tasked with troubleshooting and resolving this issue, but the root cause is a design error related to supply air diffuser selection. Supply air diffusers are typically selected based on the maximum cooling airflow requirements and the resulting noise levels. However, during heating operation, the supply airflow rate is at its minimum airflow setting which does not provide adequate room air mixing. As a result, the room becomes stratified. At the ceiling level, the air temperature might be 80°F-90°F. At the floor level, air temperatures may be closer to 60°F. Temperature stratification is a significant issue at elementary schools where the children occupy the lowest level (under 48 inches) of the room. This makes room air mixing and supply air diffuser selection even more important. However; there is little, aside from raising the space temperature setpoint, raising the minimum airflow rate, and changing the occupancy schedule that the Controls Contractor can do to compensate for this design error. These remedial measures only treat the symptoms of poor supply air diffuser selection, it does not correct it.

    Unfortunately, the blame for poorly performing HVAC systems is often directed toward the Control Contactor when the actual cause is design error. The BAS can compensate for design errors, but it cannot undo its existence or its effects. Hardware and programing adjustments can be implemented by the Control Contactor to cope with design errors, but they are still there. Part of the Design Engineer's fee typically includes field visits and as-built drawings, both of which should identify design and installation errors. Responsibility for design errors rests solely with the Design Engineers. They are not beyond reproach. The correction of design errors is why errors and omissions insurance (professional liability) exists. The Controls Contractors install their BAS components in the optimal locations available at the time of installation and documents where the component manufacturer's installation recommendations cannot be satisfied.

11. **Drift**. Sensor drift is a natural characteristic of sensors and sensor transmitters that results in the degradation of accuracy over time. In general, temperature sensors typically have minimal risk of sensor drift unless they experience physical damage or wear. Sensor transmitters that measure humidity and carbon dioxide typically experience higher risk of sensor drift especially when they operate at the extremes of their sensor range.

12. **DUT** is the abbreviation for Device Under Test and refers to the device being tested or calibrated. This term is

synonymous with UUT or Unit Under Test.

13. **Extrapolation** describes the calculation of unknown values that are outside the range of known values. This methodology assumes that trends in the data will continue. For example, if are testing the operation of pressure transmitter that is rated for 1-5 VDC as the pressure varies from 0-100 PSIG and we measure 5.1 VDC. The pressure indication at 5.1 VDC would be 102.5 PSIG. The calculation methodology for extrapolation is exactly the same as that of Interpolation. A full description of this calculation will follow.

14. **Full Scale (%FS) Accuracy** is an accuracy specification where allowable error is based on the full-scale output or range of the sensor. Therefore, the specified error is the same no matter where the reading is in the instrument range. For example, if a 0-100 PSIG pressure transmitter has a 0.1% FS accuracy, then the pressure sensor reading would be accurate to ±0.1 PSIG across the entire sensor range. The test data indicates that the sensor reading is most accurate at the full-scale reading and becomes less accurate as the value decreases.

Indicated Pressure (PSIG)	Error (PSIG)	Range of Actual Pressures (PSIG)
100	±0.1	99.9 to 100.1
50	±0.1	49.9 to 50.1
25	±0.1	24.9 to 25.1

Table 8 - Full Scale Accuracy Example

15. **Hysteresis** is a characteristic typical of pressure transmitters where the output signal from the transmitter differs depending on whether the pressure is increasing or decreasing. If the two characteristic curves are plotted on the same graph, the maximum difference between the two curves at the same pressure defines the hysteresis. According to the diagram, the maximum deviation or hysteresis occurs at 50 PSIG.

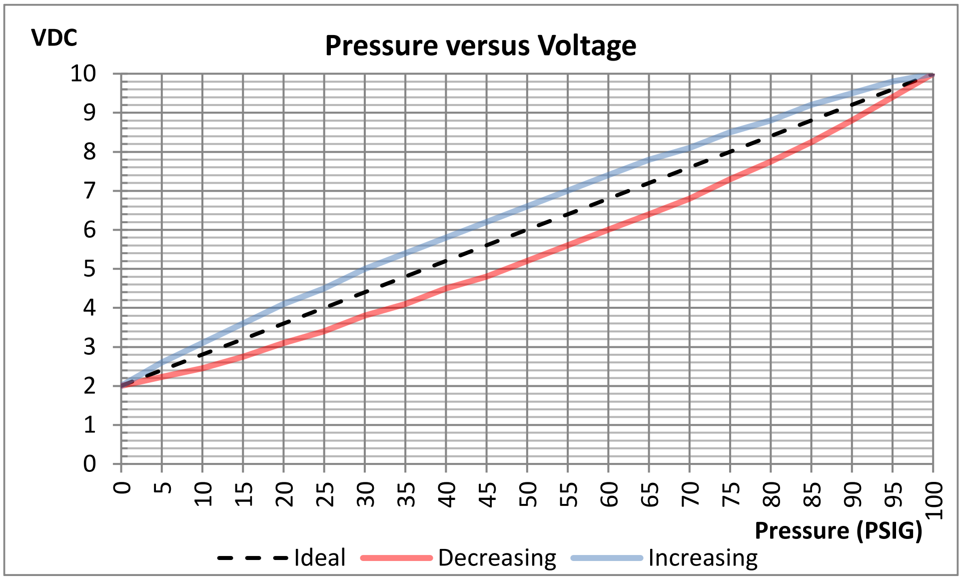


Figure 18 - Hysteresis Curve Example

16. **Installation Error** describes the signal error that results from the installation of the sensor and transmitter. This type of error typically results when the installation recommendations of the manufacturer have not been followed. Installation of the unit in the wrong or less than optimal location is perhaps the most common cause of installation error. For example, the installation of a temperature sensor at the point where two fluid streams meet will not provide an accurate temperature reading because the two fluid streams are not yet fully mixed. Installation of the temperature sensor well downstream of this mixing point will provide a much better indication of the fully-mixed temperature. Mechanical designs typically place wall-mounted room temperature sensors in the wrong location (next to light switch) for convenience rather than the location that will provide the most accurate indication and control of space temperature. As a result, they are installed in the wrong locations. This is an example of a design error that causes an installation error. Installation errors are also caused by installers that are not familiar with the BAS components they are installing or the systems in which they are installing them. Education and training of the installation staff is critically important to the proper installation of BAS components and accuracy of readings.

17. **Instrument Range** refers to the measurement range of the sensor included in the instrument, sensor, or transmitter. For example, an ADPT may have an instrument range of 0-5 inches W.C. or a carbon dioxide transmitter may have an instrument range of 0-2,000 PPM carbon dioxide concentration. This represents the full detection range of the reference instrument, sensor, or sensor transmitter.
18. **In situ Testing** describes the fact that the sensor, sensor transmitter, or device is tested in its installed location. Most BAS input and output devices are tested in situ rather than being removed and sent to a calibration lab or the manufacturer for calibration.
19. **Interpolation** describes the calculation of unknown values that are inside the range of known values. This methodology assumes that trend or pattern in the data will continue. For example, if are looking at resistance temperature tables and want to know what the temperature would be between two known points, we would interpolate the new temperature reading based on the measured resistance which is between two known values. Interpolated values are considered to be more accurate than extrapolated values. A full description of this calculation will follow.
20. **Low-flow hunting** describes a modulating control damper actuator used in a duct-mounted airflow measuring station that constantly cycles between fully closed and barely open. This behavior also occurs in pressure-independent terminal units whose airflow capacity is too high for the immediate load or its minimum airflow setpoint is too low to provide stable airflow control. The point of instability occurs when the velocity signal that coincides with the minimum airflow setpoint is at or below the point at which the control damper is barely open. When the control damper fully closes, the velocity signal and resulting airflow indication is below setpoint, but when it opens the airflow setpoint is quickly surpassed. The only solutions that does not require changes in airflow measuring station and duct sizes are to decrease the duct static pressure and/or increase the airflow setpoint until stable flow control can be established. Otherwise, the duct and airflow measuring station must be modified to a more appropriate size.
21. **Measurand** is the quantity being measured. Some resources on accuracy or calibration may not refer to the actual parameter being measured (distance, temperature, pressure, position, etc.). They often use the generic term "measurand" to refer to the myriad of physical parameters that might be measured and evaluated.
22. **Measurement Error** is the difference between the reference value provided with a calibrated instrument and the BAS-indicated value. From Equation 4, the closer the BAS reading is to the reference reading, the smaller the measurement error. The error can be positive or negative depending on whether the BAS reading is higher or lower than the reference instrument readings.

$$\text{(Equation 4)} \qquad \text{Measurement Error} = \text{Reading}_{\text{INSTRUMENT}} - \text{Reading}_{\text{BAS}}$$

23. **Nonlinearity** describes the characteristic of a sensor/transmitter output signal that is nonlinear. Thermistors provide a signal that is nonlinear by design, but transmitters produce an output signal that is proportional or linearly related to the sensor reading (when it is operating properly).

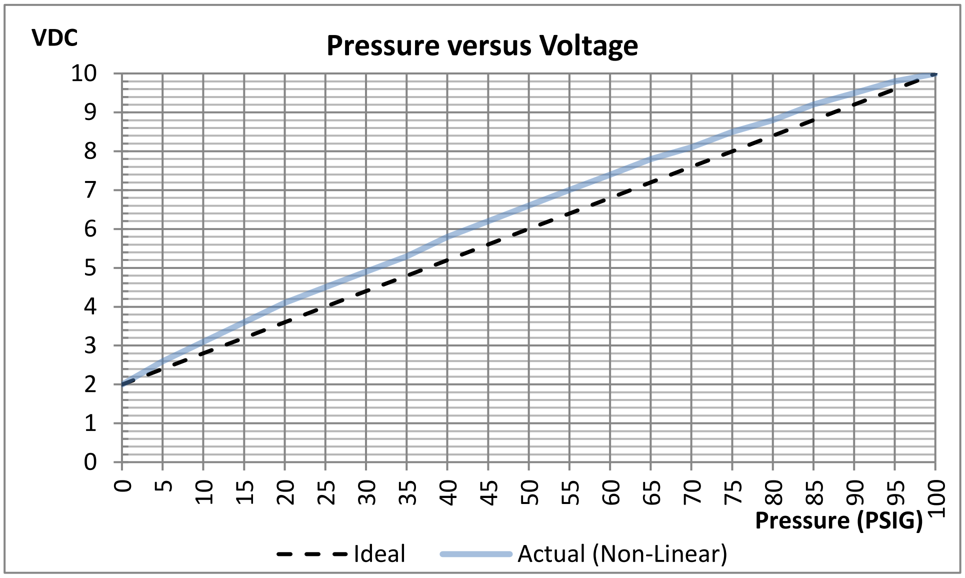


Figure 19 - Non-Linear Characteristic Curve Example

However, it is not uncommon to encounter transmitters that produce output signals that are not perfectly linear. If the calibration tolerance is exceeded because of nonlinearity, replacement is recommended rather than trying to adjust the scale and offset values.

24. **Non-Repeatability** describes the characteristic of a sensor/transmitter that produces an output signal that is not repeatable. Even when all test and environmental conditions are exactly the same, the output signals vary from the previous reading. If a sensor/transmitter exhibits any degree of non-repeatability, then its replacement is recommended.

25. **Offset** is a value that has two possible applications. When an analog input of a JACE controller is being configured, it requires the entry of Scale and Offset factors. These values are the parameters used to define the linear equation that calculates the sensor reading from the transmitter's voltage or milliamp signal. The second application relates to the calibration of temperature sensors. When the temperature reading requires correction to match the reference reading, an offset is added to the temperature reading. The offset in both applications can be positive or negative. Chapter 3: BAS Inputs and Outputs will explain this in greater detail.

26. **Percentage of Reading (%RD) Accuracy** is an accuracy specification where the allowable error is based on the reading currently displayed (not the full scale) by the unit being tested. Because the accuracy is dependent on the actual sensor reading, the error changes proportionately with the sensor reading (as opposed to being fixed). For example, if a 0-100 PSIG pressure transmitter has a 0.25% RD accuracy, then at 100 PSIG the pressure sensor would be accurate to ±0.25 PSIG. At 50 PSIG, the pressure transmitter would be accurate to ±0.125 PSIG. At 25 PSIG, the pressure transmitter would be accurate to ±0.0625 PSIG. The test data indicates that the sensor reading becomes more accurate as the value decreases.

Indicated Presssure (PSIG)	Error (PSIG)	Range of Actual Pressures (PSIG)
100	±0.25	99.75 to 100.25
50	±0.125	49.875 to 50.125
25	±0.0625	24.9375 to 25.0625

Table 9 - Percent of Reading Accuracy Example

27. **Precision** refers to the how close multiple measurements are to each other. Readings with a high degree of precision are typically repeatable and consistent. Precision does not mean accuracy, but the goal for the BAS sensor readings is to be both accurate and precise. Precision has a second meaning that we must be aware of. The number of decimal places in a number is also referred to as precision. For example, pi (π) may be represented 3.141593 or 3.14. The first number has a higher degree of precision than the second. For most setpoints in HVAC control, no decimals are required, so they may be represented as whole numbers. Most sensor/transmitter readings require no more than one decimal place. To display a higher degree of precision is typically a waste, unless we are dealing with very low pressures measured in inches W.C. Supply duct static pressures are typically represented with two decimal places while space pressurization is typically represented with three decimal places depending on the application. Setpoints of static pressure readings are typically set to one degree less precision than the reading.

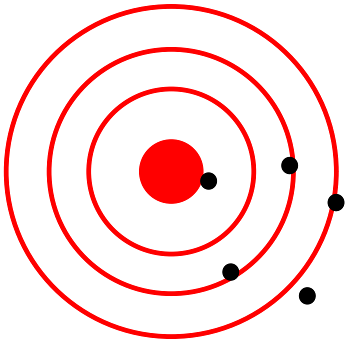


Figure 20 - Less Precise Pattern

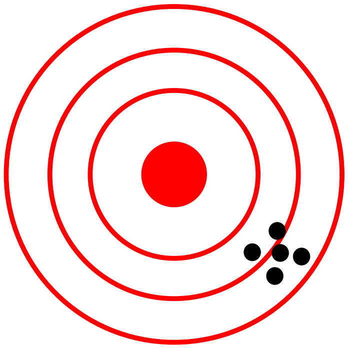


Figure 21 - More Precise Pattern

Figure 22 - Both Accurate and Precise

Revisiting the target practice example used to demonstrate the concept of accuracy, the patterns above show that higher levels of precision translate to tighter patterns. Ideally, the sensors and transmitters are both accurate and precise.

28. **Reference Instruments** refer to the instruments used to validate or compare to the BAS-indicated sensor/sensor transmitter value. These instruments provide the reference readings and are considered to be the "true" or correct value. As such, they should be calibrated to NIST-traceable standards to ensure that they are operating correctly and providing accurate readings.

29. **Reference Readings** are the measurements provided by reference instruments which are considered to be the correct or true values when making comparisons with BAS input and output devices.

30. **Reference Temperature** describes the standard temperature reading corresponding to the base resistance of the thermistor or RTD. Thermistors are typically rated for a reference temperature of 77.0 °F. Both 10k Ohm and 20k Ohm thermistors will indicate through the BAS a temperature of 77.0 °F when its resistance is at 10k Ohm and 20k Ohm, respectively. RTDs typically have a reference temperature of 32.0 °F at their base resistance.

31. **Resistance Temperature Table** (RTT) is a dataset of resistance values and its corresponding temperature which cover the operating range of the thermistor or RTD. Given the resistance, the corresponding temperature can be calculated from the RTT and vice versa.

32. **Resolution** describes the smallest detectable change in the input and output signals. Resolution of the input signals (sensors and transmitters) is based largely on the sensor/signal range and the bit level of the BAS controller's Analog to Digital Converter (ADC). Likewise, resolution of the output signals (analog signals for actuators, VFDs, chiller setpoints, etc.) is based on the output signal range and the bit level of the controller's Digital to Analog Converter (DAC). The higher the bit level, the higher the signal resolution. BAS controllers often have different bit levels for the input and output signals. Chapter 3: BAS Inputs and Outputs will explain this in greater detail.

33. **Scale** refers to the slope in the equation of a line that is used to configure an analog input of a JACE controller. Recall that a JACE analog input is defined by the entry of Scale and Offset factors. These values are the parameters used to define the linear equation that calculates the sensor reading from the transmitter's voltage or milliamp signal. Chapter 3: BAS Inputs and Outputs will explain this in greater detail.

34. **Selection Error** describes the error that results from the installation of the incorrect device or device type. For example, when an automatic reset Low-Temperature Detector (Freezestat) is installed when the specifications called for a manual reset type. A selection error can lead to configuration error when it results in the incorrect sensor or signal range. Another example would be an averaging temperature sensor that is too short to provide the minimum required coverage (length per square foot coil/duct area).

35. **Service Tolerance** refers to the maximum permissible deviation that the BAS reading may exhibit when compared to the reference reading by a calibrated instrument and still be considered usable. Service tolerances are typically expressed as a ± value from the reference reading. The service tolerance may be set at ±20% of reading, for example. If the sensor/transmitter readings obtained during the testing exceed the established service tolerance, then the device should be replaced – not calibrated. The Owner should not have to accept a device that exceeds the service tolerance.

36. **Single-Point Calibration** is the use of a single reference reading from a calibrated reference instrument to compare to the BAS-indicated reading. Single-point calibrations are typically performed on temperature sensors because they directly measure the resistance and calculate the corresponding temperature reading based on a dataset of temperature versus resistance values (typically called a Resistance Temperature Table). A single-point calibration should not be performed on sensor transmitters because two calibration points are required to identify and correct the zero and span errors. Chapter 3: BAS Inputs and Outputs will explain this in greater detail.

37. **Slope (Scale)** refers to the slope of a line. In controls, we are referring to the slope of a line defined by two operating points which define linear analog inputs and outputs. The maximum and minimum operating points (sensor and signal range) of a sensor transmitter define its ideal characteristic curve. The test points acquired during calibration define the actual performance (zero and span) of the sensor transmitter. Slope is also referred to as the rise over run or the change in Y over the change in X in the Cartesian coordinate system.

$$\text{(Equation 5)} \qquad \text{Slope} = \frac{Rise}{\text{Run}} = \frac{\Delta VDC}{\Delta\text{PSIG}} = \frac{10-2\ VDC}{100-0\ \text{PSIG}} = 0.08\ \frac{VDC}{\text{PSIG}}$$

38. **Span** is the difference between the lowest signal value and the highest signal value generated by the analog input device. Suppose that a 0-100 PSIG differential pressure transmitter with an output signal of 2-10 VDC is subjected to a pressure that varies between 0 PSIG and 100 PSIG. If its output signal varies only between 2 VDC and 9 VDC,

then its span is only 7 VDC. However, it should be 8 VDC (10 VDC – 2 VDC). In process applications, the zero and span of the sensor transmitter would be adjusted to provide the full output signal range. In comfort cooling applications, we typically do not make zero and span adjustments. We adjust the BAS analog input configuration to interpret the actual sensor transmitter performance.

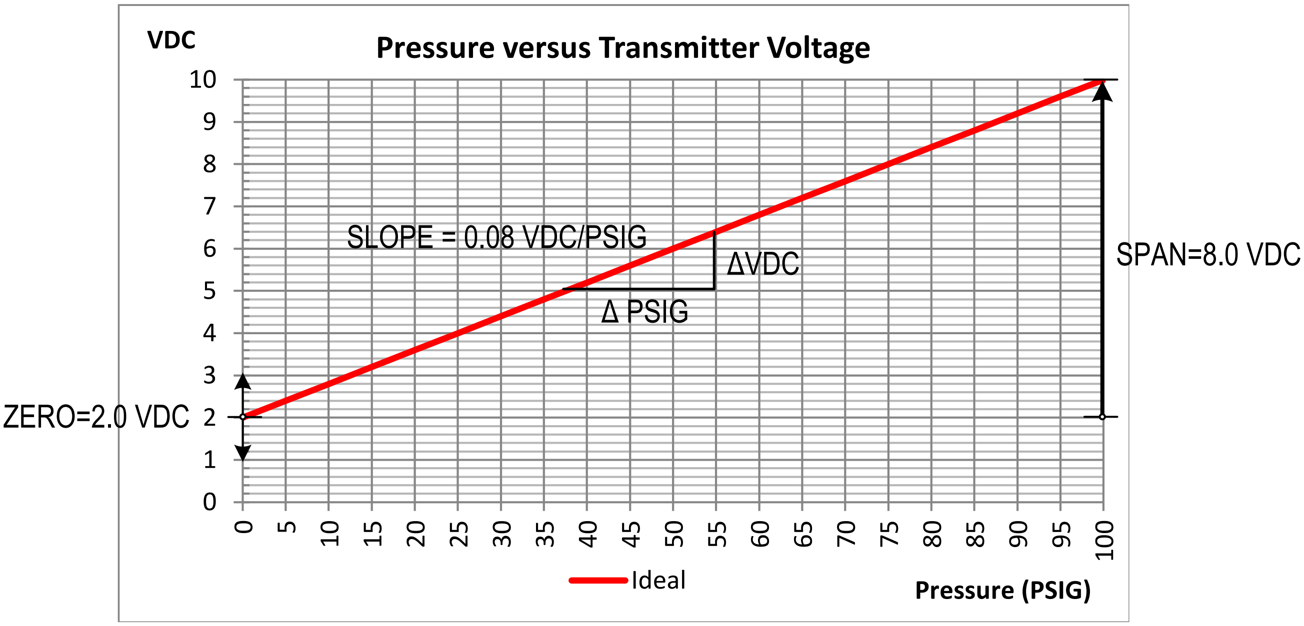


Figure 23 - Zero and Span Example

39. **Span Error** describes the error that is generated when the output of a sensor transmitter does not produce the correct signal across its sensor range. Consider a 0-100 PSIG differential pressure transmitter with an output signal of 2-10 VDC. The dashed line represents the ideal transmitter characteristic curve. The red line represents an actual characteristic curve whose span is 10% too high as indicated by its higher slope and the fact that it produces a voltage of 11 VDC (instead of 10.0 VDC) at 100 PSIG. The resulting pressure indication would be 112.5 PSIG with 100 PSIG applied test pressure. The blue line represents the actual characteristic curve whose span is 10% too low as indicated by its lower slope and the fact that it produces a voltage of 9.0 VDC (instead of 10.0 VDC) at 100 PSIG. The resulting pressure indication would be 87.5 PSIG with 100 PSIG applied test pressure. Zero and span can be adjusted on transmitters with integral zero and span adjustment potentiometers.

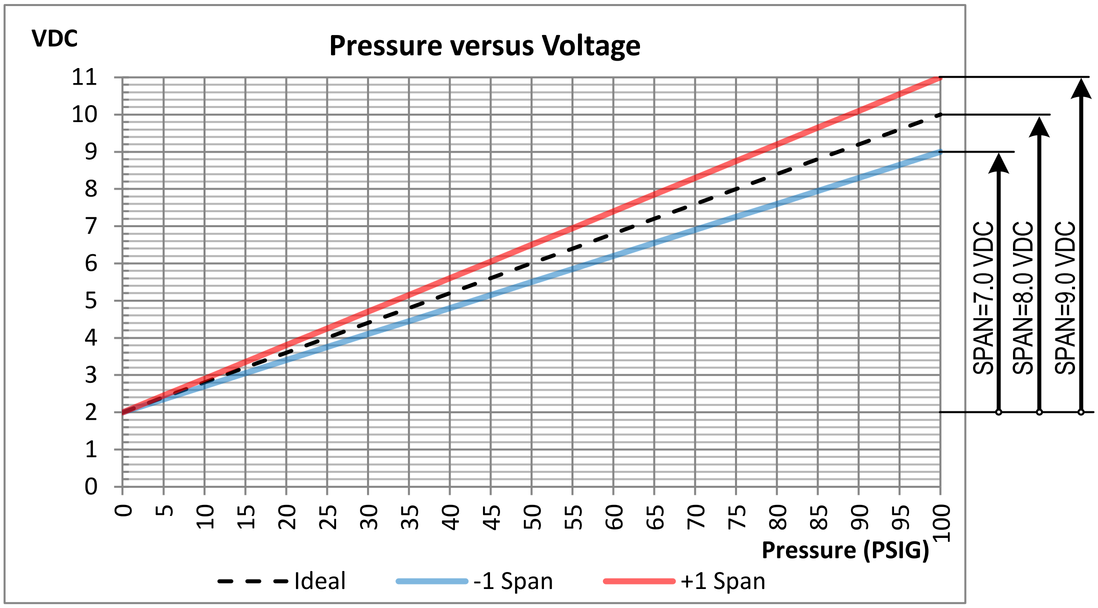


Figure 24 - Transmitter Span Error Example

40. **Temperature Error** represents the change in transmitter output signal that results from changes in ambient temperature. The accuracies of a sensor transmitter are typically defined at a standard temperature and when the actual operating conditions differ, temperature error may increase. Pressure transmitters are sensitive to temperature changes.

41. **Two-Point (or Multi-Point) Calibration** refers to the use of two or more reference points to verify the accuracy of the input and output device readings. Ideally, multiple test points are executed that demonstrate accuracy across the full range of the tested input/output device. Two points that are sufficiently far apart are necessary to correctly evaluate and correct zero and span errors. These calibration points should encompass the normal operating range of the measurand.

42. **UUT** is the abbreviation for Unit Under Test and refers to the device being tested or calibrated. This term is synonymous with DUT or Device Under Test.

43. **Zero** refers to the minimum transmitter output signal that corresponds with a zero or minimum sensor reading. The typical transmitter output signal ranges are typically 0-10 VDC, 0-5 VDC, 2-10 VDC, and 1-5 VDC. Therefore, the zero voltage output signals may be either 0, 1, or 2 VDC. If the transmitter produces a 4-20 mA signal, then the minimum output signal for a zero reading is 4 mA. When the zero signal is a non-zero value, it is referred to as a "live" zero.

44. **Zero Error** describes the error related to the starting point or zero of the sensor transmitter's output signal. The dashed line represents the ideal transmitter characteristic curve of the device under which the analog input of the BAS controller has been configured. If the sensor transmitter has only zero error, the ideal and actual characteristic curves will be parallel. If the slopes of the lines also differ, then there is also span error. Consider a 0-100 PSIG HDPT with an output signal of 2-10 VDC. At zero applied pressure, the light-blue actual characteristic curve produces a voltage of 3 VDC which the BAS would calculate a pressure reading of 12.5 PSIG. At 50 PSIG applied pressure, the actual characteristic curve produces a voltage of 7.0 VDC which the BAS would calculate a pressure reading of 62.5 PSIG. At 100 PSIG applied pressure, the actual characteristic curve produces a voltage of 11.0 VDC which the BAS would calculate a pressure reading of 112.5 PSIG. At all test pressures, the BAS-indicated pressure was 12.5 PSIG higher than the actual pressure which is a clear indication of zero error. In general, at zero applied pressure we should see zero indicated pressure. If 100 PSIG test pressure was applied, we should read 100 PSIG. If both occur during calibration, this indicates that the zero and span settings of the HDPT are correct.

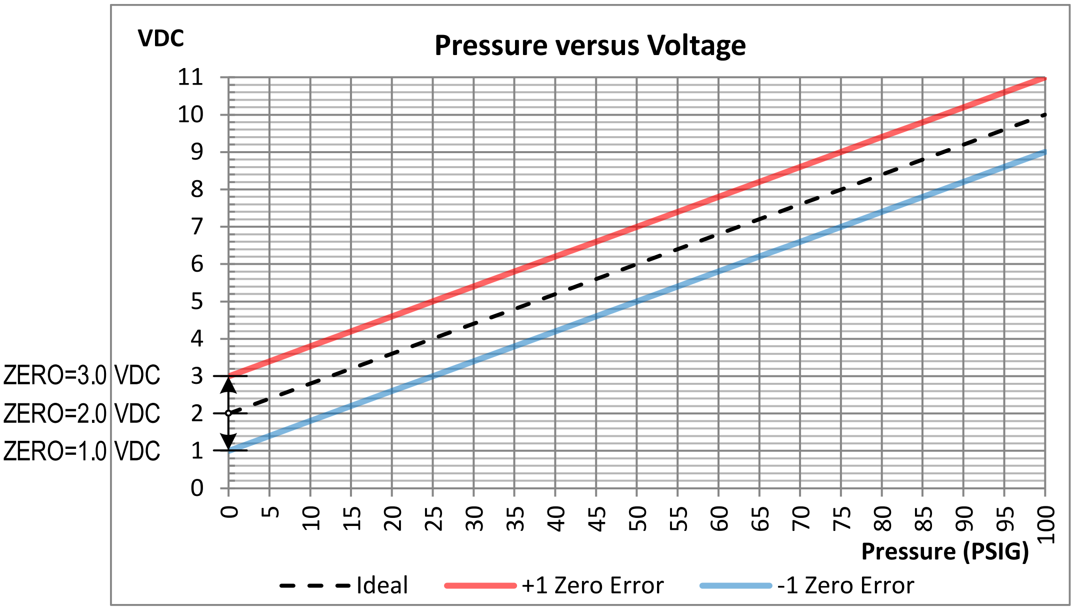


Figure 25 - Transmitter Zero Error Example

2.5 Calibration Process

Calibration is a very important step in the BAS commissioning process. The old adage that "Garbage In equals Garbage Out" very much applies to building automation systems. The accuracy of control is dependent on the accuracy of the input and output devices. Input (binary and analog) devices sample a parameter or condition and produce a signal that is monitored by the BAS. The BAS then performs comparisons, calculations, and control (PID loop) to produce corresponding output signals to control one or more process variables. To ensure the accuracy and efficiency of the system, it is critically important that the accuracy of the input and output devices also be tested and verified.

The reference readings are considered “true” or correct because the instruments have been proven accurate by NIST-traceable calibration testing at a laboratory. It is not uncommon to find that the accuracy ratings of some BAS analog inputs devices are higher than the reference instruments. This should not be a cause for concern. The calibrated reference instruments are providing a reference or basis for comparison of a “system” that is controlling environmental conditions. As a result, there are many opportunities for the readings of the highly accurate sensors and transmitters to go wrong. If the application requires high levels of accuracy, then they can be conducted with the appropriate instrumentation.

Reference instruments are used to identify and quantify the sensor/transmitter error to determine the need for correction or “calibration.” The calibration test data provides the information needed to update the sensor/transmitter readings so that they match the readings from the calibrated reference instrument. Any mass-produced device will have minor variations in its materials, manufacturing process, composition, etc. that affect its final operation. We also have to keep in mind that we are in the field calibrating BAS input and output devices. We are not in a laboratory setting where test conditions are controlled and stable. Calibration tolerances are typically prescribed for the various BAS input and output devices. As long as the calibration readings fall within the prescribed calibration tolerance levels, the BAS input/output device is deemed to be “accurate.” When it falls outside of the calibration tolerance, we must calibrate the reading (or replace it), update the analog input configuration, and retest to confirm its performance.

All too often, calibration is thought of as the comparison of the BAS input or output reading to the reading provided by a calibrated reference instrument or observation. While this step is definitely part of the calibration process, it is not the only step. Calibration of input and output devices requires several additional steps to ensure that they function correctly and provide accurate data for the control and monitoring of the associated systems. The steps of the calibration process for BAS input and output devices are outlined in the following paragraphs.

2.5.1 Define/Confirm the Operating Parameters of the Devices

Calibration begins with defining the operating parameters of the analog input, analog output, binary input, and binary output devices. This step is simply the verification that the correct device has been installed for the application. Typically, the main operating parameters of input and output devices include its sensor range, signal range, type, construction, and accuracy ratings. In addition, where it is located has some bearing on its accuracy ratings and design. Devices located outdoors or in a potentially wet environments typically require a NEMA 3x or 4 (or similar) rating. Temperature sensors (Thermistors and RTDs) are typically defined by their base resistance and mounted location. If the BAS analog input is configured to interpret the resistance signal from a 20K Ohm thermistor, it will provide a temperature reading of 77.0°F when the thermistor resistance is equal to 20,000 Ohms. However, if the BAS input is instead configured for a 10K Ohm (type 2) thermistor, the temperature reading will be 49.84°F as calculated by interpolation from the data from Table 3. This example emphasizes the importance of BAS input/output configurations matching the signal parameters of the connected devices. Standardization of sensors, transmitters, and output device types, as well as their signal ranges, reduces the potential for configuration errors.

2.5.2 Point-to-Point Check Out

The next step in the calibration process is the Point-to-Point checkout of each input and output point of the BAS controller. We first verify that the device is connected the correct input or output terminal of the BAS controller. The term “Point-to-Point Checkout” is often used loosely to indicate the verification and calibration of the BAS points. Point-to-point checkout always means verifying the installation and testing the connectivity of the input and output devices. However, it MAY or MAY NOT mean the calibration of the devices. Calibration is treated separately from point-to-point checkout for clarity and consistency.

Binary inputs of the BAS controller monitor either normally-open or normally-closed device contacts. Actuation of the contacts from their normal state is interpreted by the BAS as a change in device status. Binary input devices are verified by either making (if the connection is normally open) or breaking (if the connection is normally closed) the signal wiring connection at the device (not at the BAS controller contacts) which will cause a change in the binary input status. This can also be accomplished by simulating the conditions that would cause the actuation of the binary input device contacts. As the state of the binary input device changes, the facets will also change (Opened/Closed, On/Off, Normal/Alarm, etc.). Photograph 22 shows a current sensing relay whose status monitoring circuit has been broken to electrically simulate a de-energized conductor. This change in contact status causes a status alarm after the programmed alarm delay has expired. Analog inputs are verified by disconnecting either the power or signal wires from the device in question. Either will produce a signal change that can be used to verify connectivity. It is critical that the wiring be disconnected at the UUT – not at the BAS controller terminals. Photograph 24 shows that the discharge temperature reading goes to zero when the space temperature sensor is disconnected (Photograph 23). When VAV terminal units are equipped with both discharge and space temperature sensors, at least one of them should be disconnected to verify connectivity as well as the data point bindings to the BAS graphics. This issue is easily corrected by switching the wiring terminations at the BAS controller. The temperature sensors could also have been identified by energizing the terminal unit reheat coil and verifying which temperature sensor reading increased.

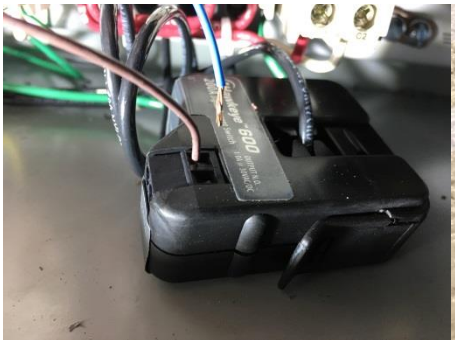


Photo 22 - Wire Removed from Current Sensing Relay

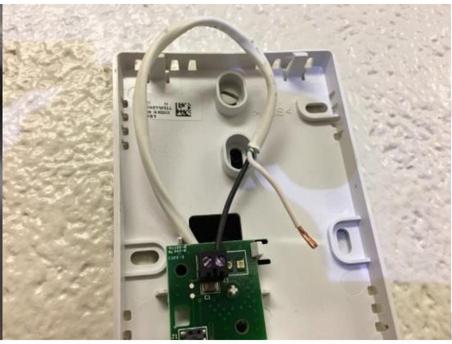


Photo 23 - Wire Removed from Space Temp Sensor

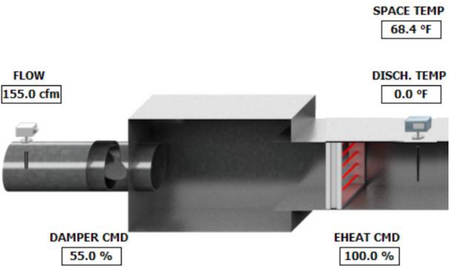


Photo 24 - VAV Graphic Showing Disconnected Discharge Temp. Sensor

Binary outputs are verified by successively changing the associated equipment command (Start/Stop, Open/Close, Enable/Disable, etc.) through the BAS and verifying that all intermediate isolation relays activate and/or the controlled device actuates or activates upon command. Dampers and valves will open and close while fans, pumps, electric resistance heaters, and compressors will energize and de-energize with changes in the binary output command. If the status of the equipment controlled by the binary output is monitored by a corresponding binary input device (current sensing relay, position switch, current transmitter, air/hydronic differential pressure switch, etc.), this is a good time to test that device as well. Photograph 27 shows an outdoor air damper that is equipped with a position feedback switch that confirms its full-open position.

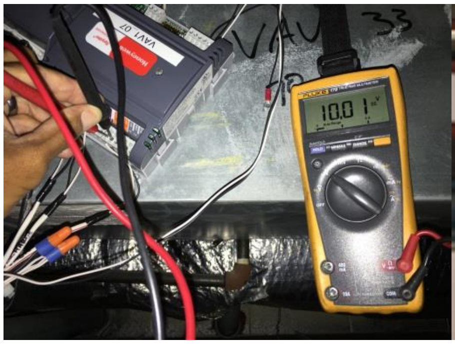


Photo 25 - 100% Valve Command (10.0 VDC Output Signal)

Photo 26 - VFD Commanded to 100% Speed Output (60 Hertz)


Photo 27 - Outdoor Air Damper Commanded Opened (Two-Position)

Analog outputs are verified by commanding each to various output levels (typically 0%, 25%, 50%, 75%, and 100%) and verifying that the output signal and controlled device respond accordingly. The signal is first verified by multimeter at the BAS controller analog output terminals as show in Photograph 25. It is then verified at the terminals of the controlled device contacts. The controlled device is then tested to verify that it correctly follows the analog signal provided by the BAS controller. The VFD display shown in Photograph 26 shows a 100% output command which results in full speed operation as indicated by the 60 Hertz speed indication.

After the device connectivity has been verified, the focus switches to verifying that it was correctly installed, located, powered, wired, configured (selector switches, dip switches, jumpers, etc.), connected (tubing, pipe, taps, thermal traps), and bound to the BAS graphics. A chart or table that has the appropriate data collection fields is typically used. The installed location should be evaluated to verify that it provides the most accurate readings. If the signal ranges of the input/output devices do not match the configuration of the corresponding BAS input or output, it will not function at all or will not report correctly. All too often, the input/output calibration initially fails because of configuration errors. These are only identified by testing and corrected by calibrating each and every input and output device.

2.5.3 Define/Confirm Error Tolerances

Many project specifications specify a maximum allowable measurement error or Calibration Tolerance for the various sensor/sensor transmitter types. In many cases, these stipulated values seem arbitrary. For example, the calibration tolerance for a temperature reading may be designated as ±3°F, but there is rarely an explanation of how this value was determined. Therefore, if the actual temperature reading is within 3°F of the reference temperature reading, then the temperature reading is considered accurate and does not require correction. An alternate approach would be to designate an allowable multiple of the manufacturer's rated accuracy rather than arbitrary values. For example, if the allowable multiple were defined as five (5), then when the measurement error exceeds five times the manufacturer-rated device error, calibration is required. A temperature sensor whose accuracy is rated at ±0.36°F would be calibrated if the difference between the BAS reading and the reference reading exceeds ±1.8°F. This approach seems more reasonable than using arbitrary values based on preferences.

To avoid confusion and potential field calculation errors, it is useful to standardize on device types, manufacturers, wiring configurations, control signals, ratings, etc. to limit the possible variations. It is also a good idea to utilize the locally accepted units of measure related to each sensor/transmitter. This will avoid the need to repetitively calculate the calibration tolerances as each sensor/transmitter reading is measured, calibrated, and remeasured. The calibration tolerances provided in the following table are not universal and are example data entries for this discussion. They are not recommended for use. The final calibration tolerance values will be dependent on the sensor/transmitter ranges, how critical the data point is to the HVAC system control, contract documents, and the Owner requirements.

Signal Type	Sensor/ Transmitter Range	Sensor/Transmitter Accuracy	Calibration Tolerance (+/-)	Service Tolerance (+/-)
Air Temperature (Outside, Space, Duct)	-22°F to 158°F	±0.36°F	1.8°F	10°F
Hydronic Temperature	-40°F to 302°F	±0.36°F	1.8°F	10°F
Humidity (Outside, Space, Duct)	0-100 %RH	±1.8 %RH	9%RH	15%RH
Electrical Voltage	0-500 VAC	±3 %FS	15 VAC	30 VAC
Electrical Current	0-500A	±3 %FS	15 Amps	30 Amps
Air Differential Pressure Transmitter-Duct	0-5 In. W.C.	±1.0 %FS	0.25 In. W.C.	0.5 In. W.C.
Air Differential Pressure Transmitter-Space	-0.25-0.25 In. W.C.	±1.0 %FS	0.05 In. W.C.	0.1 In. W.C.
Carbon Dioxide Concentration	0-2000 PPM	±3 %RD or ±30 PPM	90 PPM	180 PPM
Airflow Rate-Differential Pressure	0-1.5 In. W.C.	±2 %RD	0.03 In. W.C.	0.15 In. W.C.
Hydronic Differential Pressure Transmitter	0-50 PSIG	±0.5 %FS	0.5 PSIG	5 PSIG
Airflow Rate-Thermal Dispersion	0-3000 FPM	±2 %RD	120 FPM	240 FPM
Hydronic Flow- Turbine Meter	0-500 GPM	±2 %RD	20 GPM	50 GPM
Hydronic Flow-Electromagnetic Meter	0-500 GPM	±0.4 %RD	4 GPM	20 GPM

Table 10 - Example Accuracy and Calibration Tolerance Data

2.5.4 Establish Steady-State Conditions

Comparison readings should be performed while the system under test is operating under steady-state conditions. This means that the system is operating under normal conditions with no transient loads which would cause the system to react erratically. Calibration readings should never be taken while the system is in transition from one state (unoccupied to occupied, morning warm-up or cool-down) to another or while significant changes in load are occurring. This is especially true for sensors that require time to acclimatize to the ambient conditions (temperature, humidity, carbon dioxide, etc.). Sensors that sample flowing gas and liquid streams require much less time to acclimatize. However, it is still best to posture the system to minimize the potential for incompletely-mixed air or liquid streams.

The system may already be operating under steady-state conditions. However, we need to be sure that it will continue to do so for the duration of the calibration work. For example, when terminal unit airflow readings are calibrated against flow hood readings, the space temperature setpoints are typically set to 55°F-60°F to ensure that they remain at the full cooling airflow rate. Setting the space temperature setpoint to 70°F (from 74°F) is typically a mistake because the terminal units may actually reduce the space temperature to this setpoint. Once the space temperature setpoint is reached, the supply airflow will begin to reduce which disrupts the airflow calibration process. If the terminal unit control mode can be overridden to maximum cooling airflow, this is preferable because changes to space temperature setpoints and their restoration are not required. Prior to calibrating the airflow indications of terminal units it is good practice to observe the supply fan speed and duct static pressure readings. Both should be steady with little to no deviation from setpoint. If the duct static pressure is constantly fluctuating, override the fan speed to a fixed setting.

Space temperature sensors are often difficult to calibrate because they may be under the influence of many factors (sunlight, supply air steams, equipment, people, proximity to heat loads, exterior walls, room pressure, interaction with high-mass walls, etc.). Setting your temperature meter next to a wall-mounted space temperature sensor can lead to some surprising comparisons. Disabling the air handling unit and any heat loads (copy machines, computers, etc.) in the space and returning first thing in the morning or at night often yields superior temperature sensor calibration results. This effectively creates ideal steady-state conditions and eliminates many of the factors which impede the accurate calibration of the space temperature sensors.

Establishing steady state conditions for duct-mounted or system-mounted sensors is typically implemented with valve and damper overrides. For example, overriding the dampers in an air-handling unit for 100% outdoor or 100% return air minimizes the effects of improper mixing, damper leakage, stratification, etc. In addition, all heating and cooling coils in the air-handling unit should also be disabled or overridden to 0% capacity to prevent any temperature changes caused by modulating control valves or staging equipment. Closure of manual isolation valves is also recommended to ensure no-flow conditions by eliminating possible control valve leakage. These overrides create steady-state conditions which make it conducive to testing and calibrating several temperature sensors at the same time. Calibration of airflow measuring stations often requires overrides of the dampers, operating modes, as well as the fan speeds (through a VFD) to ensure that the airflow does not change during the calibration process.

Establishing steady state conditions in hydronic systems is similarly implemented with equipment overrides. Testing hydronic system temperature sensors in a central plant requires that central plant equipment such as boilers, chillers, and cooling towers be disabled while flow is maintained. Several hours should be allotted to allow any residual heat within the equipment to dissipate prior to testing and calibrating hydronic temperature sensors. When the central plant inlet and outlet temperature are essentially the same, calibration may begin. Under these steady-state conditions, it is possible to test and calibrate several hydronic temperature sensors at the same time. Testing and calibrating may also proceed with the equipment operating, but this introduces additional variables (fluid mixing, equipment staging, and capacity modulation) into the situation that reduce the accuracy of the calibration results.

When system operating conditions are in transition or under the influence of changing loads, the difference between the BAS-indicated reading and the reference readings or observations may be appear larger or even smaller than actual. Establishing steady-state conditions is vital to ensuring fewer iterations and maximum accuracy of the calibration process because it eliminates potential sources of measurement error. In summary, setpoint changes, equipment isolation, output device overrides, or disabling of the equipment or system may be necessary to create the optimum conditions for accurate sensor/transmitter calibration.

2.5.5 Comparison to Reference Readings

To evaluate the accuracy of BAS input and output devices, it is necessary to compare their BAS-indicated readings to reference readings or physical observations. The difference between these two values is then compared to the established calibration and service tolerances for that device. The results of the initial testing establish the "as-found" calibration results. A variety of instruments are required to provide the reference readings to make these comparisons. These reference instruments should be calibrated to NIST-traceable standards to ensure that they are accurate and fully functional. Not all instruments are sent off for calibration. Magnehelic® gauges and Bourdon-tube pressure gauges, for example, are typically not sent off for calibration. Their calibration can be verified by comparing their readings to those provided by calibrated instruments.

Several temperature comparisons are taken over the calibration range to determine the final offset value that is entered into the BAS controller's analog input configuration for the temperature sensor. These reference points should be concentrated in the normal operating range of the temperature sensor. Multi-point calibrations take into account several comparisons between reference readings provided by calibrated instruments and BAS-indicated temperature readings. Multiple readings provide an indication of the sensor accuracy and repeatability as the temperature changes.

Recall that the analog input of the BAS controller is initially configured with the ideal characteristic curve parameters. All sensor transmitters, even new ones, have varying levels of zero and span errors. Consequently, they will have various levels of configuration error if the sensor transmitter is not tested and calibrated. At least two points of comparison are required to evaluate and calibrate the transmitter reading. These reference points should be sufficiently apart to at least encompass the normal operating range of the sensor transmitter. The line formed between the two reference points is compared to the line defined by the transmitter's programmed characteristic curve to determine how well they agree. This comparison also allows us to determine whether the sensor transmitter produces an output signal that correctly corresponds to its sensor reading. Testing is required to determine the transmitter's current performance so that its analog input can be configured to match it, thereby eliminating the configuration error. The results may indicate a need to calibrate the transmitter if the results do not fall within the calibration tolerance. The analog input is configured with the calibration test results to allow the BAS controller to correctly interpret the sensor transmitter's actual performance (output signal versus sensor reading). Ideally, the calibration range should be equal to the sensor range to ensure that it reports correctly across its entire range, but it is common to use a smaller calibration range in the field.

Photo 28 - Air Temperature Comparison

Photo 29 - Hydronic Temperature Comparison

Photo 30 - Hydronic Flow Comparison with Ultrasonic Flow Meter

Some sensor transmitters are conducive to the application of simulated test media. For example, pressures may be simulated with a calibration pump and reference pressure gauge or manometer. This allows the HDPT to be tested across its full sensor range and its corresponding output signal verified. Some carbon dioxide transmitters have a calibration gas port where carbon dioxide gas of a known concentration may be applied and its output signal evaluated. Most other sensors and sensor transmitter are tested with hand-held reference instruments that are used to acquire comparison readings in close proximity to the UUT. However, testing the sensor/sensor transmitter across its full sensor range is typically not possible. This issue will be more fully explained in Chapter 3: BAS Input and Output Devices.

Photo 31 - Hydronic Diff. Press. Transmitter Comparison with Calibration Pump and Test Gauge

Photo 32 - Magnehelic® Gauge and Calibration Pump to Calibrate an Air Differential Pressure Transmitter

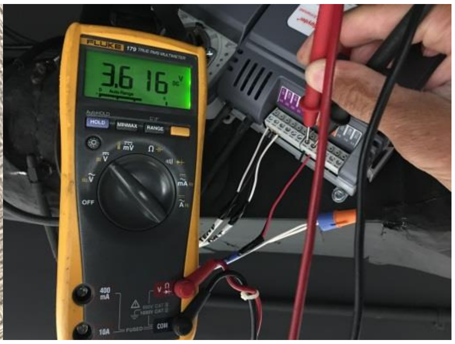


Photo 33 - Analog Output Signal to Control Valve Measured at BAS Controller

Binary output signals are cycled between On and Off to verify that with each change in command, the voltage at the BAS controller terminals is measured, the intermediate relay status indications are confirmed, and the end device/equipment control is verified. Analog output devices are verified by overriding the analog output command to 0%, 25%, 50%, 75%, and 100% output signals. At each increment, the analog output signal is measured with a multimeter to verify that the BAS controller produces the correct signals. The same signals are tested at the controlled equipment or device terminals to verify that the control signals reach it. Finally, the controlled equipment or device is tested to verify that it properly interprets the analog control signals. Analog output signals control equipment output capacities (boiler output, chiller output, VFD speed, electric resistance heater capacity) and damper/valve actuators positions. The polarity and range of the control signal must be coordinated with the controlled equipment to be properly recognized.

2.5.6 Correction or Calibration of the Input/Output Signal

The final step in the calibration process involves the implementation of the corrective actions required to correct or calibrate the readings. If the "As-found" calibration results satisfy the calibration tolerance, nothing more is required and the "As-Found" calibration results are copied to the "As-Left" fields of the calibration sheet. However, if the as-found calibration results exceed the calibration tolerance, then correction of the BAS-indicated readings is required. Occasionally, the difference between the BAS-indicated reading and the reference reading or physical observation exceeds the service tolerance. In this case, the device should be replaced and the calibration process restarted from step one. Do not waste time calibrating a device that exceeds the service tolerance.

Temperature sensors that exceed the calibration tolerance will require the entry of a temperature offset value that is added to all temperature indications. This value may be positive or negative depending on whether the BAS-indicated values are higher than or lower than the reference temperature readings. When corrections are required for sensor transmitter readings, there are two distinct methods to accomplish it. In the process environment, the zero and span of the sensor transmitter output signal is adjusted until it accurately represents the ideal characteristic curve. In the comfort cooling environment, the analog input configuration is typically adjusted to accurately represent the performance of the sensor/sensor transmitter. The calibration test data (reference instrument reading, BAS-indicated reading, and transmitter output signal) provides the data points necessary to update the configuration of the BAS controller's analog input. If the performance does not satisfy the service tolerance, then it is replaced and tested to confirm accuracy. If the sensor/sensor transmitter is not tested, the transmitter will report incorrectly because of configuration error. With a correctly configured and calibrated sensor transmitter, its performance will be accurate across its calibration range. More detailed information on this subject will be provided in Chapter 3.

After the analog input of the BAS controller has been calibrated, the device is tested one final time to confirm that it produces results that satisfy the calibration tolerance. If it does not, verify that you have steady-state conditions, calculate new correction factors, and retest to verify whether they produce the desire results. The final readings constitute the "As-Left" calibration data.

2.6 Post-Calibration Documentation

Following the calibration process, documentation of the sensor/transmitter calibration work performed by the Controls Contractor and Commissioning Agent is typically taken off the work site where it is either archived or included in a report. It is unfortunate that it is typically not left on site where it would be most beneficial to the next Control Technician, building manager, or Commissioning Agent. The controls submittal provides the original control system design intent and a copy is typically left in the local controls panel. Including the input and output device calibration results in the As-Built Control Submittal makes the most sense, but it is not customary to do this yet. Alternatively, a calibration sticker or tag that has its identification, configuration, calibration date, and calibration results could be applied to each calibrated device.

2.7 Factory Calibration versus Field Calibration

Some people believe that if a sensor or transmitter is factory calibrated, field testing and calibration is not required. When an input device has been "factory calibrated" it means that its function and accuracy has been tested at the factory prior to shipping and that it met the minimum accuracy requirements on the day that it was tested. However, since the factory calibration, it has been handled, packaged, shipped, scanned, possibly radiated, and stored until transportation to the job site. In transit, it has been exposed very likely to both high and low temperatures as well as physical forces (bumps, drops, stacking, etc.). It is then unpacked, positioned, and installed in its final position. Control and power wiring are then installed and terminated between the input device, BAS controller terminals, and power supply. The length and gauge of the wiring used, as well as the integrity of the terminations and wiring connections can also affect the final readings. If a 250 Ohm or 500 Ohm resistor is installed across the BAS controller terminals to convert the current signal to a voltage signal, variations in the resistance can also affect the final reading. Following the installation and wiring of the device, the analog input of the BAS controller that receives the device signal must be correctly configured to correctly interpret the signal, linked to the appropriate control logic blocks, and correctly bound to the BAS graphics. As you can see, there are many opportunities for errors. The factory calibrated component is now part of a larger system with several additional components and connections whose operation has to be reviewed and tested to ensure accurate readings and stable control. It is not just the sensor/transmitter that is being tested, it's the entire system that delivers, displays, and calculates output signals based on the readings. Therefore, all sensors/transmitters must be field tested and calibrated to ensure proper operation and accurate results, even those that were factory calibrated.

2.8 Integrated Factory Controllers

The input and output points of equipment with packaged controls requires testing and calibration just like the controls provided by the Controls Contractor. When the packaged units are installed, there typically is very little to no onsite calibration of their input/output devices by the installing contractor. Their startup procedures are typically concerned with the electrical service and verifying that the major components of the system function. Testing and calibration of the input and output devices is not a concern. Onsite testing and calibration work is typically performed by the Controls Contractor or Commissioning Agent. The same tools and procedures are utilized, but there are several limitations. When testing the input sensors of a typical BAS controller, it is recommended that the system be overridden to a particular state or operating mode so that system changes are not occurring during the calibration process. This is often difficult to achieve with integrated controllers. The integrated point names are often cryptic and require the review of supplemental documents to determine what each point does. It is not uncommon for many of the binary and analog output points to be configured as readable (instead of writable). Therefore, a simple point override to enable a system component (fan, pump, electric resistance heater, or compressor) or stroke the damper or valve actuator to verify its operation is often not possible. To get actuators to stroke, you must override and/or simulate sensor/transmitter readings or implement setpoint changes that will cause the actuator to stroke. These methods of testing integrated equipment controllers are much more time consuming and still produce questionable results. When differences are detected between the reference instrument readings and the BAS-indicated values, there often is no corresponding integration point to calibrate the readings. Some packaged units provide sensor calibration through their user interface and manual control of output commands, but these features are not universal among equipment manufacturers. In addition, the integrated equipment is typically under a one- or two-year warranty through the installing contractor and they are responsible for performance and warranty issues. If the sensor/transmitter or other component must be replaced, it can be a long process to get this done through an equipment manufacturer or their service department.

2.9 Equation of a Line

Because the sensor transmitters output an analog signal that is proportional to its sensor signal, the BAS controller uses linear equations to mathematically represent the relationship between the voltage signal received and the corresponding sensor reading. The two-dimensional Cartesian coordinate system is a tool that allows us to visualize the results of equations based on two variables (typically X and Y). The origin is the point on the graph where both the X and Y values are equal to zero. In an X-Y coordinate plane where the X values are identified along the horizontal axis and the Y values are identified along the vertical axis, the equation of a straight line in Slope-Intercept form is provided by Equation 6. This equation states that the Y value is dependent on the value of the independent variable X, the slope of the line (m), and its starting point b (Y-intercept). The slope (m) provides the measure of the change in the Y value per unit change in the X value per Equation 7. Given any two coordinates or ordered pairs of X,Y points on the X-Y coordinate plane, the equation of a line that passes through both points can easily be formed.

(Equation 6) $$\mathrm{Y} = \mathrm{m} * \mathrm{X} + \mathrm{b}$$

Figure 26 shows a generic line and its equation is provided. We will go through the steps required to determine the equation of this line which is defined by at least two points defined by ordered pairs of X,Y coordinates: $X_1,Y_1 = 0,2$ and $X_2,Y_2=10,10$. The first step is to determine the slope or inclination of this line. The slope of the line represents the change in the Y value per unit change in the X value. It may also be thought of as the ratio of the "rise" over the "run." Using the two pairs of X,Y coordinates provided above, the slope of the line is calculated as follows:

(Equation 7) $$Slope = m = \frac{Rise}{Run} = \frac{Change\ in\ \mathrm{Y}}{Change\ in\ \mathrm{X}} = \frac{\mathrm{Y}_2-\mathrm{Y}_1}{\mathrm{X}_2-\mathrm{X}_1} = \frac{10-2}{10-0} = \frac{8}{10} = 0.8$$

Once the slope of the line (m) has been determined, we then determine the value of b (also called the Y-Intercept). We can observe from this example, that it crosses the Y axis at 2, but it is not always so obvious. The remainder of this section explains how the equation of this line is formed. This knowledge is key to the calibration of sensor transmitter readings.

To calculate the Y-intercept, we substitute the slope of the line (m) and one of the known ordered pair of X,Y ($X_2=10,Y_2=10$) coordinates into Equation 6. We then solve the resulting equation for b (Y-intercept). It does not matter which point is chosen because the answer will be the same.

(Equation 8) $$(10) = 0.8 * (10) + b$$

(Equation 9) $$10 = 8 + b$$

(Equation 10) $$10 - 8 = 8 - 8 + b$$

(Equation 11) $$b = 2$$

Now that we have determined the Y-intercept, we can substitute the slope and Y-Intercept values back into Equation 5 to provide us with the equation of the line that calculates any X or Y value along the line when one of the variables is known.

(Equation 12) $Y = 0.8 * X + 2$

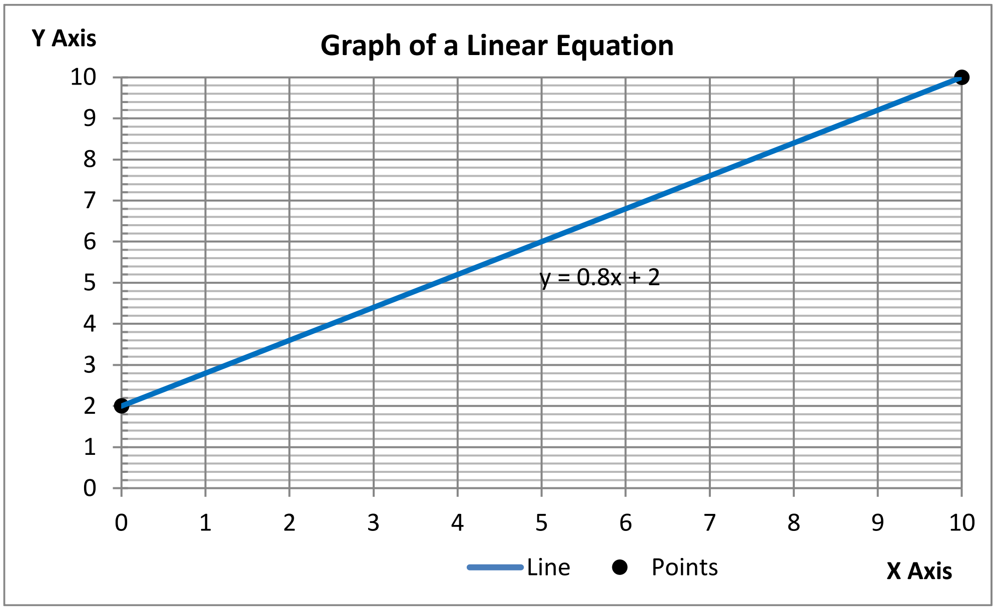


Figure 26 - Graph of a Linear Equation

We just reviewed the steps for defining the equation of a line given two points on that line using the slope-intercept form. This equation allows us to calculate the Y value when the value of X is known. To verify that the equation is correct, we can substitute X values into the equation and review the results. Notice that the Y value in each column increases by 0.8 for each unit change in X value. Recall that the slope or m represents "rise/run" or slope of the line when graphed. Notice also that the starting point for Y is 2 which represents the Y-intercept or b in the equation of the line. Lastly, we note that the ordered pairs of X,Y values that were used to define this equation are also included in the possible results.

X	0	1	2	3	4	5	6	7	8	9	10
Y	2	2.8	3.6	4.4	5.2	6	6.8	7.6	8.4	9.2	10

Table 11 - Equation Verification

The BAS controller uses the same methodology to calculate the sensor reading from the signal (voltage or current) provided by the sensor transmitter. The process of defining this equation is no different, only the nomenclature of the variables changes. Instead of a graph of X,Y values, we have a sensor transmitter reading versus signal graph where the X axis is called the signal axis (typically labeled VDC) and the Y axis is typically labeled with the units of measure for the sensor type (carbon dioxide, humidity, current, velocity, airflow, etc.). The slope or m is called Scale and the Y-intercept or b is called the Offset.

2.10 Linear Interpolation

Linear interpolation is commonly used to determine values that fall between two known sets of values. For example, given the Resistance Temperature Table below, how do we calculate the temperature when the resistance is measured at 18,000 Ohm? First, the two data points that encompass this reading would be selected. The resistance falls between the resistance values for 50°F and 55°F and we also can infer that the answer will be closer to 55°F because 18,000 is closer to 17,435 Ohms than it is to 19,900 Ohms. The unknown temperature is interpolated from the known temperature versus resistance values.

Temperature (°F) or X	Resistance (Ohms) or Y
50	19900
X	18000
55	17435

Table 12 - Typical Reset Schedule

To solve for the temperature based on a resistance of 18,000 Ohms, we utilize the Point-Slope form of the equation of a line (Equation 13). With this form, we only need one point along the line and the slope of the line to create the equation. The known values provide the data necessary to calculate the slope (m) of the line.

(Equation 13) $$Y - Y_o = m * (X - X_o)$$

We first solve this equation for Y by adding Y_o to both sides of the equation. Then we calculate the slope of the line between the two reference points.

(Equation 14) $$Y - Y_o + \boldsymbol{Y_o} = m * (X - X_o) + \boldsymbol{Y_o}$$

(Equation 15) $$Y = m * (X - X_o) + Y_o$$

(Equation 16) $$Slope = m = \frac{Rise}{Run} = \frac{Change\ in\ \mathrm{Y}}{Change\ in\ \mathrm{X}} = \frac{17435\Omega - 19900\Omega}{55°\mathrm{F} - 50°\mathrm{F}} = \frac{-2465\Omega}{5°\mathrm{F}} = -493\,\frac{\Omega_Y}{°\mathrm{F}_X}$$

After the slope (m) of the line is determined, enter the slope (m), one ordered pair of X,Y readings, and the known Y value into the Equation 15 to calculate the corresponding unknown X value. It does not matter which data point is chosen because the result will be the same.

(Equation 17) $$18000\Omega = \left(-493\,\frac{\Omega_Y}{°\mathrm{F}_X}\right) * (X - 50°\mathrm{F}) + 19900\Omega$$

(Equation 18) $$18000\Omega - 19900\Omega = \left(-493\,\frac{\Omega_Y}{°\mathrm{F}_X}\right) * (X - 50°\mathrm{F}) + 19900\Omega - 19900\Omega$$

(Equation 19) $$-1900\Omega/\left(-493\,\frac{\Omega_Y}{°\mathrm{F}_X}\right) = \left(-493\,\frac{\Omega_Y}{°\mathrm{F}_X}\right) * (X - 50°\mathrm{F})/\left(-493\,\frac{\Omega_Y}{°\mathrm{F}_X}\right)$$

(Equation 20) $$3.85°\mathrm{F} = (X - 50°\mathrm{F})$$

(Equation 21) $$3.85°\mathrm{F} + 50°\mathrm{F} = (X - 50°\mathrm{F}) + 50°\mathrm{F}$$

(Equation 22) $$X = 53.85°\mathrm{F}$$

2.11 Linear Extrapolation

The linear extrapolation calculation is exactly the same as outlined above. The only difference is that that unknown value is outside the range of known values. For example, given the Resistance Temperature Table below, how do we calculate the temperature when the resistance is measured at 20,000 Ohms? For this example, we will assume that this is the only available data. Ordinarily, the two data points that encompass this reading would be selected for interpolation. The resistance falls outside the resistance values for 50°F and 55°F. We can infer from the data that the answer will be a value that is less than 50°F. The unknown temperature is extrapolated from the known temperature versus resistance values.

Temperature (°F) or X	Resistance (Ohms) or Y
X	20000
50	19900
55	17435

Table 13 - Typical Reset Schedule

The slope of the line is exactly the same as calculated above. Enter the slope (m), one ordered pair of X,Y readings, and the known Y value into the Equation 15 to calculate the corresponding unknown X value. It does not matter which data point is chosen because the result will be the same.

(Equation 23) $$20000\Omega = \left(-493\,\frac{\Omega_Y}{°\mathrm{F}_X}\right) * (X - 50°\mathrm{F}) + 19900\Omega$$

(Equation 24) $$20000\Omega - 19900\Omega = \left(-493\,\frac{\Omega_Y}{°\mathrm{F}_X}\right) * (X - 50°\mathrm{F}) + 19900\Omega - 19900\Omega$$

(Equation 25) $$100\Omega / \left(-493\,\frac{\Omega_Y}{°\mathrm{F}_X}\right) = \left(-493\,\frac{\Omega_Y}{°\mathrm{F}_X}\right) * (X - 50°\mathrm{F}) / \left(-493\,\frac{\Omega_Y}{°\mathrm{F}_X}\right)$$

(Equation 26) $$-0.2°\mathrm{F} = (X - 50°\mathrm{F})$$

(Equation 27) $$-0.2°\mathrm{F} + 50°\mathrm{F} = (X - 50°\mathrm{F}) + 50°\mathrm{F}$$

(Equation 28) $$X = 48.8°\mathrm{F}$$

2.12 Reset Schedule

The reset schedule is a tool that automates the adjustment of one variable based on changes in another. For example, variable-air-volume air-handling units are commonly programmed to reset their supply air temperature based on the return air temperature (or outdoor air temperature). As the return air temperature increases, this infers an increased cooling load in the spaces requiring lower supply air temperatures. As the return air temperature reduces, this infers a decreased cooling load in the spaces which permits higher supply air temperatures. The supply air temperature setpoint may reset based on the following reset schedule.

Return Air Temperature or RAT (°F)	Supply Air Temperature or SAT (°F)
70	60
76	55

Table 14 - Typical Supply Air Temperature Reset Schedule

This calculated supply air temperature setpoint value is used by the PID loop that modulates the air-handling unit's chilled water control valve. This reset schedule automatically adjusts the supply air temperature setpoint based on the return air temperature which precludes the need to manually adjust it throughout the day or maintain the air-handling unit discharge air temperature at 55°F when it is not required. While using this reset strategy, it is important to monitor the space temperatures, terminal unit damper positions, and the return air humidity levels. Adjustments or disabling of the supply air temperature reset may be required when parameters are exceeded.

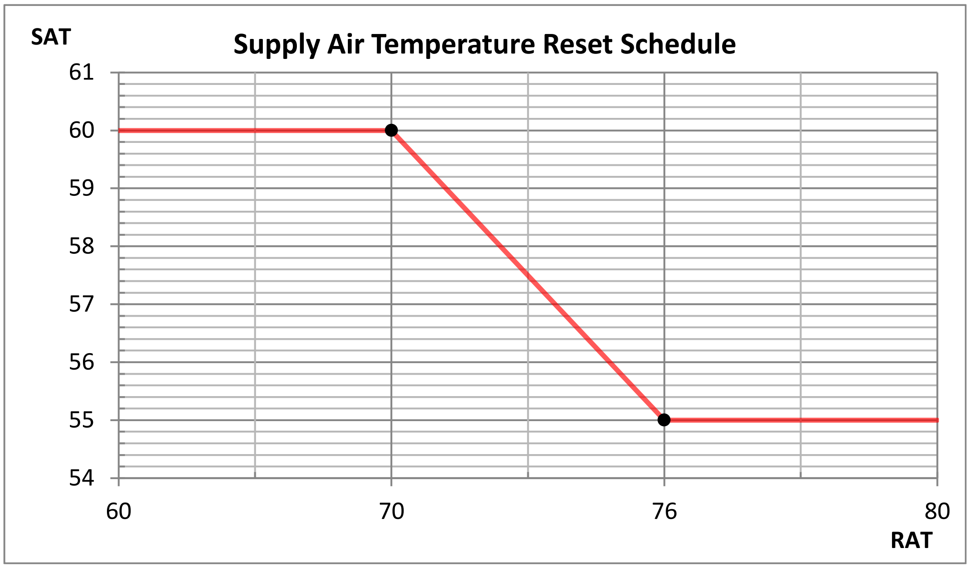


Figure 27 - Graph of a Reset Schedule

A reset schedule has three distinct zones – below the reset range (<70°F), within the reset range (between 70°F and 76°F), and above the reset range (>76°F). When the return air temperature is below 70°F, the supply air temperature setpoint is fixed at 60°F. When the return air temperature is above 76°F, the supply air temperature setpoint is fixed at 55°F. When the return air temperature is between 70°F and 76°F, the supply air temperature setpoint is linearly interpolated. Suppose that we wanted to calculate the supply air temperature when the return air temperature is 74.3°F.

Return Air Temperature or RAT (°F)	Supply Air Temperature or SAT (°F)
70	60
74.3	Y
76	55

Table 15 - Interpolation Example

To solve for the supply air temperature setpoint based on a return air temperature of 74.3°F, we again utilize the modified Point-Slope form of the equation of a line (Equation 15). With this form, we only need one point along the line and the slope of the line to create the equation. The reset schedule parameters provide the data necessary to calculate the slope (m) of the line. After the slope (m) of the line is determined, enter the slope, one ordered pair of X,Y readings, and the known X value into Equation 29 to calculate the corresponding unknown Y value.

(Equation 29) $$Y = m * (X - X_o) + Y_o$$

(Equation 30) $$Slope = m = \frac{Rise}{Run} = \frac{Change\ in\ \mathrm{Y}}{Change\ in\ \mathrm{X}} = \frac{55°\mathrm{F} - 60°\mathrm{F}}{76°\mathrm{F} - 70°\mathrm{F}} = \frac{-5°\mathrm{F}}{6°\mathrm{F}} = -0.833 \frac{°\mathrm{F}_Y}{°\mathrm{F}_X}$$

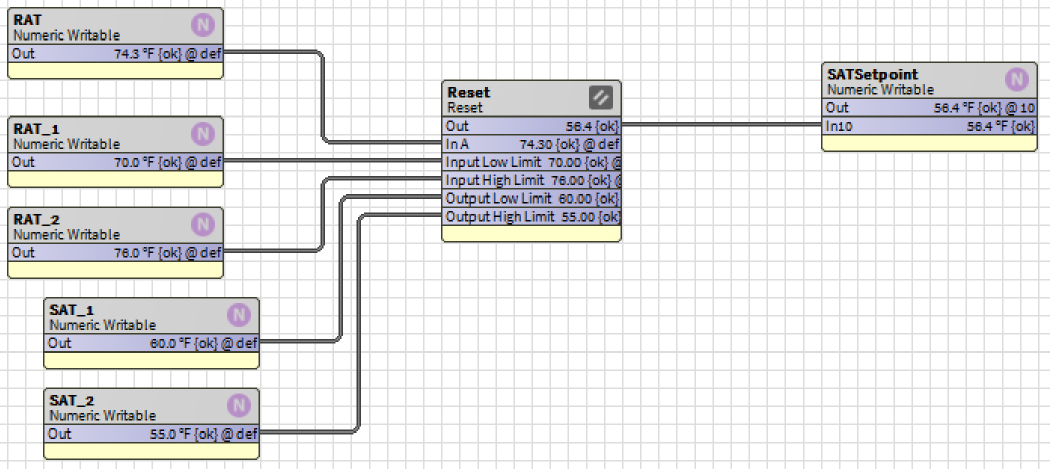
(Equation 31) $$Y = \left(-0.833 \frac{°\mathrm{F}_Y}{°\mathrm{F}_X}\right) * (74.3°\mathrm{F} - 70°\mathrm{F}) + 60°\mathrm{F}$$

(Equation 32) $$Y = \left(-0.833 \frac{°\mathrm{F}_Y}{°\mathrm{F}_X}\right) * (4.3°\mathrm{F}) + 60°\mathrm{F}$$

(Equation 33) $$Y = -3.58°\mathrm{F} + 60°\mathrm{F}$$

(Equation 34) $$Y = 56.4°\mathrm{F}$$

In practice, a reset block or line code function is used to automate this calculation (Figure 28), but knowing how the reset value is calculated allows us to determine the validity of the answer. It is very easy to incorrectly connect the data points to the wrong reset block input slot. Testing of reset functions is always recommended to ensure that the calculated value is accurate. As the return air temperature changes throughout the day, the calculated supply air temperature setpoint is automatically calculated based on the reset schedule parameters.


RAT
Numeric Writable
Out 74.3 °F {ok} @ def

RAT_1
Numeric Writable
Out 70.0 °F {ok} @ def

RAT_2
Numeric Writable
Out 76.0 °F {ok} @ def

SAT_1
Numeric Writable
Out 60.0 °F {ok} @ def

SAT_2
Numeric Writable
Out 55.0 °F {ok} @ def

Reset
Reset
Out 56.4 {ok}
In A 74.30 {ok} @ def
Input Low Limit 70.00 {ok} @
Input High Limit 76.00 {ok} @
Output Low Limit 60.00 {ok}
Output High Limit 55.00 {ok}

SATSetpoint
Numeric Writable
Out 56.4 °F {ok} @ 10
In10 56.4 °F {ok}

Figure 28 - Reset Schedule Block Program Example

To save BAS controller processing power and reduce network traffic, the calculated setpoints from reset schedules are updated at regular time intervals (60 minute, 30 minutes, 15 minutes, etc.) There is no need to continuously update them throughout the day. Reset schedules are not one size fits all. They may need tweaking at different seasons, operating modes, or conditions. A secondary reset schedule may be required in some applications. Reset schedules help the Owner/BAS operator by automating setpoint adjustments that would normally require manual adjustments. Reset schedules are commonly used in hot water heating plants to reset the hot water supply temperature based on the outdoor air temperature and they are calculated in exactly the same manner.

2.13 Graphing of Calibration Test Results

When two lines are graphed on the same coordinate plane, it allows us to visually compare the actual performance of the UUT to its programmed characteristic curve. Sensor transmitters are always initially programmed with the manufacturer's performance parameters that define the "ideal" characteristic curve. The calibration process entails testing to determine the actual performance characteristics. This comparison allows us to eliminate configuration error and define how the BAS controller interprets the signal provided by the sensor transmitter based on test data. Configuration error is the most common error for the sensor transmitters and graphing of the calibration results provides visual confirmation.

Graphing the actual performance against the programmed characteristic curve over the sensor transmitter range indicates what is causing the error. If the two lines are drawn right on top of one another, then the actual performance agrees very well with the programmed or expected performance. If the lines are parallel and only their starting points are different, this indicates zero error. If the two graphed lines are not parallel, this indicates span error. If the starting points are unequal and the slopes of the lines are also not parallel, this indicates both zero and span error. Graphing the results of the sensor transmitter calibration is a valuable tool that gives us greater insight and understanding into the calibration process.

2.14 Review

1. A ______________________________ is a graphical means of relating the sensor reading to its output signal reading.
2. The transmitter characteristic curves for the ideal and actual sensor performance should be ________________ if it only has zero error.
3. ________________ error results when the programmed range of the transmitter output signal does not match the actual output signal.
4. True or False: The instrument range will always be smaller than the calibration range. Answer: ________
5. _____________________ describes how well a sensor/transmitter reading agrees with readings from calibrated reference instruments.
6. The Characteristic curve for a transmitter with only span error will have a different ________________ than the ideal characteristic curve.
7. _____________________ is the difference between the sensor/transmitter reading and the readings from a calibrated reference instrument.
8. What is the range of actual pressures for a 0-50 PSIG hydronic differential pressure transmitter with 0.5% RD accuracy and a 40 PSIG reading? _____________________
9. What is range of actual pressures for a 0-100 PSIG hydronic differential pressure transmitter with 0.5% FS accuracy and a 25 PSIG reading? _____________________
10. The process of comparing the BAS sensor/transmitter reading to readings acquired with calibrated instruments and updating the analog input configuration to correct the reading per test data is called ____________________.
11. The characteristic curve for a thermistor is _________________.
12. True or False: %RD accuracy results in the same error no matter where the sensor reading is in the instrument range. Answer: ________
13. When the resistance is equal to the thermistor's base resistance, the temperature reading should indicate _______°F.
14. ____________________ are used to change the setpoint based on another variable between upper and lower limits.
15. The failure to provide sufficient duct lengths for the proper installation of AFMS is an example of what type of error? _____________________
16. Installation of a probe temperature sensor where an averaging temperature sensor should have been installed is an example of what type of error? _____________________

2.15 References

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11. https://www.workaci.com/
12. https://instrumentationtools.com/accuracy-resolution-range/
13. https://www.mccdaq.com/TechTips/TechTip-1.aspx
14. https://www.mmcontrol.com/mamac/pdf/R-Ttables.pdf

Chapter 3 - BAS Inputs and Outputs

3.1 Typical Low-Voltage Thermostat

In most of our homes is an electronic device that very much resembles a simple building automation system. It's the low-voltage thermostat that controls our heating and cooling system(s) to maintain the space temperature at the desired setpoint. It has many of the features of a typical BAS. It has inputs, outputs, and programmed logic. It even has a graphical user interface which is composed of a small screen that displays the time of day, space temperature, setpoints, operating modes, and schedule. The latest thermostats are Wi-Fi-capable and allow the homeowner to change the setpoints and schedules remotely from a web site or phone application interface. Yet at their core, they are a simple building automation system. However, the BAS controller is capable of doing this and so much more because its programming is customizable and it has communication, trending, alarming, and BAS graphics capabilities. Additional input and output devices can also be connected to it which makes it extremely flexible.

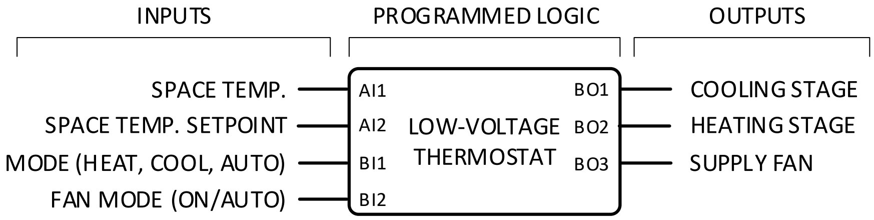


Figure 29 - Typical Residential Thermostat Input/Outputs

Photo 34 - Typical Residential Low-Voltage Thermostat

3.2 BAS Controller

BAS controllers are devices that accept input signals, process the signal data according to its programmed logic, and then produce output signals for control devices such as valves, dampers, VFDs, compressors, fans, pumps, etc. There are many manufacturers of controllers used in building automation systems, but they have common components which include the following:

1. Control board
2. Enclosure
3. Power connections (typically 24 VAC)
4. Communication terminals
5. Onboard direct current voltage terminals for powering transmitters and relays
6. Binary input terminals
7. Analog input terminals
8. Binary output terminals
9. Analog output terminals
10. Input/Output Expansion modules
11. Manual overrides (binary outputs and analog outputs)

BAS controllers are typically located within a wall-mounted Local Control Panel (LCP). This enclosure provides a physical barrier to prevent contact with the internal BAS controllers, relays, wiring, transformers, etc. If no wall space is available, the LCP may be mounted on a free-standing Unistrut structure. The LCP may be constructed on site or may be pre-assembled by the Controls Contractor at their shop. All input and output cables enter the LCP and terminate at the BAS controller terminals, relays, or at intermediate terminal blocks. The wiring is typically contained within a wire duct system, often called Panduit. Separation is maintained between high-power components and wiring for safety and to minimize signal interference. If the Controls Contractor has done a good job, all BAS controllers, power supplies, relays, and inputs and output wires will be neatly organized and labeled.

Photo 35 - Distech ECY-S1000 Controller with Expansion Modules

Photo 36 - Distech ECY-303 Controller

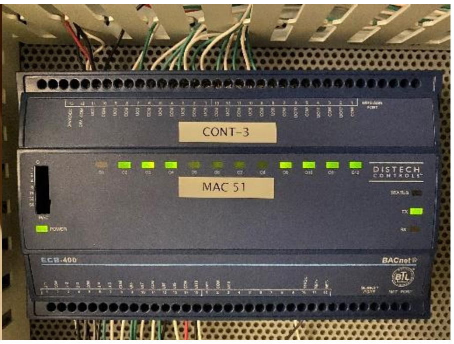


Photo 37 - Distech ECB-400 Controller

Some BAS inputs are classified as Universal Inputs or UIs. This typically means that they can be configured to monitor a variety of signals. These include dry contacts, thermistors, resistive signals, and analog (voltage and current) signals. UIs provide the highest degree of flexibility. Digital Inputs (DIs) typically can only be used with input devices that have binary status contacts. Likewise, controllers may have Universal Outputs (UOs) and Digital Outputs (DOs). Universal outputs can typically provide analog (voltage and current) as well as digital output signals. Digital outputs are typically limited to providing only digital outputs which are perfect for relays, but are useless for anything else. Digital outputs may be dry contacts or they may provide a voltage output. Jumpers and dip switches are typically provided to control whether the voltage is internally or externally provided to the outputs and to determine whether a current or voltage signal is generated. Therefore, we must be aware of the controller point types, their capabilities, and the applications that they are tasked to implement. Each manufacturer is unique, so be sure to refer to their controller installation instructions.

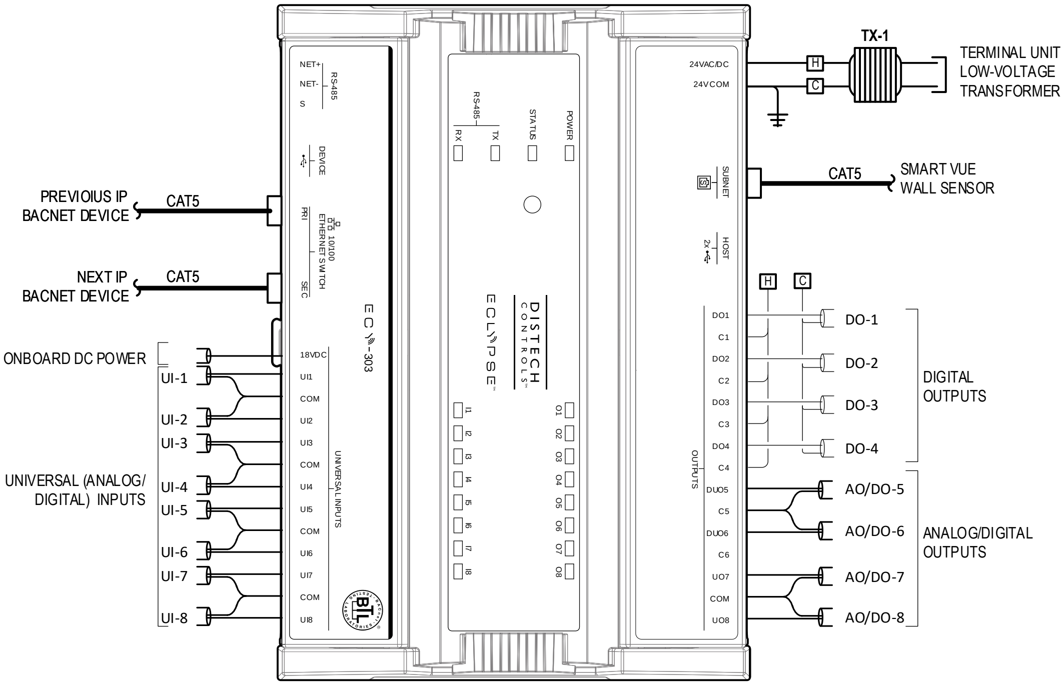


Figure 30 - Distech ECY-303 BACnet-Compatible Controller

Some controllers are capable of expanding the number of physical inputs and outputs. The Distech Eclypse ECY-S1000 controller is very scalable. It can handle up to 12 input/output modules and can accommodate up to 320 points making it capable of controlling anything from an air-handling unit to a large central plant with room to spare. The S1000 has proven very useful as an air-handling unit controller which typically requires a higher point count. There are often surprises due to differences in interpretation of the sequences of operations or BAS requirements on the plumbing plans that were not provided. Additional modules can be added to the S1000 controller alleviating the need to remove wires and reland them on a new controller. The number of controllers used on controls projects is decreasing of the high point capability of the S1000 controller. On some BAS projects, the S1000 is the only field programmable controller required. It comes with either a 28, 48, or 320 point license. It's a great controller that can be ordered with a web-based graphical user interface to display graphics, trends, alarms, and schedules without a JACE.

3.3 Low-Voltage Transformers

A Low-Voltage Transformer (LVT) provides 24 VAC power for the BAS controllers. It is also referred to as a power supply. In most LCPs you will also find a power switch and a 120 VAC convenience outlet for Control Technician's laptop and network switches. Functional Devices, Inc. produces the PSH line of enclosed class 2 power supplies that provide these functions in a pre-assembled unit (Photograph 38 & 40). They are typically used in high-visibility and frequently-accessed LCPs where the Controls Contractors want to leave a lasting impression on the quality of their work. It gives the LCP a very professional look and an engineered feel. This power supply is a welcome sight for all Control Technicians and Programmers. With the transformer, convenience outlets, and power switches inside the LCP, it is less likely that random people will connect power tools to them or flip the residential-grade rocker switches just to see what they do. If required, additional foot-mounted and hub-mounted power supplies (Photograph 39) are typically used for the remaining VA load (valve and damper actuators, transmitters, relays, etc.) requirements.

LVTs with built-in circuit breakers are recommended over those without. If a low-voltage wire is crossed or shorted, catastrophic damage will occur to the LVT. Replacement of the LVT will then require disassembly and rewiring of all wiring connections. This can be avoided if an LVT with circuit breaker is used because the circuit breaker will protect the LVT and connected circuits from damage.

Photo 38 - Enclosed Transformer with High/Low Switches and Circuit Breaker

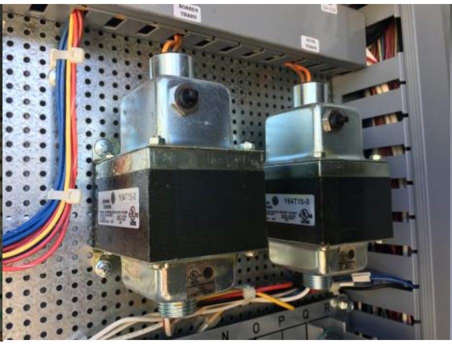


Photo 39 - Foot and Hub Mount Transformers with Circuit Breaker

Photo 40 - 500 VA Enclosed Transformer with Five 100 VA Switched Circuits

With increasing frequency, enclosed 300 VA and 500 VA low-voltage transformers are installed adjacent to LCPs (Photograph 40). Functional Devices, Inc. manufactures the PSH300A and PSH500A low-voltage transformers. These larger LVTs provide either three or five individually controlled 100 VA Class 2 circuits to power the controllers and field devices. This provides several advantages to the LCP installation. First, the LVT does not take up space inside the LCP, so there is more room for controllers and wire duct. Secondly, it minimizes the exposure to high voltage 120 VAC wiring inside the LCP making it safer for all. Thirdly, it produces a cleaner, more organized installation because it reduces clutter in the panel. In installations where the terminal units, fan coil units, or unit ventilators are not provided with 120 VAC power, these LVTs are often used to power several equipment controllers in a daisy-chain fashion. The load on each circuit is typically limited to 80% of the VA capacity of the transformer.

3.4 Controls System Grounding

LVTs provide the power necessary to operate the BAS and its components. They convert the available high-voltage sources (480 3ø VAC, 208 3ø VAC, 277 1ø VAC, 240 1ø VAC, or 120 1ø VAC) into low-voltage (24 VAC typically) potential for use by the BAS. In general, 120:24 VAC transformers are installed in LCPs to power the BAS controller, input/output devices, and associated system components. The wires that power the high-voltage side of the LVT consist of hot, neutral, and ground conductors. The ground conductor is typically bonded to the LCP backplane per the National Electric Code which puts it at the same electrical potential as the electrical ground system. This can be verified by measuring voltage between the high voltage ground and the LCP backplane. If this measurement is not zero, then the LCP backplane is not grounded and you should inform the electrician.

Many BAS controllers require that the secondary common terminal of the LVT be grounded. This ensures that the common terminal provides a zero ground reference for the low-voltage circuits. Others control components like the JACE, for example, require no grounded common. Follow the manufacturer's installation recommendations for the controllers and connected devices to ensure that no damage occurs. With proper grounding of the LVT and the BAS controller, zero voltage will be measured on its common terminal and 24-27 VAC will be measured on its hot terminal when referencing a grounded terminal or LCP back plane (provided the LVT is not overloaded). If a short-circuit occurs on the low-voltage side of the transformer, it will be safely conducted back to ground and the fuse or circuit breaker will disable this circuit. In all cases, BAS controllers should be grounded in accordance with the manufacturer's installation requirements. This typically means that the common or ground terminal of the BAS controller is bonded to ground (typically the backplane of the LCP). It would be very nice if the manufacturers of LVTs provided a switch, jumper, or similar device that would ground the 24 VAC common terminal to the electrical ground.

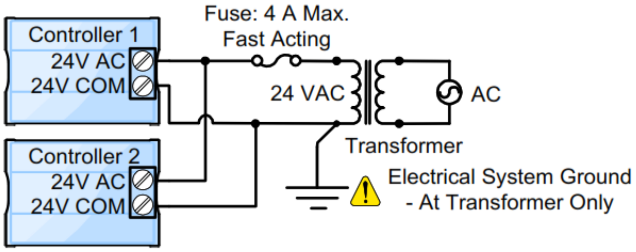


Figure 31 - Typical Distech Controls, Inc. Power Wiring Detail

In some installations, 24 VAC power is supplied by 120:24 VAC transformers in another LCP. In this situation, the LCP has no connection to ground and this may present signal and/or communication issues when it is connected (by conduits and wiring) to other panels or devices (VFDs, electric steam humidifiers, chillers, boilers, air-handling units, etc.) that may be at different electrical potentials. Verify that the secondary common of the LVT providing the power to this LCP has been grounded. If communication or signal (AI, AO, BI, BO) issues are encountered, it may be necessary to install ground wires to adjacent equipment, structural elements, electrical panels, etc. that are properly grounded. If there is any measurable voltage potential (AC or DC) between the low-voltage common or ground terminal of the BAS controller and the LCP backplane, control cabinet, or conduits, additional grounding and bonding may be required.

3.5 Electromagnetic Interference

Electromagnet Interference is an unwanted signal that blocks, attenuates, or superimposes on the desired electrical signal. EMI is generated by electric motors, generators, current switching equipment, and high-powered conductors. EMI can be picked up by BAS power, signal, and communication wires within the connected equipment (variable frequency drives, electric resistance heaters, electric humidifiers, boilers, chillers, etc.) through inductive coupling. This is why it is important to separate high- and low-power wiring within the equipment enclosure and local control panels. Static on the radio station during a lightning strike or when a nearby hair dryer is operating are examples of EMI. Cell phones and radios used in close proximity to some field reference instruments cause erratic and erroneous readings due to EMI. The ground connection provides a path to drain any EMI that the BAS wiring may have absorbed. BAS controllers are especially susceptible to communication failures caused by EMI. Mitigation of EMI typically requires a multi-point approach which may include, but is not limited to:

1. Grounding of LCP backplane and door.
2. Grounding of shielded cables.
3. Grounding of the BAS controller per the manufacturer's installation recommendations.
4. Grounding of the secondary side of the low-voltage 120:24 VAC transformers.
5. Grounding of RS-485 shielded wires at one end.
6. Use of shielded, twisted pair cable.
7. Physical separation of high-power conductors and low-voltage signal, power, and communication wires.
8. Avoid parallel paths with high-power conductors.
9. Attach wires to metal surfaces as opposed to leaving them in free air.
10. Run low-voltage cables within metal conduits.

3.6 Binary Inputs

Binary Input (BIs) signals are provided by devices that have a set of either normally-open or normally-closed electrical contacts that indicate their status. Through programming, the opening and closing of the device contacts (changes in electrical continuity) are interpreted as a change in state. Each state is typically assigned a facet which describes the state. Binary inputs are also referred to as Digital Inputs (DIs) and these terms are used interchangeably. The way the binary input signal is interpreted by the BAS depends on the configuration (normally-closed/normally-open and momentary/maintained) of the binary input, relay logic, wiring, and the associated programming.

Binary Input Device	Application	Facets/Units
Low-Temperature Detector	Coil Freeze Protection	Normal/Alarm
Smoke Detector/FACP Relay Module	Smoke Detection	Normal/Alarm
Emergency Shutdown Switch (Estop)	Emergency HVAC Shutdown	Normal/Alarm
Current Sensing Relay	Motor/Load Operating Status	On/Off
Air Differential Pressure Switch	Fan Operating Status	On/Off
Air Differential Pressure Switch	Filter Status	Clean/Dirty
Air Differential Pressure Switch	High/Low Static Safety	Normal/Alarm
Water Differential Pressure Switch	Pump Operating Status	On/Off
Water Differential Pressure Switch	Proof of Flow Status	On/Off or Flow/No Flow
Water Differential Pressure Switch	Pressure Drop Monitoring	Clean/Dirty
Water Differential Pressure Switch	High/Low Pressure Shutdown	Normal/Alarm
Hydronic Flow Switch	Proof of Flow Status	Flow/No Flow or On/Off
Hydronic Flow Switch	Pump Operating Status	On/Off
Occupancy Detector	Occupancy Override	Occupied/Unoccupied
Occupancy Detector	Standby Temperature Control	Standby/Normal
Occupancy Override Switch	Occupancy Override	Enabled/Disable
Position Feedback	Damper/Valve Position Proof	Open/Closed
Liquid Detector	Condensate/Leakage Detector	Normal/Alarm
Liquid Level Indicator	Cooling Tower Water Level Monitoring	High/Low or Normal/Alarm
Liquid Level Indicator	Tank Level Monitoring	High/Low or Normal/Alarm

Table 16 - Binary Input Examples

Figure 32 shows an example of how a Current Sensing Relay (CSR) might be configured in a Distech controller or similar. Figure 33 shows how the same device is configured in a JACE panel. The binary input is configured to monitor the status contacts of a CSR used for monitoring the operating status of an air-handling unit supply fan. The output contacts of the CSR are wired to the binary input terminals of the BAS controller.

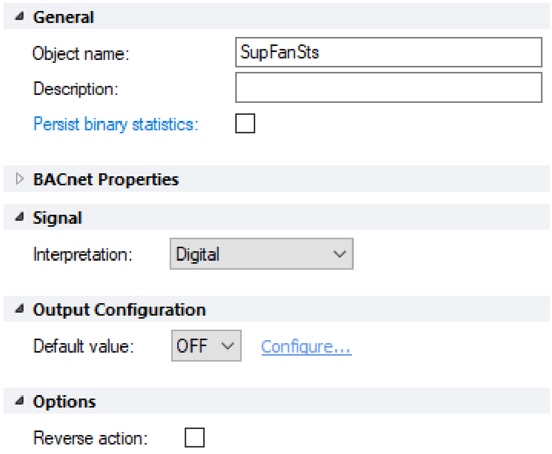

General
Object name: SupFanSts
Description:
Persist binary statistics: ☐
BACnet Properties
Signal
Interpretation: Digital
Output Configuration
Default value: OFF Configure...
Options
Reverse action: ☐

Figure 32 - Distech EC GFX Binary Input Configuration

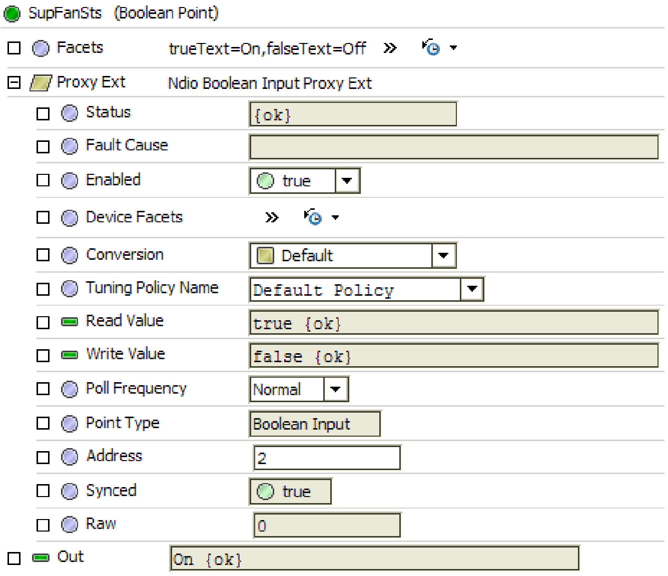

SupFanSts (Boolean Point)
Facets: trueText=On,falseText=Off
Proxy Ext: Ndio Boolean Input Proxy Ext
Status: {ok}
Fault Cause:
Enabled: true
Device Facets
Conversion: Default
Tuning Policy Name: Default Policy
Read Value: true {ok}
Write Value: false {ok}
Poll Frequency: Normal
Point Type: Boolean Input
Address: 2
Synced: true
Raw: 0
Out: On {ok}

Figure 33 - JACE Binary Input Configuration

The BAS controller monitors the electrical contacts for the presence or absence of electrical continuity. The CSR contacts are normally open when the current flow through its core is below the current threshold and are closed when the current flow exceeds the current threshold. The binary input of the BAS controller is configured for a maintained contact that is also normally open and the fan status is interpreted as "Off" when the CSR contacts are opened and "On" when the contacts are closed.

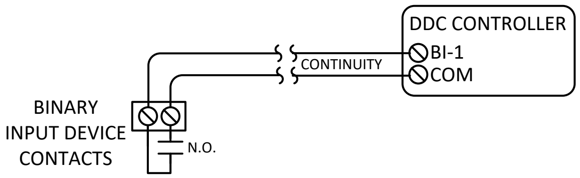


Figure 34 - Binary Input Monitoring Normally-Open Device Contacts

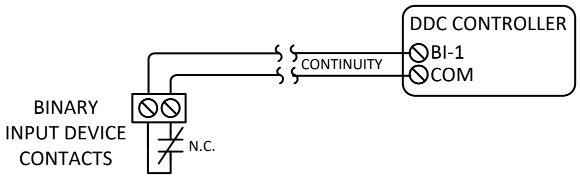


Figure 35 - Binary Input Monitoring Normally-Closed Device Contacts

Some binary input devices such as smoke detectors, occupancy detectors, and conductivity probes require 120 VAC or 24 VAC power to operate their sensors and internal circuitry, but most do not. Binary input devices may come with normally-open contacts, normally-closed contacts, or both. The choice of contacts depends on the control strategy and whether the device is used to detect an unsafe condition. The wiring for most binary input devices consists of a pair of wires that connect the binary input terminals of the BAS controller to the status contacts of the binary input device.

3.6.1 Binary Input Calibration

Calibration of a binary input device consists of comparing the setpoint of the binary input device to the readings from calibrated reference instruments. If the binary input device does not actuate its status contacts at the correct value (differential pressure, current, temperature, flow, etc.), its setpoint is adjusted. Calibration for some binary input devices requires simulating parameters (i.e. differential pressures and temperatures) that cause the status contacts to actuate. For example, to verify the setpoint of a Hydronic Differential Pressure Switch (HDPS), a pressure of a known magnitude is simulated with a high-pressure calibration pump and calibrated pressure gauge or meter. When the applied test pressure exceeds its setpoint, its status contacts actuate.

Smoke detectors, emergency shutdown switches, occupancy detectors, liquid detectors, and liquid level indicators actuate when a condition or state is detected. For these types of devices, other test methods are required which include physical activation, application of smoke, ice, or water, or cycling of equipment to cause the device status contacts to actuate. The following table provides a summary of the various binary input devices and the test methods typically performed as part of their calibration process. A multimeter or continuity tester is typically used to verify electrical continuity across the contacts or the passage or voltage or current through the contacts.

Sensor	Test Media/Method
Low-Temperature Detector	Air/Ice/Freeze Spray
Smoke Detector/FACP Relay Module	Test Smoke/FACP Relay Module/Physical Activation (Magnet/Keyed Switch)
Emergency Shutdown Switch (Estop)	Physical Activation
Current Sensing Relay	Load Current Flow/ Clamp Meter
Air Differential Pressure Switch	Air/Physical Activation (Calibration Pump/Manometer)
Water Differential Pressure Switch	System Water/Physical Activation (Calibration Pump/Test Gauge)
Hydronic Flow Switch	System Water (cycling pump)
Occupancy Detector	Physical Activation or sensor blocking
Occupancy Override Switch	Physical Activation
Position Feedback	Physical Activation/Actuator Override
Liquid Detector	Physical Activation (move float lever or apply water to conductance detector)
Liquid Level Indicator	Physical Activation (move float lever or apply water to conductance detectors)

Table 17 - Test Media and Reference Comparison versus Binary Input Device

Verifying the proper operation of a binary input device requires simulation of the conditions that cause its status contacts to actuate, observance of the status contacts, and the BAS reaction to the change in status contact position. This task typically requires the use of a multimeter or other continuity tester to verify the status (closed or open) of the device contacts in the two states. If the binary input device is a detector (smoke, condensate, position, etc.), then there is no setpoint adjustment to document. The information that is documented will resemble the following table.

BI #	Point	Design Setpoint	5.0		State	Device Contacts	BAS Status
1	High Static Safety	Actual Setpoint	5.1		State 0	Closed	Normal
		Contact Action	N.C.		State 1	Open	Alarm

Table 18 - Binary Input Calibration

3.7 Analog Inputs

Analog Input (AI) signals are provided by sensors and sensor transmitters that provide an analog output signal that indicates the magnitude of the sensed reading. This chapter makes a distinction between sensors and sensor transmitters. An analog input signal is variable and can provide values at very high resolution within the sensor operating range. Sensors are typically devices that are directly connected to and directly monitored by an analog input of a BAS controller.

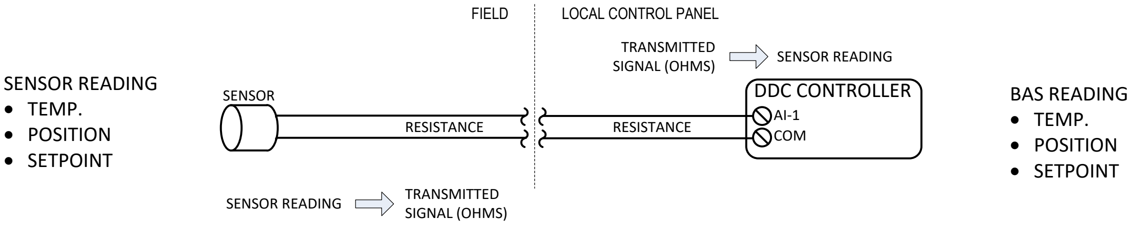


Figure 36 - Schematic of a Sensor and BAS Controller Signal Translation

Thermistors and RTDs are prime examples. Position sensors and space temperature setpoint adjustment knobs and sliders may also be directly connected to an analog input of a BAS controller. In addition to the sensors, sensor transmitters have additional circuitry that generates a standard signal (0-10 VDC, 2-10 VDC, 4-20 mA, etc.) that is proportional to the sensor reading. Therefore, the wiring, analog input configuration, testing, and calibration procedures are different.

Analog Input Device	Application	Facets/Units
Air Temperature Sensors	Temperature Monitoring and Control	°F
Space Temperature Setpoint Adjustment	Setpoint Adjustment	°F
Hydronic Temperature Sensor	Fluid Temperature Monitoring and Control	°F
Humidity Transmitter	Humidity Monitoring and Control	%RH, Wet Bulb Temp., Dew Point Temp.
Current Transmitter	Current/Load Monitoring and Control	Amps
Carbon Dioxide Transmitter	Demand-Controlled Ventilation	PPM
Air Differential Pressure Transmitter	Space/Duct Static Pressure Control/ Differential Pressure Monitoring and Control	Inches W.C.
Hydronic Differential Pressure Transmitter	Hydronic System Pressure/Differential Pressure Monitoring and Control	Feet Head, PSIG
Airflow Measuring Station	Airflow Monitoring and Control	FPM, CFM
Hydronic Flow Meter	Water Flow Monitoring and Control	FPS, GPM
Electric Actuator Feedback	Actuator Position Monitoring, failure detection	% Open

Table 19 - Analog Input Device Examples

3.8 Analog Inputs – Temperature Sensors

The most common analog input in most building automation systems is the temperature sensor. Its operation is typically based on changes in electrical resistance. Therefore, as the temperature changes, so does its electrical resistance. Most temperature sensors used in HVAC control applications are either Thermistors or Resistance Temperature Detectors (RTDs). Temperature sensors are manufactured in accordance with international standards which dictate standard resistance versus temperature profiles. This allows temperature sensors manufactured by different companies to perform exactly the same. Resistance-based temperature sensors typically used in HVAC applications are passive devices requiring no external power. Both thermistors and RTDs provide temperature readings based on changes in the resistance of the sensor. RTDs remain accurate for a longer period of time due to their design which provides long-term stability. A summary of the key differences in the temperature sensor types is provided in the following table.

Thermistors	Resistance Temperature Detectors
• Uses semiconductors (metal oxides) • Negative Temperature Coefficient • Non-linear change in resistance • Accurate over a smaller temp. range • Ideal for HVAC applications • Fast response time • Higher sensitivity • Minimal effect of wire length	• Uses pure metals (platinum & nickel) • Positive Temperature Coefficient • Linear change in resistance • Accurate over a wide temp. range • Ideal for HVAC and Industrial applications • Better long-term stability • Lower sensitivity • Reading affected by wire length

Table 20 - Summary of Resistance Temperature Sensor Differences

The following figure shows the characteristic curves for 10k Ohm Type 2, 10k Ohm Type 3, and 20K Ohm thermistors. Thermistors used in HVAC applications typically have a Negative Temperature Coefficient (NTC) as indicated by the downward sloping curves. As the temperature increases, the resistance of the thermistor decreases. These curves also show that the change in resistance per unit change in temperature is nonlinear, but the change is known and repeatable.

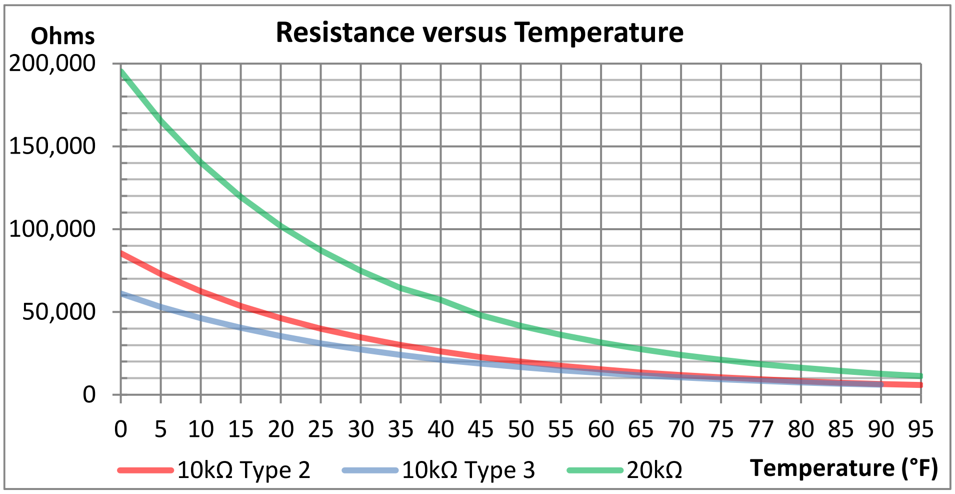


Figure 37 - Resistance versus Temperature Graphs for 10K Ohm Type2, 10K Ohm Type 3, and 20K Ohm Thermistors

Thermistors typically have a reference temperature of 77.0°F which means that when the electrical resistance across the sensor is equal to the base resistance, the temperature indication at the BAS controller will be 77.0°F. If not, there may be additional sources of resistance or connection integrity issues that may be affecting the reading. To connect thermistors and RTDs to the BAS controller input terminals a length of wire is required. Confirm the gauge of the temperature sensor wire and verify that the resistance is appropriate for the installed wire length. Electrical resistance of wire is typically based on the resistance per 1000 feet lengths. This wire is also part of the circuit that is monitored by the BAS, so it must be considered. The base resistance of thermistors is typically high (10,000 Ohms or higher) compared to RTDs (1,000 Ohms or less), so the impact on the temperature reading due to sensor wire length is typically very low.

RTDs are more susceptible to wire length variations than thermistors because their base resistance is much lower. If the resistance per 1,000 feet of 18 gauge stranded wire is 6.75 Ohms and you have 300 feet of wire (to and from), we would expect to see and additional 2.03 Ohms (300*6.75/1000) in the circuit. Therefore, we should measure ~1,002 Ohms in the circuit if we have a 1,000 Ohm RTD at 32.0°F. Using the values provided in Table 3, the effective temperature indication will be 32.92°F by interpolation. The wire length caused the temperature indication of the RTD sensor to be increased by 0.92°F. For a 10k Ohm thermistor, the same increase in resistance produces an almost negligible decrease in the indicated temperature (-0.01°F) reading. If the wire resistance differs by more than the calculated resistance, look for wire damage or loose connections.

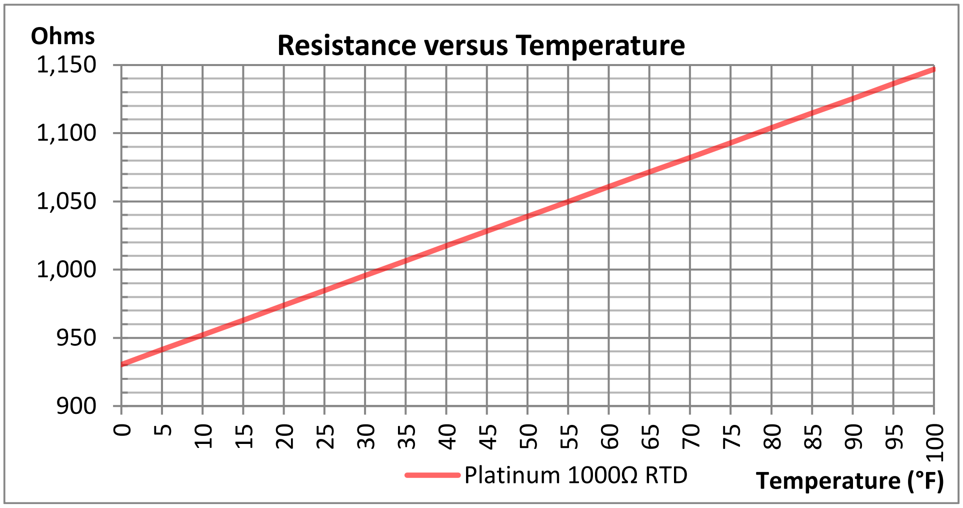


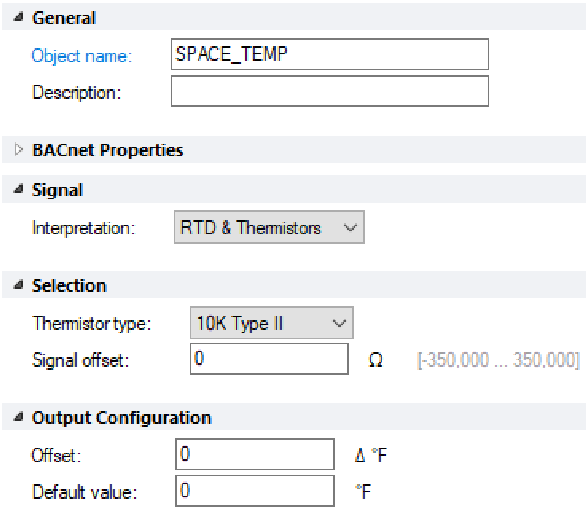
Figure 38 - Resistance versus Temperature Graph for 1000 Ohm Platinum RTD

The above figure shows a characteristic curve for a 1000 Ohm Platinum RTD. Resistance Temperature Detectors typically have a base resistance that produces the reference temperature of 32.0ºF. Therefore, when the resistance sensed by an analog input configured for a 1000 Ohm Platinum RTD is equal to 1000 Ohms, the indicated temperature is 32.0ºF. RTDs have a Positive Temperature Coefficient (PTC) as indicated by the upward slope of the characteristic curve which indicates that as the temperature increases, the resistance of the RTD also increases. This line also shows that the change in resistance per unit change in temperature is linear. RTDs typically have a lower base resistance (1000 Ohms versus 10,000/20,000 Ohms) which makes them more susceptible to resistance variations due to wire length and connection integrity.

Once the analog input of the BAS controller is configured with the temperature sensor properties, it is prepared to correctly interpret the resistance signal. This is useful information for calibrating and troubleshooting temperature sensors. Resistance decade boxes and variable resistors may be used for point-to-point checkouts and verification of programmed logic by simulating changes in temperature readings rather than waiting for them to occur or performing setpoint changes. The resistance decade box is used to simulate the effect of additional wire resistance on temperature sensor circuits. They may also be used to simulate maximum and minimum cooling demand by simulating high and low space temperatures, respectively, for pressure-independent terminal units.

3.8.1 Analog Input Configuration (Temperature Sensor Example)

Thermistors and RTDs are typically used for temperature control and monitoring of commercial HVAC systems. Configuring analog inputs for temperature sensors is typically a matter of selecting the correct temperature sensor type from a drop-down box. Odd temperature sensors that are not available in the standard selections may require the use of Resistance Temperature Tables. Each temperature sensor type has a unique characteristic curve defined by its resistance versus temperature relationship that allows the BAS to determine the temperature from the resistance signal. The Distech controller uses primarily 10k Ohm thermistors (Type 2 and 3) and JACE input/output panels use primarily 10k Ohm (Type 3) thermistors with the option to use other temperature sensors. A decade resistance box may be used to verify the temperature sensor selection by removing the temperature sensor from the wires, connecting it across the temperature sensor wires, and verifying that the reference temperature is displayed when the base resistance is applied.



General
Object name: SPACE_TEMP
Description:

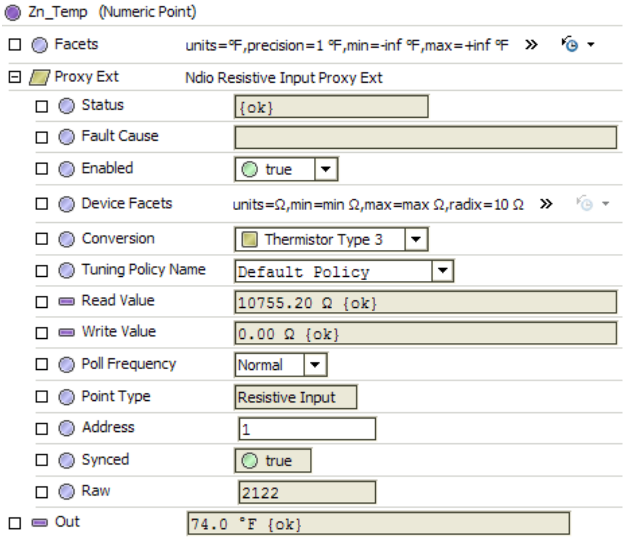
BACnet Properties

Signal
Interpretation: RTD & Thermistors

Selection
Thermistor type: 10K Type II
Signal offset: 0 Ω [-350,000 ... 350,000]

Output Configuration
Offset: 0 Δ °F
Default value: 0 °F

Figure 39 - Distech EC-GFX Temperature Sensor Configuration



Zn_Temp (Numeric Point)
☐ Facets units=°F,precision=1 °F,min=-inf °F,max=+inf °F
⊟ Proxy Ext Ndio Resistive Input Proxy Ext
  ☐ Status {ok}
  ☐ Fault Cause
  ☐ Enabled true
  ☐ Device Facets units=Ω,min=min Ω,max=max Ω,radix=10 Ω
  ☐ Conversion Thermistor Type 3
  ☐ Tuning Policy Name Default Policy
  ☐ Read Value 10755.20 Ω {ok}
  ☐ Write Value 0.00 Ω {ok}
  ☐ Poll Frequency Normal
  ☐ Point Type Resistive Input
  ☐ Address 1
  ☐ Synced true
  ☐ Raw 2122
☐ Out 74.0 °F {ok}

Figure 40 - JACE Temperature Sensor Configuration

3.8.2 Temperature Sensor Calibration

Temperature sensors are typically either thermistors or RTDs which are resistance-based devices that produce a predictable electrical resistance change with temperature variations. In order to calibrate temperature sensors, the BAS readings are compared to reference readings provided by calibrated temperature meters. After calibration, the temperature reading is most accurate at the calibrated temperature(s). As the temperature diverges from the calibration temperatures, the resultant correction may diminish. Therefore, it is good practice to calibrate temperature sensors at the temperatures anticipated during normal operation. If this normal operating range is small (less than 10°F), then a single-point calibration is typically acceptable. If the normally expected temperature range is greater than 20°F, then a multi-point calibration may be warranted.

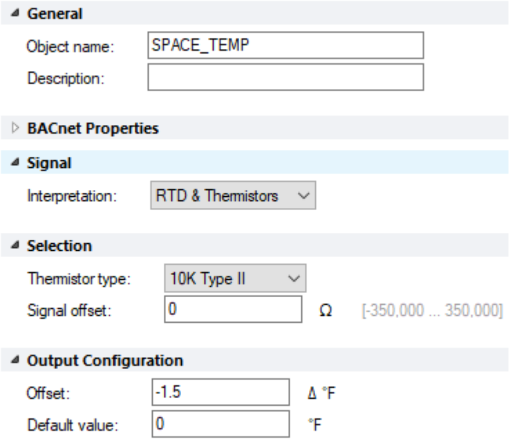

General
Object name: SPACE_TEMP
Description:
BACnet Properties
Signal
Interpretation: RTD & Thermistors
Selection
Thermistor type: 10K Type II
Signal offset: 0 Ω [-350,000 ... 350,000]
Output Configuration
Offset: -1.5 Δ °F
Default value: 0 °F

Figure 41 - Distech EC-GFX Temperature Sensor Calibration

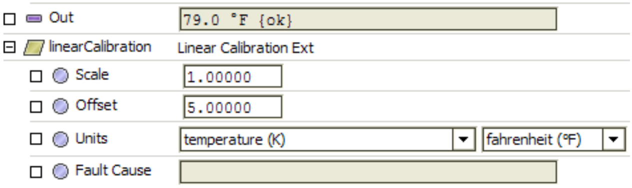

☐ Out 79.0 °F {ok}
⊟ linearCalibration Linear Calibration Ext
☐ Scale 1.00000
☐ Offset 5.00000
☐ Units temperature (K) fahrenheit (°F)
☐ Fault Cause

Figure 42 - JACE Temperature Sensor Calibration

The number of temperature calibration points used to determine the final offset value that is entered into the BAS controller's analog input configuration varies. It could be a single reading or it could take into account multiple readings. Typically, several readings are taken over a range of temperatures to get an indication of the general behavior. The BAS analog input for each temperature sensor accepts a single offset that is used to correct all temperature readings. Therefore, the average difference between the reference readings and the BAS-indicated readings is typically entered into the BAS controller's analog input configuration as the offset. The calibration readings should be taken in the range that the temperature sensor is expected to operate. For example, a discharge air temperature sensor on an air-handling unit supplying air to variable-air-volume terminal units should be calibrated in the 55°F to 60°F range where it will typically operate.

Most controllers will have a field where the temperature reading offset is entered after a comparison between the reference reading and BAS controller temperature reading is made. To calibrate temperature readings in a JACE panel requires the direct input of the required offset in the linear calibration extension to correct the temperature reading. This effectively adds the offset value (X°F) to all temperature readings calculated from the resistance temperature table. The Scale factor should NEVER be modified to calibrate thermistor readings. The scale value should only be used with sensors or sensor transmitters that produce a linear output signal. Therefore, this should never be used with thermistors. Some application-specific controllers do not provide temperature sensor calibration capabilities. Therefore, if temperature readings are beyond the calibration tolerance, they must be replaced until acceptable temperature readings can be achieved.

3.9 Analog Inputs – Sensor Transmitters

Sensor transmitters require electrical power to provide the linear analog output signal that is monitored by the BAS controller. Sensor transmitters are also referred to as simply "Transmitters" because they measure a physical parameter (temperature, humidity, carbon dioxide, differential pressure, flow, etc.) with its sensor and generate or "transmit" a standardized output signal (0-5 VDC, 2-10 VDC, 0-10 VDC, or 4-20 mA) that is proportional to the sensor value.

The two lines shown in following figure show the output of two different sensor transmitter configurations. The coarse dashed line shows a pressure transmitter whose output varies from 2 VDC to 10 VDC as the pressure varies from 0 PSIG to 100 PSIG. The fine dashed line shows a pressure transmitter whose output varies from 0 VDC to 10 VDC as the pressure varies from 0 PSIG to 100 PSIG. It is common to see multi-range pressure transmitters which use dial, dip switch, jumpers, or wiring terminals to determine the sensor range and output signal.

The output of the sensor transmitter is connected to an analog input of a BAS controller which is configured to properly interpret this signal. This standardization of the sensor transmitter output signals allows a multitude of manufacturers to produce these units, yet have the same performance characteristics. In HVAC control, thermistors and RTDs are generally used instead of temperature transmitters because they cost significantly less ($10-$20 as opposed to $200-$750) and do not require 24 VAC power. The following table provides examples of the most commonly-used sensor transmitters and their typical output signals.

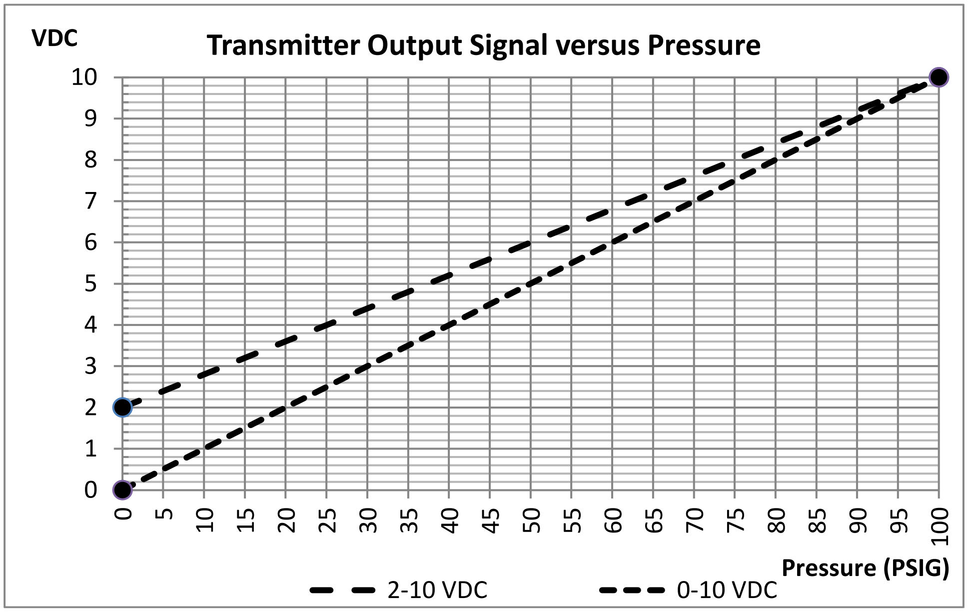


Figure 43 - Typical Sensor Transmitter Signals versus Pressure

The analog input of the BAS controller must be configured to correctly interpret the analog signal produced by the sensor transmitter. This process is shown schematically by following figure. In most cases, the BAS programming happens days, weeks, or months before the input and output devices are actually installed. The Control Technician/Programmer configures the analog input signals based on the available documentation which consists of the ATC submittal, mechanical drawings, and project specifications.

Sensor Transmitter	Rating	Percent Range					Units/Facets
		0%	25%	50%	75%	100%	
Temperature (Pt 1k Ohm RTD)	55-95	55	65	75	85	95	°F
Carbon Dioxide Concentration	0-2,000	0	500	1000	1500	2000	PPM CO_2
Carbon Monoxide Concentration	0-200	0	50	100	150	200	PPM CO
Air Differential Pressure Transmitter	-0.25 to 0.25	-0.25	-0.125	0	0.125	0.25	Inches W.C.
Air Differential Pressure Transmitter	0-5.0	0	1.25	2.5	3.75	5	Inches W.C.
Hydronic Differential Pressure	0-50	0	12.5	25	37.5	50	PSIG
Humidity	0-100	0	25	50	75	100	%RH
Air Velocity	0-3000	0	750	1500	2250	3000	FPM
Hydronic Flow	0-500	0	125	250	375	500	GPM
Voltage	0-600	0	150	300	450	600	Volts AC
Amperage	0-200	0	50	100	150	200	Amps
Transmitter Output #1	0-10	0	2.5	5	7.5	10	Volts DC
Transmitter Output #2	2-10	2	4	6	8	10	Volts DC
Transmitter Output #3	0-5	0	1.25	2.5	3.75	5	Volts DC
Transmitter Output #4	1-5	1	2	3	4	5	Volts DC
Transmitter Output #5	4-20	4	8	12	16	20	mA

Table 21 - Sensor/Transmitter Signal Examples

It is not uncommon to find configuration errors. This may be due to a lack of coordination between the programmer and installing technician (or subcontractor) or the installation of the incorrect load resistor. If the correct sensor transmitter is unavailable, an available sensor transmitter is often installed with the intention of replacing it when the correct unit arrives or updating the analog input configuration of the BAS controller to match the installed sensor transmitter. However, this change does not always happen. It is not anyone's intention to install input and output devices that are incorrectly configured. It is a natural risk and consequence of performing steps over time and through multiple people. This enforces the need for documentation and communication. The calibration process meant to identify and correct these issues.

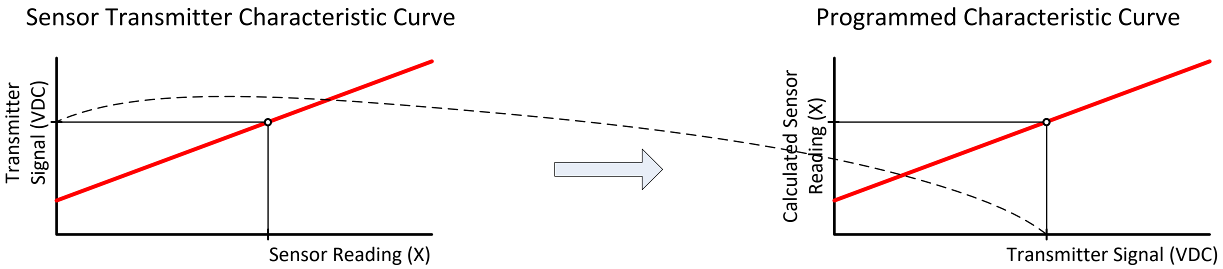
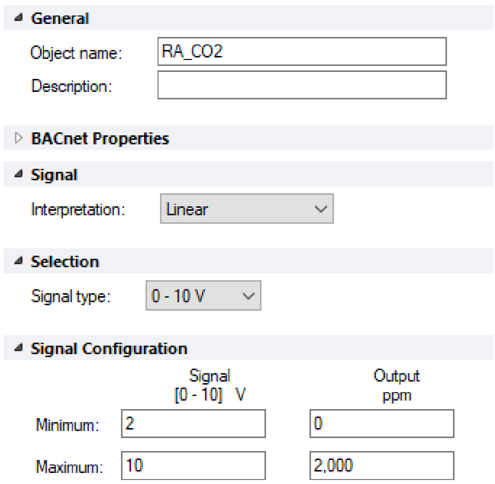


Figure 44 - Transmitter and Programmed Characteristic Curves

Some BAS controllers allow the direct entry of analog input device parameters into a table (as shown in Figure 45) while others require the entry of Scale and Offset parameters (as shown in Figure 46). The following sections illustrate how an analog input device might be configured using both the tabular and the Scale/Offset configurations. Distech controllers (and similar) provide a tabular analog input configuration and the Scale and Offset values are calculated internally by the BAS controller. However, when the analog inputs are configured in a JACE controller (or similar), the configuration process requires the entry of the Scale and Offset values. Therefore, the Control Technician/Programmer must calculate the required Scale and Offset values prior to entering them in the analog input configuration. Most Control Technicians/Programmers use a spreadsheet to automate this calculation process. The mathematics required to calculate the Scale and Offset will be explained.



General
Object name: RA_CO2
Description:

BACnet Properties

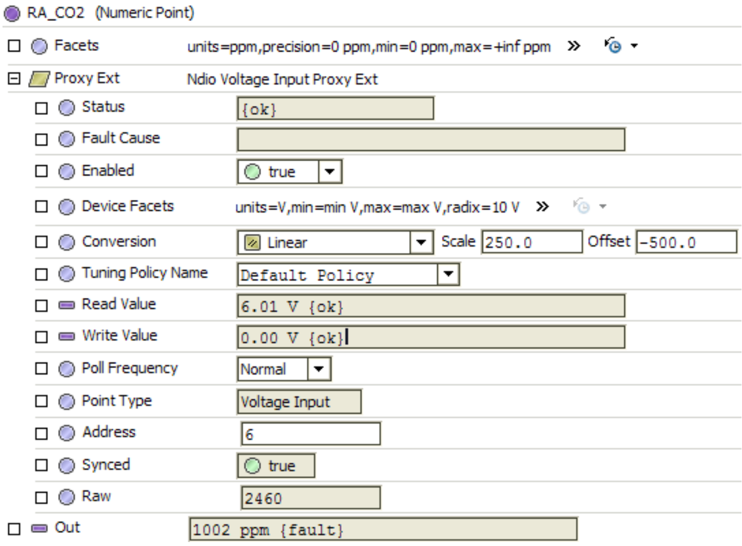
Signal
Interpretation: Linear

Selection
Signal type: 0 - 10 V

Signal Configuration

	Signal [0 - 10] V	Output ppm
Minimum:	2	0
Maximum:	10	2,000

Figure 45 - Distech EC-GFX Carbon Dioxide Transmitter Configuration



RA_CO2 (Numeric Point)
Facets: units=ppm,precision=0 ppm,min=0 ppm,max=+inf ppm
Proxy Ext: Ndio Voltage Input Proxy Ext
Status: {ok}
Fault Cause:
Enabled: true
Device Facets: units=V,min=min V,max=max V,radix=10 V
Conversion: Linear Scale 250.0 Offset -500.0
Tuning Policy Name: Default Policy
Read Value: 6.01 V {ok}
Write Value: 0.00 V {ok}
Poll Frequency: Normal
Point Type: Voltage Input
Address: 6
Synced: true
Raw: 2460
Out: 1002 ppm {fault}

Figure 46 - JACE Carbon Dioxide Transmitter Configuration

3.9.1 Analog Input Configuration (Carbon Dioxide Transmitter Example)

Suppose that we want to configure a BAS controller to correctly interpret the signal from a carbon dioxide transmitter with a sensor range of 0-2,000 Parts per Million (PPM) and an output signal range of 2-10 VDC. The Distech controllers (and similar) allow direct entry of the analog input device parameters into a table as shown in Figure 45. This analog input configuration makes it very easy to configure any sensor transmitter. All required mathematics is automatically performed by the BAS controller. Given a voltage signal from the sensor transmitter, the BAS controller calculates the resultant carbon dioxide concentration (PPM).

Reading	Carbon Dioxide (PPM)	Signal (VDC)
Minimum	0	2
Maximum	2,000	10

Table 22 - Carbon Dioxide Transmitter Configuration

If the same carbon dioxide transmitter is connected to a JACE input/output panel, it requires the entry of Scale and Offset values as shown in Figure 46. The scale and offset values are constants which define the linear equation that the BAS controller uses to calculate carbon dioxide concentration from the voltage signal provided by the carbon dioxide transmitter. The Scale and Offset values are initially calculated from the ideal characteristic curve parameters (Table 22) of the sensor transmitter. Figure 46 shows the carbon dioxide transmitter with a 6.01 VDC signal and it calculates a carbon dioxide concentration of 1,002 PPM. The indicated carbon dioxide concentration confirms that the Scale and Offset factors are properly set, but it is not yet calibrated.

3.9.2 Scale and Offset Calculations

Because the sensor transmitter outputs an analog signal that is proportional to its sensor signal, the BAS controller uses linear equations to mathematically represent the relationship between the voltage signal and the corresponding sensor reading. The equation of a line is used to calculate the sensor reading from the voltage signal generated by the sensor transmitter. In Chapter 2: BAS Calibration we reviewed how the equation of a line is created using the Slope-Intercept and Point-Slope forms. The process of defining the equation of a line for a sensor transmitter is no different; only the nomenclature changes.

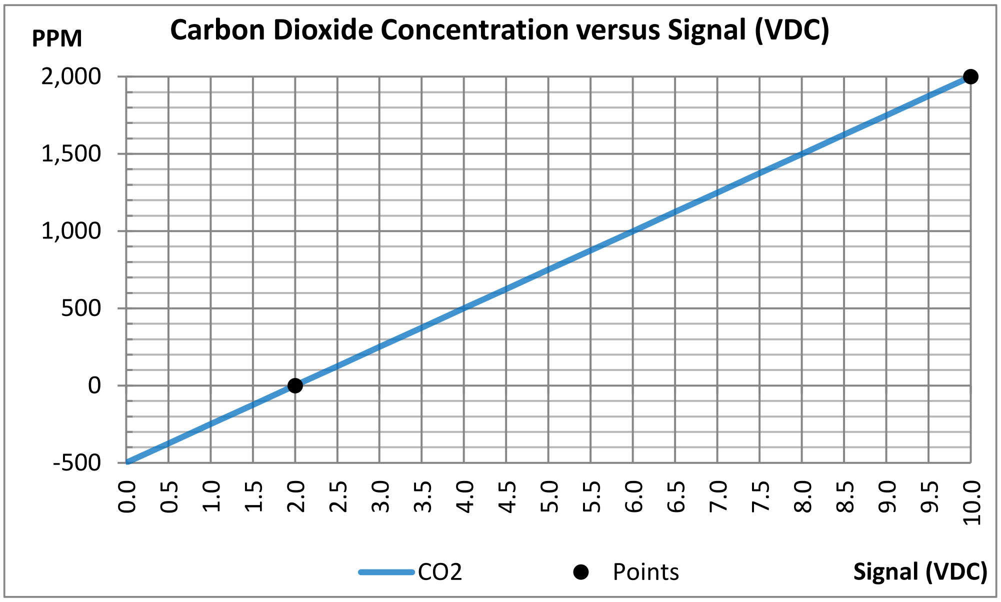


Figure 47 - Ideal Characteristic Curve of a Carbon Dioxide Transmitter

Instead of a graph of X,Y values, we have a transmitter signal versus sensor reading graph where the X axis is called the signal axis (typically labeled VDC) and the Y axis is called the sensor reading (carbon dioxide, humidity, current, velocity, etc.t) axis where the appropriate units of measure are typically used. The slope (or m) of the line is called the Scale and the Y-intercept (or b) is called the Offset. JACE panels (and similar) require the entry of Scale and Offset values in order to interpret the analog signal from the sensor transmitter. Any two points on a sensor transmitter graph may be used to define the scale and offset constants which define the equation of the line that passes through them. This section explains how the Scale and Offset values are determined.

Figure 47 provides a graph of the carbon dioxide level versus voltage signal for a typical carbon dioxide transmitter. The manufacturer provides the performance specifications of the sensor transmitter in the form of a sensor range and an output signal range. This example transmitter produces a 2-10 VDC signal as the carbon dioxide concentration varies from 0 PPM to 2,000 PPM (Table 22).

We just have to know how to interpret this data and use it to define the linear equation that calculates the sensor reading from the voltage signal provided by the sensor transmitter. The performance parameters define two points (2 VDC, 0 PPM & 10 VDC, 2k PPM) on the transmitter performance graph. At 2 VDC, the indicated carbon dioxide concentration is 0 PPM. At 10 VDC, the indicated carbon dioxide concentration is 2,000 PPM. The equation of a line initially defined by Equation 6 is redefined according to the sensor transmitter variables as follows:

(Equation 35) $$PPM_{CO2} = Scale * VDC + Offset$$

The Scale (m) represents the change in carbon dioxide concentration (PPM) per unit change in transmitter signal (VDC). Using the manufacturer's transmitter data provided in Table 22, the Scale (also referred to as slope or m) is calculated as follows:

(Equation 36) $$Scale = \frac{Change\ in\ CO2\ PPM}{Change\ in\ VDC} = \frac{2000\ \mathrm{PPM} - 0\ PPM}{10\ VDC - 2VDC} = \frac{2000\ PPM}{8\ VDC} = 250\frac{PPM}{VDC}$$

Once the Scale has been determined, we then calculate the Offset (also referred to as Y-Intercept or b). To do this, we substitute the Scale and either of the data points (0 PPM at 2 VDC or 2,000 PPM at 10 VDC) into the equation. It does not matter which point is chosen because the answer will be the same. We solve for the Offset value as follows:

(Equation 37) $$(2{,}000\ PPM) = 250\frac{PPM}{VDC} * (10\ VDC) + b$$

(Equation 38) $$2{,}000\ \mathrm{PPM} = 2{,}500\ PPM + Offset$$

(Equation 39) $$2{,}000\ PPM - 2500\ PPM = 2{,}500\ PPM - 2{,}500\ PPM + Offset$$

(Equation 40) $$Offset = -500\ PPM$$

Therefore, using the analog input configuration provided in Table 22, the equation of the line which represents the carbon dioxide concentration based on the voltage reading from the carbon dioxide transmitter is as follows:

(Equation 41) $$PPM_{CO2} = 250\frac{PPM}{VDC} * V - 500$$

With both the Scale (250) and Offset (-500) calculated, these values can then be entered into the analog input configuration of the JACE controller (or similar) as shown in Figure 46. This process may initially seem complicated and tedious, but it is actually very easy once you have done it a couple of times. Most Control Technicians and programmers use a spreadsheet to quickly calculate the Scale and Offset parameters based on the sensor-transmitter parameters. Once this spreadsheet is built, it can be used for all sensor transmitters.

To verify the accuracy of the equation, enter values representing -25%, -12.5%, 0%, 12.5%, 25%, 37.5%, 50%, 62.5%, 75%, 87.5%, and 100% of the voltage signal range into the equation to calculate the corresponding carbon dioxide concentration (PPM). The signal range is 2-10 VDC, but the 0 VDC and 1 VDC values and their results were included in the following table to illustrate the values of PPM_{CO2} when the signal is equal to zero. We calculated previously that the Offset of the linear equation that calculates the carbon dioxide concentration is -500. The results in this table indicate that the calculated Offset was correctly determined. At zero (0 VDC) voltage, the calculated carbon dioxide concentration is -500 PPM. The same is shown graphically in Figure 47.

Percent Range	Voltage (VDC)	Carbon Dioxide Concentration (PPM)
-25%	0	-500
-12.5%	1	-250
0%	2	0
12.5%	3	250
25%	4	500
37.5%	5	750
50%	6	1000
62.5%	7	1250
75%	8	1500
87.5%	9	1750
100%	10	2000

Table 23 - 0-2000 PPM Carbon Dioxide Transmitter Reading versus Voltage (2-10 VDC)

When the sensor transmitter output signal range starts at zero, as opposed to 1 VDC, 2 VDC, or 4 mA, or any other non-zero value, the calculation of the Scale and Offset values is very easy. This example transmitter produces a 0-10 VDC signal as the carbon dioxide concentration varies from 0 PPM to 2,000 PPM as shown in the following table. Following the same process outlined above, the Scale will simply be the maximum value of the sensor range divided by the maximum value of the signal range.

Percent Range	Voltage (VDC)	Carbon Dioxide Concentration (PPM)
0%	0	0
10%	1	200
20%	2	400
30%	3	600
40%	4	800
50%	5	10000
60%	6	1200
70%	7	1400
80%	8	1600
90%	9	1800
100%	10	2000

Table 24 - 0-2000 PPM Carbon Dioxide Transmitter Reading versus Voltage (0-10 VDC)

Using the procedure above, the Scale or slope would be 200 PPM/VDC and the Offset or Y-Intercept will be zero. In other words, the equation of the line that provides the sensor value from the voltage (or amperage) signal passes through the origin of the graph (0 VDC, 0 PPM CO2). After enough repetition, most Control Technicians can calculate or commit to memory the Scale and Offset factors required for a variety of sensor transmitters that they typically encounter.

(Equation 42) $$PPM_{CO2} = m * VDC + b$$

(Equation 43) $$Scale = m = \frac{2000\ PPM - 0\ PPM}{10\ VDC - 0VDC} = \frac{2000\ PPM}{10\ VDC} = 200\frac{PPM}{VDC}$$

(Equation 44) $$(2{,}000\ PPM) = 200\frac{PPM}{VDC} * (10\ VDC) + b$$

(Equation 45) $$2{,}000\ \mathrm{PPM} = 2{,}000\ PPM + b$$

(Equation 46) $$2{,}000\ PPM - 2000\ PPM = 2{,}000\ PPM - 2{,}000\ PPM + b$$

(Equation 47) $$b = Offset = 0\ PPM$$

(Equation 48) $$PPM_{CO2} = 200 * VDC$$

3.9.3 Transmitter Wiring Configurations

Most sensor transmitters used in HVAC applications utilize either two-wire or three-wire configurations. Both wiring configurations work equally well at short to moderate distances. The two-wire configuration is typically used if the transmitter is a long distance (>250 feet) from the BAS controller. Transmitters utilize either 24 Volt Direct Current (VDC) or 24 Volt Alternating Current (VAC) transformers for the required power. These power sources are typically located in the LCP, but they may also be located at the sensor transmitter end of the circuit if it is located remotely. For example, air and hydronic differential pressure transmitters are typically located where they sample (2/3 to 3/4 down the longest duct/pipe run) the system – not in the LCP. Air differential pressure transmitters are often located in the LCP and the pneumatic tubing run to the sampling point (2/3 to 3/4 down the longest duct run) in smaller duct distribution systems.

Photo 41 - IDEC DC 120 VAC to 24 VDC Power Supply

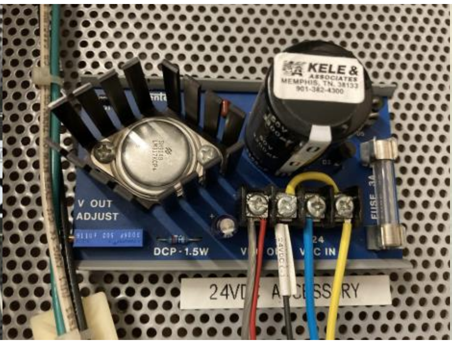


Photo 42 - Kele DCP-1.5-W DC 24 VAC to 24 VDC Power Supply

Photo 43 - BAS Controller 18 VDC Power Terminal

The DC power will typically come from three places: a 120 VAC to 24 VDC power supply, a 24 VAC to 24 VDC power supply, or from the BAS controller auxiliary DC contacts. IDEC DC power supplies are preferred by many Controls Contractors because its load is supplied by a 120 VAC circuit and does not impact 24 VAC Volts-Amps (VA) loading. It also has a clean and professional look. Direct current power supplies, BAS controllers, and the sensor transmitters should be wired and grounded in strict compliance with the manufacturer's installation recommendations to provide the correct signal references.

3.9.3.1 Two-Wire Transmitter Wiring

Two-wire transmitters require a circuit that is composed of a DC power supply (typically 24 VDC), a sensor transmitter, and the analog input of a BAS controller. This configuration is generally known as a "loop-powered" transmitter circuit. The negative terminal of the DC power supply connects to the BAS controller's common terminal to provide the DC current signal reference. The analog output of the transmitter is connected to the positive or signal terminal of the analog input on the BAS controller.

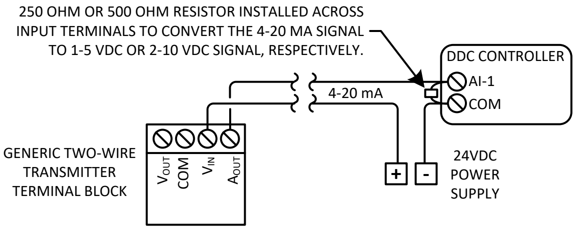


Figure 48 - Two-Wire Transmitter Wiring (w/ Load Resistor)

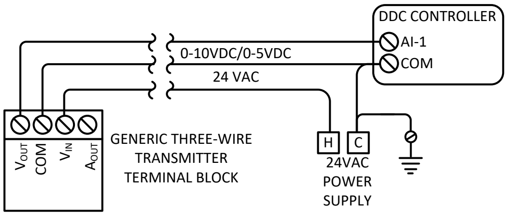


Figure 49 - Three-Wire Transmitter Wiring

The current flows through the conductor from the positive terminal of the 24 VDC power supply to the sensor transmitter's voltage input terminal. As the parameter measured by the sensor transmitter changes, the current flow through this circuit changes proportionately. Many Controls Contractors prefer the loop-powered transmitter because they require only two-conductor cable, are simple to wire, and can function over very long distances (>250 feet). The analog input of the BAS controller must also be configured for a 4-20 mA input signal in order for it to correctly interpret the transmitter's output signal.

3.9.3.2 Milliamp to Voltage Signal Conversion

If a voltage signal to the BAS controller's analog input is required, then a load resistor is used to convert the transmitter's current signal to a voltage signal as shown in Figure 47. With a 250 Ohm or 500 Ohm resistor across the analog input terminals of the BAS controller, the 4-20 milliamp current signal from the sensor transmitter is converted to a 1-5 VDC or 2-10 VDC voltage signal, respectively. Recall Ohm's Law which states that voltage is equal to current multiplied by resistance.

(Equation 49) $$\mathrm{V} = \mathrm{I} * \mathrm{R}$$

(Equation 50) $$\mathrm{V} = 4\ \mathrm{mA} * 500\ \mathrm{Ohms} = 2\ \mathrm{VDC}$$

(Equation 51) $$\mathrm{V} = 20\ \mathrm{mA} * 500\ \mathrm{Ohms} = 10\ \mathrm{VDC}.$$

(Equation 52) $$\mathrm{V} = 4\ \mathrm{mA} * 250\ \mathrm{Ohms} = 1\ \mathrm{VDC}$$

(Equation 53) $$\mathrm{V} = 20\ \mathrm{mA} * 250\ \mathrm{Ohms} = 5\ \mathrm{VDC}$$

The low end of the voltage scale is calculated by multiplying 4mA by 500 Ohms to arrive at 2 VDC. The upper end of scale is similarly calculated by multiplying 20 mA by 500 Ohms to arrive at 10 VDC. If a 250 Ohm load resistor is installed across the input terminals of the BAS controller, then the input signal will have a 1-5 VDC signal range. Variations in the resistance of the load resistor will create variations in the resultant voltage measured by the BAS controller. These minor variations are verified and corrected through the calibration process. If any manipulation of the resistor or wires is required, be sure to remove power from the sensor transmitter and BAS controller prior to loosening the terminals. Catastrophic damage to the BAS controller and sensor transmitter is possible if this precaution is not followed.

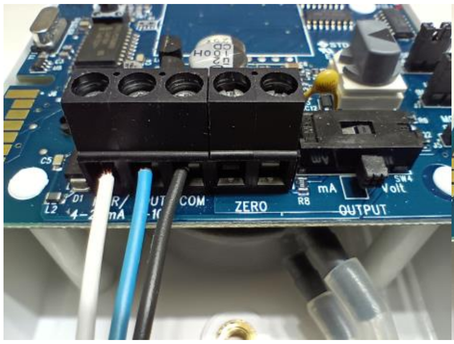


Photo 44 - Three-wire Transmitter Configuration

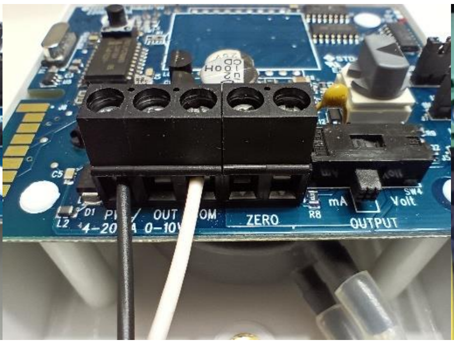


Photo 45 - Two-wire Loop-powered Transmitter Configuration

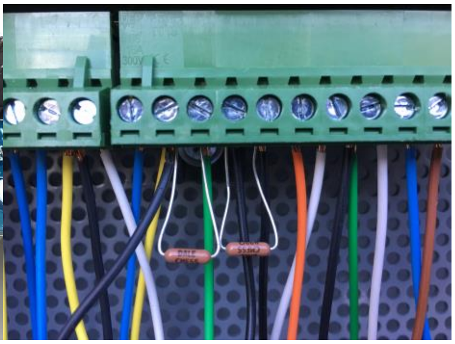


Photo 46 - Signal Conversion with 500 Ohm Resistors

3.9.3.3 Three-Wire Transmitter Wiring

Many Controls Contractors will utilize a three-wire configuration instead of the two-wire configuration because it offers more signal flexibility. They can provide either a current (4-20 mA) or voltage (0/2-10 VDC) signal without the use of load resistors. In addition, the three-wire connection can typically utilize either a 24 VAC or 24 VDC power source. Most Control Technicians prefer to use a three-wire voltage signal (as opposed to the two-wire 4-20 mA current signal) from a transmitter because of the ease of testing the voltage signal and because no load resistors are required. Current measurements require that the wiring be disassembled to put the multimeter leads in line with the circuit (unless a Fluke 773 is available). Three-wire transmitters are typically wired to provide a voltage signal (0/2-10 VDC or 0/1-5 VDC). Signal measurement requires that the multimeter probes contact either the input terminals at the BAS controller or the output terminals of the transmitter (Common and V_{OUT}).

When long wire lengths are required, we must be cognizant of the observed signal readings from the three-wire transmitter. The performance of the three-wire transmitters depends on many factors including the distance, wire resistance, and transmitter specifications. If the supply voltage to the transmitter does not meet the minimum required voltage, it will not function properly or not at all. If the transmitter does not produce the full output signal range when calibrated, this is a sign that the wire length is too long (or circuit resistance is too high) resulting in excessive voltage drop. If these issues are encountered, the two-wire, loop-powered transmitter configuration is recommended because they are constructed for distance. This change will require modification of the analog input configuration of the BAS controller, a DC voltage source, and a 250 Ohm or 500 Ohm load resistor. The following table provides a summary of the various wiring and resistor configurations that are possible and their resulting control signal.

Wiring Configuration	Power Supply Voltage	Resistor Configuration	Transmitter Signal
Two-Wire	24 VDC	No Load Resistors	4-20 mA
Two-Wire	24 VDC	500 Ohm Load Resistor	2-10VDC
Two-Wire	24 VDC	250 Ohm Load Resistor	1-5 VDC
Three-Wire	24 VAC/24 VDC	No Load Resistors	4-20 mA
Three-Wire	24 VAC/24 VDC	No Load Resistors	0/2-10VDC
Three-Wire	24 VAC/24 VDC	No Load Resistors	0/1-5 VDC

Table 25 - Transmitter Signal Matrix

3.9.4 Sensor Transmitter Calibration

To simply compare the sensor transmitter reading provided by the BAS to a reference reading from a calibrated instrument and add an offset is grossly inadequate for calibration purposes. Yet, this is the standard "calibration" methodology used and taught by most in the industry. The calibration process in building automation has been simplified to the point that the minimum work that qualifies as "calibration" is no longer performed. If a reasonable reading is observed, it is deemed acceptable. The newness of the sensor transmitter is falsely equated with accuracy, so a great many sensors and sensor transmitters are never calibrated. Offsets may be applied. Most Controls Technicians and Programmers are typically not equipped to calibrate every sensor transmitter they install and configure. Building automation in the comfort control arena is not the same as the process environment. We don't typically adjust the zero and span of sensor transmitters. Many devices do not come with this capability. However, at a minimum, we need to be able to determine the accuracy of the sensor transmitter and adjust the analog input configuration based on this test data. This will require an investment on the part of Controls Contractors to equip their technicians and programmers with the tools, education, and instrumentation required to perform field calibration of sensors and sensor transmitters.

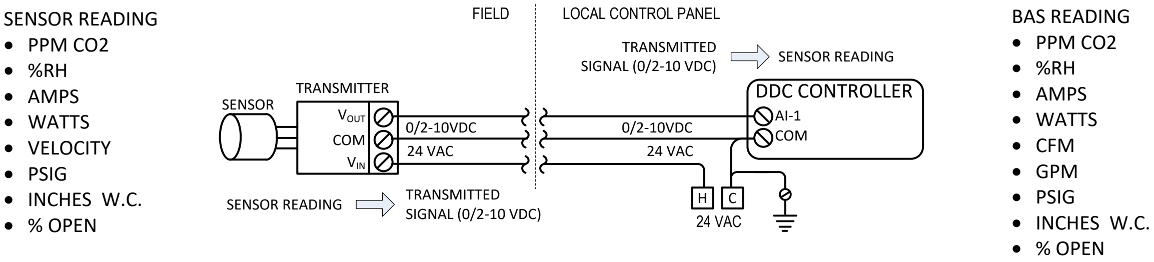


Figure 50 - Schematic of a Sensor Transmitter and BAS Controller Signal Translation

In order for the BAS to display the correct reading, the sensor transmitter must accurately generate or "transmit" an analog output signal that is proportional to its sensor signal. The BAS controller is programmed to interpret the analog signal it receives from the sensor transmitter. It uses linear equations to calculate the sensor reading from the voltage signal. Refer to Figure 50 for a schematic of this process. As the description indicates, calibration of sensor transmitters is a two-part process. First, the transmitter signal versus sensor reading must be verified and calibrated to ensure that it produces an accurate output signal for the given current ambient or simulated test conditions. If signal is outside the calibration tolerance and within the service tolerance, its zero and span must be adjusted to provide the required performance. However, for comfort cooling applications we do not typically adjust the zero and span of analog input devices as would be done in the process environment. If the sensor transmitter accuracy exceeds the service tolerance, replacement is recommended. Secondly, the configuration of the analog input of the BAS controller is updated to exactly match the actual sensor transmitter performance to ensure that it accurately calculates the sensor reading from the transmitter signal. Calibrating the final reading of any sensor transmitter requires both steps.

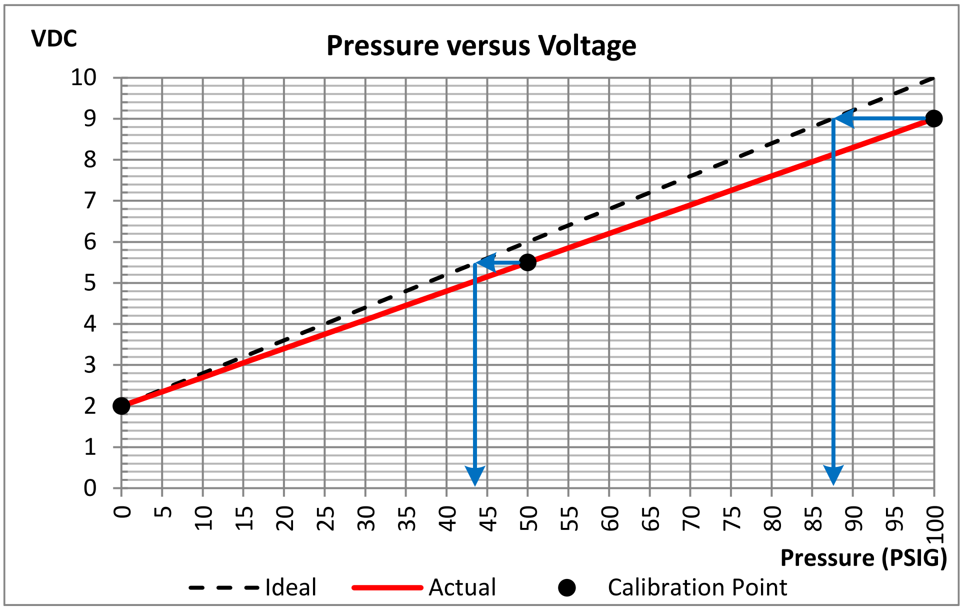


Figure 51 - Pressure versus Voltage Signal Graph

The output signal from the sensor transmitter must be compared to reference readings to verify that it generates the correct output signal for the current ambient or simulated conditions. Then the analog input configuration of the BAS controller must also be verified to ensure that it properly interprets the actual signal of the installed transmitter. Both steps are required to calibrate the sensor transmitter reading. It should not be assumed that the sensor transmitter generates the correct output signal. Nor can it be assumed that the analog input of the BAS controller is correctly configured to interpret the sensor transmitter signal. It is entirely possible for the sensor reading provided by the BAS to appear correct even though the sensor transmitter output signal is beyond the calibration tolerance and the analog input of the BAS controller is incorrectly configured. If the sensor readings indicated by the BAS and the reference instrument do not agree, it is necessary to determine whether the sensor transmitter is producing the incorrect output signal, the analog input of the BAS controller is incorrectly configured, or both.

In order to calibrate sensor transmitters, we first review the current configuration of the analog input that monitors its signal. It is initially configured with the ideal characteristic curve parameters. Like any sensor transmitter, it produces an analog output signal that is proportional to its sensor reading. The transmitter configuration will resemble the data in the following table which shows a HDPT that produces a 2-10 VDC signal as its pressure sensor reading changes from 0-100 PSIG. Figure 51 shows the graphs of the ideal and actual pressure versus voltage signals for the HDPT.

Reading	Transmitter Signal (VDC)	Sensor Transmitter (PSIG)
Minimum	2	0
Maximum	10	100

Table 26 - Initial Transmitter/BAS Controller Configuration

When the sensor transmitter is connected to the analog input of a JACE panel, it requires the entry of scale and offset values that define the equation used to calculate the sensor reading from the transmitter signal. A spreadsheet that calculates the scale and offset values was constructed to calculate the required values and preclude the unnecessary repetition of calculating these values. Based on the manufacturer's transmitter specifications provided in above table, the scale and offset values are calculated based on section 3.9.2 as follows:

Volts (DCV)	Pressure(PSIG)
2	0
10	100

Calculated Scale= 12.50
Calculated Offset= -25.00

Table 27 - Initial Scale-Offset Calculations

When 0, 50, and 100 PSIG test pressures are applied to the HDPT, it produces the corresponding voltage signals and pressure indications provided in the following table. This initial test data constitutes the "As-Found" calibration data. Using the original analog input configuration provided in Table 26, these voltages result in incorrect pressure readings. Why? First, the HDPT does not produce the correct voltage signal because of zero and/or span errors. Secondly, the analog input of the BAS controller is not configured with the actual performance parameters of the HDPT which results in configuration error.

Reading	Test Pressure (PSIG)	BAS-Indicated Pressure (PSIG)	Transmitter Signal (VDC)	Ideal Signal (VDC)
1	0	0	2.0	2.0
2	50	43.75	5.5	6.0
3	100	87.5	9.0	10.0

Table 28 - Calibration Readings

This HDPT voltage signal starts at 2.0 VDC, so there is no zero error. The HDPT output signal indicates span error because it does not produce the full span (8.0 VDC). It produces an output signal of only 7.0 VDC (9.0 VDC-2.0 VDC). Therefore, the maximum pressure indication would be only 90.0 PSIG when 100 PSIG test pressure is applied. This HDPT should either be replaced or its zero and span adjusted, so that it produces the correct signal for the applied pressure. Be sure to strictly follow the manufacturer's instructions for making zero and span adjustments. If the pressure transmitter readings still appear to be inaccurate or it does not provide accurate readings across its full range, then replacement is recommended. The Owner should not have to accept a sensor transmitter that does not perform properly.

Normally, this HDPT would be removed from service because of its excessive error and replaced. However, we will continue with the calibration process to illustrate the entire process. If the HDPT voltage signals are found to be accurate, the configuration of the analog input of the BAS controller is updated to match the actual performance demonstrated by the calibration readings. This update allows the BAS controller to properly interpret the analog signal provided by the HDPT and eliminates configuration error. At least two-point calibration points are performed using the maximum and minimum values that can be simulated or observed in the field. More calibration points may be used if deemed necessary. Ideally, the calibration points should encompass the normal operating range.

Reading	Sensor Transmitter (PSIG)	Transmitter Signal (VDC)	BAS-Indicated Pressure (PSIG)
Minimum	0	2.0	0.0
Maximum	100	9.0	100.0

Table 29 - Final "Calibrated" Transmitter/BAS Controller Configuration

When the analog input device is connected to a JACE panel, an additional step is required because its interpretation of the transmitter signal is based on the entry of scale and offset parameters. Based on the actual transmitter performance data provided in following table, the updated scale and offset values are calculated as follows:

Volts (DCV)	Pressure (PSIG)
2.0	0
9.0	100.0

Updated Calculated Scale= 14.29
Updated Calculated Offset= -28.57

Table 30 - Updated Scale-Offset Calculations

The analog input configuration is then updated with the new Scale and Offset values which correct the programmed linear equation to match the calibration test data. If this is not done, the sensor reading produced by the transmitter will not be accurately calculated. The sensor transmitter is retested to confirm the accuracy and this final test data set constitutes the "As-Left" calibration data. With the sensor transmitter calibrated, it now accurately reports the sensor reading across its calibration range. As previously stated, this HDPT would typically be replaced because of its low accuracy.

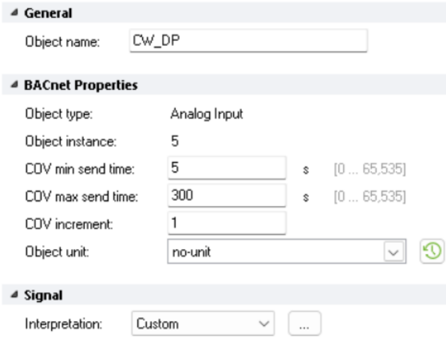
Some transmitters are not very easily field-calibrated. Pressures across the entire instrument range can be simulated with calibration pumps or compressed gases and applied to pressure transmitters. However, carbon dioxide, humidity, and current are parameters that are not very easily field simulated. These types of sensor transmitters require the acquisition of calibration readings at different times of the day or under various operating modes or loadings to provide calibration readings that are sufficiently far apart to allow a two-point calibration. The following table provides a summary of the reference instruments and test methods that may be required to test and calibrate the various analog input devices.

Sensor/Transmitter	Test Media	Reference Method/Instrument
Air Temperature Sensors	Air	Temperature Meter & Temp. Probe
Space Temperature Setpoint Adjustment	Physical Activation	Electrical Resistance, Observe setpoint change
Hydronic Temperature Sensor	Water	Temperature Meter (Water bath, Drain, Pipe Surface Temperature, reference sensor)
Humidity Transmitter	Air	Humidity Meter, Sling Psychrometer
Current Transmitter	Equipment Current Flow	Clamp Meter, VFD Reading
Carbon Dioxide Transmitter	Air/Calibration Gas	Carbon Dioxide Meter/Calibration Gas
Air Differential Pressure Transmitter	System Air/Test Pressure	Manometer and Calibration Pump
Hydronic Differential Pressure Transmitter	System Fluid/Test Pressure	Hydronic Manometer and Calibration Pump
AirFlow Measuring Station	System Airflow	Duct Traverse, Summation of Hood Readings
Hydronic Flow Meter	System Fluid	Ultrasonic Flow Meter or Flow Measurement with Hydronic Manometer
Electric Actuator Feedback	Actuator	Observation/Voltage

Table 31 - Summary of Sensor/Transmitter Testing Methods

If you are fortunate enough to work with Distech controllers, the EC-gfx software has a custom signal option that allows the entry of up to 32 reference points in the analog input configuration (Figure 52). Transmitter calibration typically consists of either three (0%, 50%, 100%) or five (0%, 25%, 50%, 75%, 100%) points of reference if the sensor parameter can be easily simulated. A differential pressure transmitter is a prime example because pressure increments can be simulated with a calibration pump or pressure-regulated gas (air, nitrogen, etc.) source. Initially, the ideal voltage readings are entered into this table which assumes an ideal or 100% accurate sensor transmitter. When the calibration is performed, the ideal transmitter signal voltages are replaced with the actual voltage readings. The voltage reading at each test pressure increment is entered into the voltage signal versus sensor reading table (Figures 53 & 54). This procedure provides the highest accuracy in the transmitter reading because calibration points are distributed throughout the sensor transmitter range instead of the two extremes.

Occasionally, the actual voltage signal produced by the sensor transmitter may exceed 10 VDC. Suppose that the differential pressure transmitter produced a 10.2 VDC signal when a test pressure of 100 PSIG was applied. This means that the HDPT has zero error, span error, or both. Some BAS controllers may not allow the entry of voltage signal values over 10 VDC in the analog input configuration. If this situation is encountered, the collected calibration test data can be used to interpolate the pressure reading at 10 VDC. This value is then entered in the analog input configuration for the pressure reading corresponding to 10 VDC. Alternatively, if a calibration pump or adjustable compressed air/gas source is used, the applied test pressure can be lowered until the HDPT voltage signal measures 10.0 VDC and this pressure entered into the analog input configuration. Either calibration method is valid. The final step is to determine if the error at full scale is within the service tolerance because this HDPT will not be capable of reading the full sensor range (0-100 PSIG). If the HDPT error is beyond the service tolerance, its replacement is recommended.



Object name: CW_DP

Object type: Analog Input

Object instance: 5

COV min send time: 5 s [0 ... 65,535]

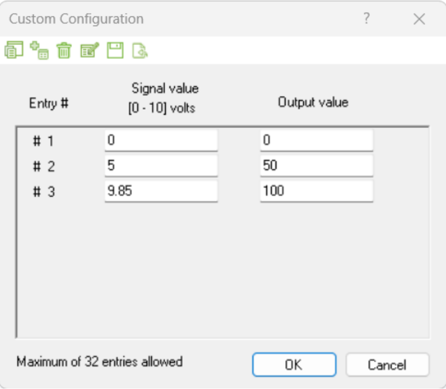
COV max send time: 300 s [0 ... 65,535]

COV increment: 1

Object unit: no-unit

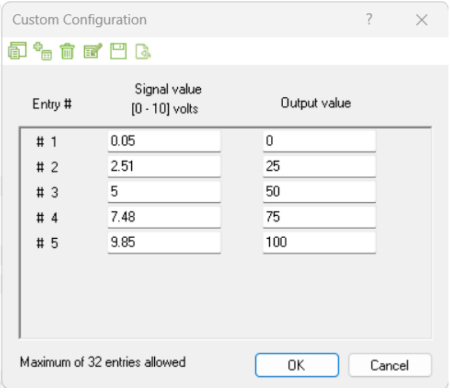
Interpretation: Custom

Figure 52 - EC-gfx Custom Analog Input Configuration



Entry #	Signal value [0 - 10] volts	Output value
# 1	0	0
# 2	5	50
# 3	9.85	100

Figure 53 - Three-Point Configuration/Calibration



Entry #	Signal value [0 - 10] volts	Output value
# 1	0.05	0
# 2	2.51	25
# 3	5	50
# 4	7.48	75
# 5	9.85	100

Figure 54 - Five-Point Configuration/Calibration

3.9.5 Sensor Transmitter Calibration – Calibration Range Less than Sensor Range

We are often required to calibrate sensor transmitters using ambient conditions, system overrides, calibration gases, or other means because we cannot test the sensor transmitters over their full sensor range. Carbon dioxide, humidity, and current transmitters are prime examples. Carbon dioxide transmitters can be tested with either a hand-held carbon dioxide meter or calibration gas depending on its construction. Calibration gases are available that allow us to test the accuracy at certain carbon dioxide concentrations. Calibration gases are more accurate than the carbon dioxide transmitter, so they are a very good reference for calibration readings. If 400 Parts per Million (PPM) and 1000 PPM carbon dioxide gases are used, then the calibration range is defined by these carbon dioxide concentrations. The following table provides the analog input configuration for a typical carbon dioxide transmitter.

Reading	Carbon Dioxide (PPM)	Signal (VDC)
Minimum	0	2
Maximum	2,000	10

Table 32 - Initial Analog Input Configuration

When the analog input device is connected to a JACE panel or similar, the carbon dioxide concentration is based on the entry of scale and offset parameters. The initial scale and offset values are calculated as follows:

Volts (DCV)	CO2 (PPM)
2	0
10	2000

Initial Scale= 250.00
Initial Offset= -500.00

Table 33 - Initial Scale-Offset Calculation for Analog Input Configuration

The following calibration data was acquired after applying the calibration gases to the carbon dioxide transmitter.

Reading	Test/Instrument (CO2 PPM)	BAS Reading (CO2 PPM)	Volts (VDC)
Minimum	403	437.5	3.75
Maximum	1,012	1,147.5	6.59

Table 34 - Calibration Gas Readings

From the calibration test data, we can graph two lines (Figure 55). The red line represents the equation of the line that passes through the ideal BAS readings for carbon dioxide concentration. It assumes a 100% accurate carbon dioxide transmitter, meaning that when 2 VDC equates to 0 PPM CO2, 6 VDC equates to 1,000 PPM CO2, and 10 VDC equates to 2,000 PPM CO2. The green line represents the equation of the line that passes through the reference readings provided by the calibrated gas or hand-held meter.

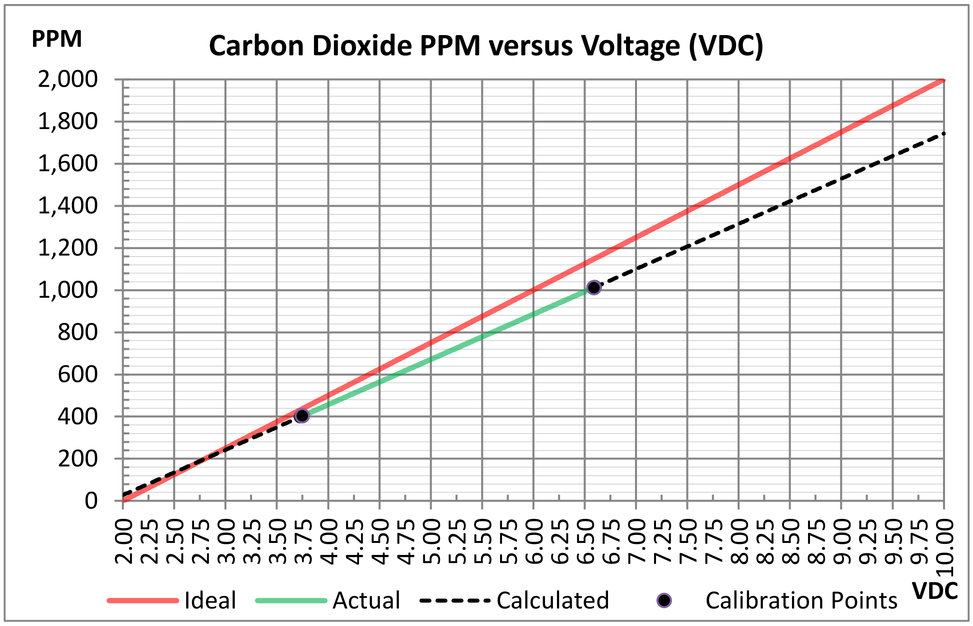


Figure 55 - Calibration Range Graph

The BAS-indicated values are based on the initial analog input configuration provided in Table 32. Any error in the BAS carbon dioxide concentration readings is therefore based on the error generated by the carbon dioxide transmitter. Calibration of the carbon dioxide transmitter with calibrated test gases at two distinctly different concentrations provides us with an indication of its actual performance.

Volts (DCV)	CO2 (PPM)
3.75	403
6.59	1,012.0

Updated Calculated Scale=	214.44
Updated Calculated Offset=	-401.14

Table 35 - Updated Scale-Offset Calculations

Using these data points, Scale and Offset values are calculated and used to graph the two lines based on a common voltage range (2-10 VDC) so that they may be compared. In addition, they allow the calculation by extrapolation of carbon dioxide concentration at the extreme ends of the carbon dioxide transmitter range as represented by the black dashed lines. The extreme values are required because the analog input voltage range is generally either 0-10 VFD or 2-10 VDC.

If the voltage range of the analog input were limited to 3.75-6.59 VDC, then the carbon dioxide reading would not go below 437 PPM even though the voltage may actually go below 3.75 VDC. Likewise, if the carbon dioxide reading would not exceed 1147 PPM even when the voltage signal exceeds 6.59 VDC. Therefore, based on the carbon dioxide transmitter performance between 400 PPM and 1000 PPM, we can calculate the performance at 2 VDC and 10 VDC for input in the analog input configuration.

(Equation 54) $$\text{PPM} = 214.44 * 2\text{VDC} - 401.14 = 27.7\ PPM$$

(Equation 55) $$\text{PPM} = 214.44 * 10\text{VDC} - 401.14 = 1743.2\ \text{PPM}$$

We now have the information required to update the analog input configuration so that it accurately interprets the voltage signal provided by the carbon dioxide transmitter.

Reading	Carbon Dioxide (PPM)	Signal (VDC)
Minimum	27.70	2
Maximum	1743.2	10

Table 36 - Final Scale-Offset Calculations

The graph (Figure 55) of the calibration data indicates that the error of the carbon dioxide transmitter is highest at the high end of the scale. However, the accuracy of the carbon dioxide transmitter may be deemed acceptable within the calibration range if it falls within the service tolerance. The maximum possible carbon dioxide reading assuming a linear voltage versus test pressure signal is 1743.2 PPM. At the low range of the scale, the minimum carbon dioxide reading will be 27.7 PPM. To verify that the points calculated at the extreme ends of the voltage scale are correct, the scale and offset values are recalculated and show that the scale and offset values are preserved. These values confirm that the analog input configuration points of above table are correct. In addition, the calculated scale and offset values calculate exactly match the values previously calculated in Table 35.

Volts (DCV)	CO2 (PPM)
2	27.7
10	1,743.2

Updated Calculated Scale= 214.44
Updated Calculated Offset= -401.14

Table 37 - Verified Scale-Offset Calculations

Graphing the results allows us to perform a complete evaluation of the sensor transmitter. The same procedure is used for all sensor transmitters that are evaluated with a calibration range that is less than the sensor range.

3.9.6 Single-Point Calibration

Some sensor transmitters are not easily calibrated with multiple points that span the sensor range. For example, it is difficult to acquire two comparison points with humidity, carbon dioxide, voltage, and current transmitters because they are not easily simulated in the field and the system may not substantially change the readings. In addition, the options for creating or simulating two distinctly different conditions is often limited. We typically cannot acquire two points of comparison that cover a significant portion of the sensor range in short succession. Therefore, they often must be calibrated at different times of the day, week, or year or with system overrides. Even then, obtaining two calibration points that are sufficiently apart may be a challenge. In these cases, a single calibration point is often deemed acceptable as long as other points are checked at a later time. The single point calibration will get the indicated and reference readings to agree, but as the sensor transmitter readings diverge from the calibration point, the accuracy may degrade.

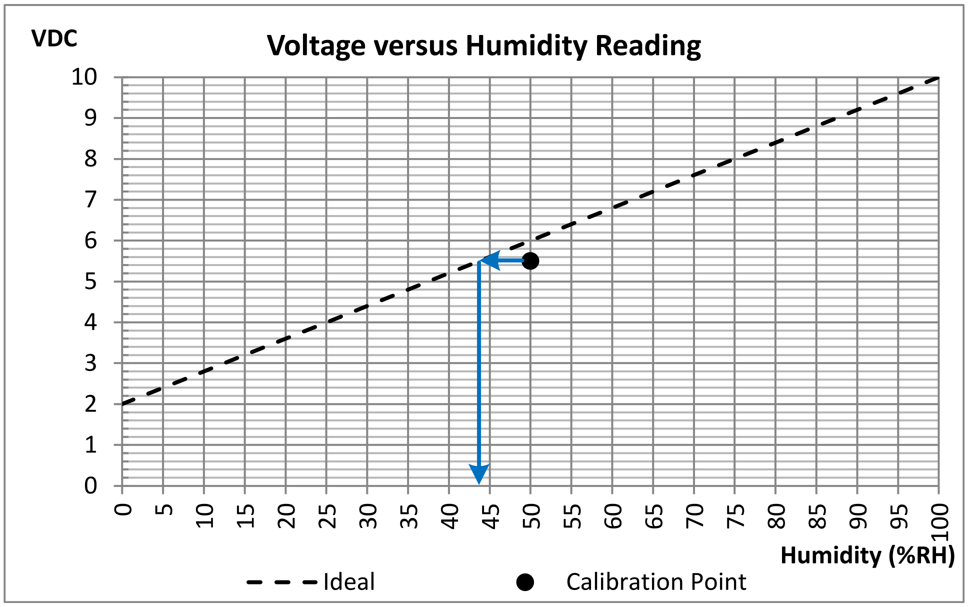


Figure 56 - Single-Point Calibration Comparison

When a single calibration reading is used to calibrate a sensor transmitter reading, only the zero should be adjusted. Recall that sensor transmitters produce a linear output signal based on the sensor reading. Likewise, the analog input of the BAS controller is configured to calculate the sensor reading based on the signal (0-10 VDC, 2-10 VDC, 4-20 mA, etc.) received from the sensor transmitter. Linear equations are used to make these sensor reading calculations based on the voltage signal. In this example case, the pressure transmitter should produce an ideal characteristic curve based on 2 VDC signal at 0 PSIG and 10 VDC signal at 100 PSIG. A single point calibration, by definition, will only provide a single point from which to evaluate its performance. To determine what corrections are required to fully calibrate a sensor transmitter, at least two calibration points are required. The slope of the actual performance curve (pressure versus voltage signal) can only be determined with at least two calibration points. If a single calibration point must be used, only the zero of the programmed analog input should be modified. The scale or slope of the programmed line should never be modified.

Reading	Sensor Transmitter (%RH)	Transmitter Signal (VDC)	Instrument Humidity (%RH)	Ideal Transmitter Signal (VDC)
1	43.75	5.5	50.0	6.0

Table 38 - Initial Test Results

A single-point calibration on a humidity transmitter will be demonstrated on a humidity transmitter that has a signal range of 2 VDC to 10 VDC as the sensor range varies from 0 %RH to 100 %RH. The analog input of the BAS controller will have been programmed for the same parameters. If the analog input was configured in a JACE or similar controller where scale and offset factors are used, they would be calculated based on the figures shown in Figure 56 and would result in a Scale of 12.5 and an Offset of -25.

Volts (DCV)	%RH
2	0
10	100.0

Updated Calculated Scale= 12.50
Updated Calculated Offset= -25.00

Table 39 - Initial JACE Analog Input Configuration

A reference reading by a calibrated instrument provides a 50.0% RH reading. However, at the same time the BAS provides a humidity reading of 43.75 %RH and the humidity transmitter produces a voltage signal of 5.5 VDC. If the humidity transmitter were producing the correct voltage, it would have a 6.0 VDC signal for a 50 %RH sensor indication. This indicates that the humidity transmitter is not producing the correct output signal for the given humidity conditions. The black dashed line in Figure 56 represents the voltage versus humidity line and the dot indicates the reference instrument reading and humidity transmitter voltage signal.

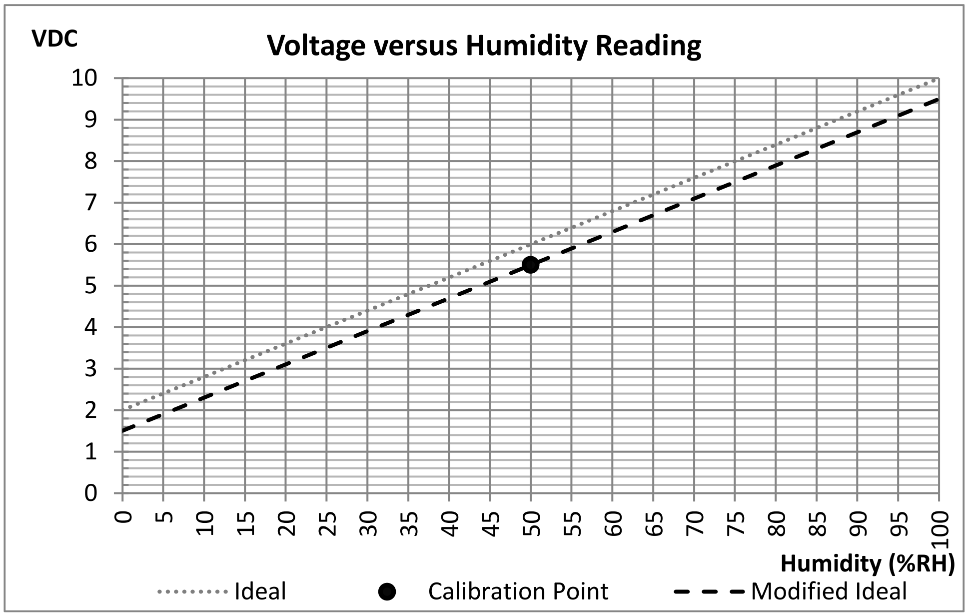
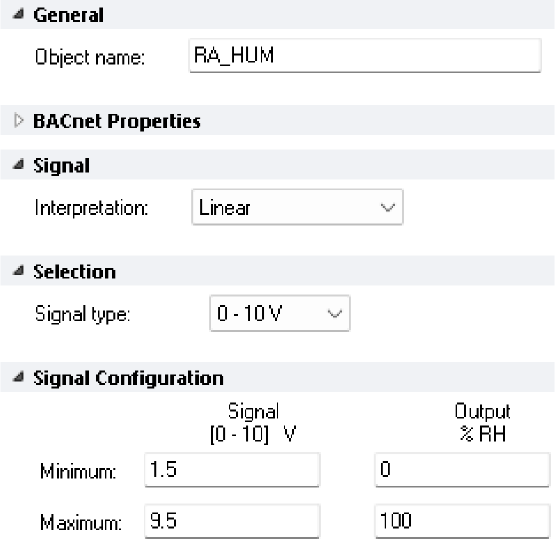


Figure 57 - Single-Point Calibration Correction

A single calibration point will not indicate how the voltage signal changes with increasing and decreasing humidity. It will not provide an indication of whether the zero and span are correct. However, it does provide a snapshot comparison at the calibration point. This single calibration reading will be used to correct or calibrate the humidity reading indicated by the BAS controller to the value provided by the calibrated reference instrument. Based on the configuration of the analog input, a 50%RH sensor reading should be produced when a 6.0 VDC signal is provided. The BAS controller is properly interpreting the signal provided by the humidity transmitter (assuming 100% accuracy). However, the signal produced by the humidity transmitter is 0.5 VDC lower than it should be at 50 %RH. Therefore, to correct the BAS humidity reading, a negative 0.5 VDC offset (or zero correction) is added to both (minimum & maximum) output signal values in the analog input configuration values as shown in Figure 58. This basically redefines the voltage signal that corresponds to 50 %RH from 6.0 VDC to 5.5 VDC and leaves the slope of the humidity transmitter performance curve (humidity versus voltage signal) unchanged as shown in Figure 57.



General

Object name: RA_HUM

BACnet Properties

Signal

Interpretation: Linear

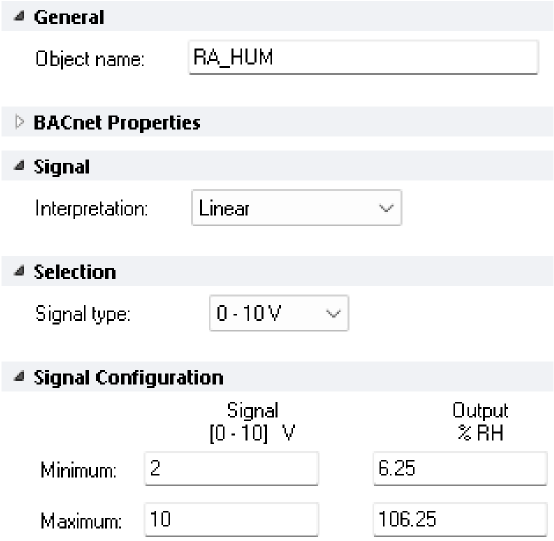
Selection

Signal type: 0 - 10 V

Signal Configuration

	Signal [0 - 10] V	Output % RH
Minimum:	1.5	0
Maximum:	9.5	100

Figure 58 - Humidity Transmitter Voltage Signal Correction



General

Object name: RA_HUM

BACnet Properties

Signal

Interpretation: Linear

Selection

Signal type: 0 - 10 V

Signal Configuration

	Signal [0 - 10] V	Output % RH
Minimum:	2	6.25
Maximum:	10	106.25

Figure 59 - Humidity Transmitter Output Correction

Alternatively, the voltage signal readings may remain the same (2 VDC/10 VDC) and the output values are corrected. This method may be required with controllers that do not allow output signal values above 10 VDC. Adding a 6.25 %RH offset to the output values (maximum and minimum %RH values) in the analog input configuration of Figure 59 also redefines the output reading produced at 5.5 VDC from 43.72 %RH to 50 %RH. Either method is valid. What is most important is that the correction be applied to both values as this essentially shifts the entire curve up or down to match the value at the calibration point. Until more calibration points are used, this is the best calibration method.

If the analog input was configured in a JACE or similar controller where scale and offset factors are used, they would be recalculated based on the values shown in Table 40 which would result in a Scale of 12.5 and an Offset of -18.75. By adding the correction to the voltages, the slope of the voltage versus humidity lines is preserved. The Scale in Table 40 is the same as the value previously calculated in Table 39 which confirms that the slope of the lines are equal.

Volts (DCV)	%RH
1.5	0
9.50	100

Updated Calculated Scale= 12.50
Updated Calculated Offset= -18.75

Table 40 - Final JACE Humidity Transmitter Analog Input Configuration (Voltage Correction)

If we now consider the output (%RH) correction, the Scale and Offset values are calculated in the exact same way. They would be recalculated based on the values shown in Table 41 which result in a Scale of 12.5 and an Offset of -18.75. Notice that the recalculated Scale and Offset values are the same as those calculated by the voltage correction (Table 40) which indicates that the corrections are equal and that the slope of the lines are equal.

Volts (DCV)	%RH
2.0	6.25
10.0	106.25

Updated Calculated Scale= 12.50
Updated Calculated Offset= -18.75

Table 41 - Final JACE Humidity Transmitter Analog Input Configuration (Output Correction)

Following the comparison of the BAS-indicated humidity to the calibrated reference reading and update of the analog input configuration, the humidity reading has been calibrated. However, because we do not know the equation of the humidity transmitter's actual characteristic curve, the accuracy of the reading may degrade as the humidity diverges from the calibration reading. We will not know how the accuracy is affected with changes in humidity level until at least two calibration points of comparison are used.

3.9.7 Analog to Digital Converter

Inside each BAS controller is an Analog to Digital Converter (ADC) which takes the analog sensor/transmitter reading and converts it to digital form. The bit level of the ADC and the signal range determine the signal resolution or the smallest increment of change that can be measured. Consult the manufacturer's data for the BAS controller to verify the bit level of the ADC. For example, an eight-bit controller can resolve a 0-10 VDC transmitter signal into 256 discrete increments resulting in 0.039 VDC per increment. If the 0-10 VDC signal represented an Air Differential Pressure Transmitter (ADPT) with a 0-10 inches W.C. range, then the smallest measurable static pressure change would be 0.04 inches W.C.

(Equation 56) $$Increments = 2^8 = 256$$

(Equation 57) $$Resolution_{Voltage} = \frac{10\ VDC}{256\ Increments} = \frac{0.039\ VDC}{Increment}$$

(Equation 58) $$Resolution_{Static\ Pressure} = \frac{10\ Inches\ W.C.}{10\ VDC} X \frac{0.039\ VDC}{Increment} = \frac{0.04\ Inches\ W.C.}{Increment}$$

This example shows that the smallest increment of change in the static pressure reading is four hundredths of an inch W.C. If the supply duct static pressure setpoint was 1.5 inches W.C., this BAS controller would be able to maintain the duct static pressure (1.5±0.04 inches W.C.) at setpoint with minimal changes in VFD speed modulation. However, if this reading was used to monitor and control space pressurization to 0.05 inches W.C., it would have serious difficulty because the smallest increment of measurable static pressure change would be much too high. The smallest increment of change is nearly 80% of the setpoint value (0.05±0.04 inches W.C.). To improve the signal resolution, an ADPT with a smaller range could be selected. If an ADPT with a 0-1 inch W.C. range were used, the smallest measurable static pressure would reduce to 0.004 inches W.C. This ADPT would have a much better chance at controlling the space pressurization (0.05±0.004 inches W.C.) than the 0-10 inch W.C. ADPT. This exemplifies the importance of matching the sensor range to the operating range of the parameter being measured and controlled.

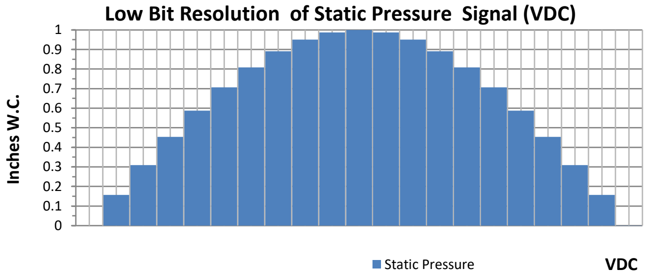


Figure 60 - Low Bit Resolution Example of an Air Differential Pressure Transmitter Signal

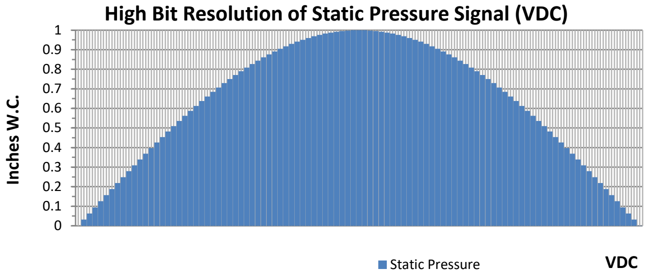


Figure 61 - High Bit Resolution Example of an Air Differential Pressure Transmitter Signal

If this eight-bit controller was upgraded to a BAS controller with a 16-bit ADC, then it would be able to resolve the analog signal into 65,536 discrete increments. As a result, the smallest change in static pressure that could be measured with a 0-10 inch W.C. ADPT would be 0.0000153 inches W.C. This would provide much better resolution resulting in a signal that very closely approximates the analog signal.

(Equation 59) $$Increments = 2^{16} = 65{,}536$$

(Equation 60) $$Resolution_{Voltage} = \frac{10\ VDC}{65{,}536\ Increments} = \frac{0.0000153\ VDC}{Increment}$$

(Equation 61) $$Resolution_{Static\ Pressure} = \frac{10\ Inch\ W.C.}{10\ VDC} X \frac{0.0000153\ VDC}{Increment} = \frac{0.0000153\ Inch\ W.C.}{Increment}$$

These examples of ADC are provided to aid the reader in understanding the operation of BAS controllers. Accuracy and stability of the reading depends not only on the accuracy of the sensor/transmitter, but also on the range of the sensor/transmitter and the bit level of the BAS controller. The following figures provide graphical examples of the differences in signal resolution as a result of the ADC bit level. Higher bit levels provide a signal that more closely resembles the analog signal provided by the sensor transmitter. This concept becomes especially important when the sensor readings are small.

3.9.8 Induced Voltages

Induced voltages can cause problems for all BAS controller inputs and outputs, but low-voltage analog inputs are especially susceptible because of the small signals that are involved. When control wires are run parallel to high-power electrical conduits it is possible for the low-power control wiring to pick up induced voltages. To complicate the matter even further, the induced voltage may be transient making them difficult to detect. Electrical conduits carrying high-power wiring cannot always be avoided, so we have to be aware of the potential for induced voltage so that it may be identified during testing and corrected. The induced voltage can sometimes be greater than the change in transmitter output signal that is monitored by the BAS controller. This, in effect, hides or masks the actual change in transmitter signal which can significantly affect control system performance.

If induced voltages are suspected, first verify that the BAS controllers and 24 VAC secondary common wires are grounded. Then disconnect the sensor wires from the BAS controller contacts, power supply, and sensor/transmitter. Measure the voltage across the wires and between each wire and ground. With no induced voltage, the measurements should yield zero voltage. Also, measure the voltage between the shield and ground. If you have any measurable voltage, it is most likely due to control wiring having been installed in close proximity of high-power conductors. Verify that the shield is grounded (if equipped). If it is not grounded, ground it to see if the signal improves or results change. Sometimes, what we suspect is induced voltage is actually EMI and grounding the shield will safely dissipate this unwanted signal. Relocation or rerouting of the controls wiring may be required to prevent induced voltages. De-energize suspected high-voltage circuits to verify which ones are creating the induced voltages.

3.10 Binary Outputs

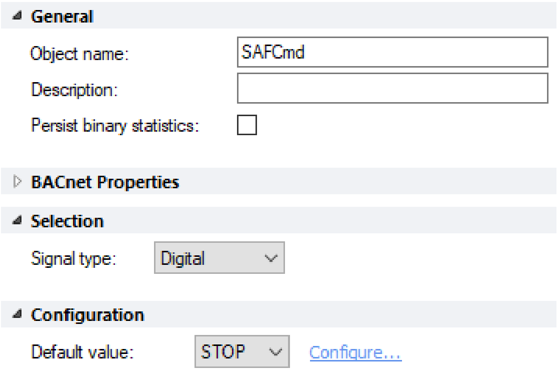
3.10.1 General

Binary Outputs (BOs) generate binary signals (contact closure or 24 VAC voltage) that are used to enable/disable equipment or to open/close valves and dampers. Binary outputs are also referred to as Digital Outputs (DOs) and these terms are used interchangeably. They are typically the end result of a series of data comparisons. Equipment controlled by binary output commands include fans, pumps, compressors, damper actuators, valve actuators, electric resistance heaters, boilers, chillers, humidifiers, etc.

Binary Output	Application	Facets/Units
Fan Start	Fan Control	Start / Stop
Pump Start	Pump Control	Start / Stop
Damper Command	Flow Control (Two-position)	Open / Close
Valve Command	Flow Control (Two-position)	Open / Close
Electric Resistance Heat Command	Perimeter/Duct Heat	Start / Stop
Heat Trace Command	Pipe Freeze Protection	Enabled / Disabled
Chiller Enable	Chiller Control	Enabled / Disabled
Boiler Enable	Boiler Control	Enabled / Disabled
Direct Expansion Compressor Enable	Temperature Control	Start / Stop
Humidifier Enable	Humidity Control	Enabled / Disabled
Variable Frequency Drive Enable	Variable Frequency Drive Control	Enabled / Disabled

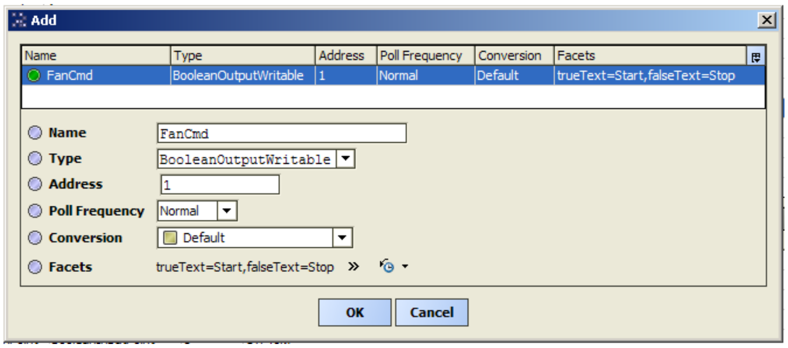
Table 42 - Examples of Equipment Controlled by Binary Outputs

The voltage and amperage of the BAS controller's binary output contacts are typically rated for 24 VAC and 500 mA. The voltage and amperage of most controlled equipment are rated for much higher values. Isolation relays are used to provide electrical isolation between the BAS controller's low-voltage binary output contacts and the control circuits of much higher potential. Isolation relays will be discussed in greater detail in Chapter 5: Relays, Contactors, and Starters.



Object name: SAFCmd
Description:
Persist binary statistics: ☐
Signal type: Digital
Default value: STOP

Figure 62 - Distech EC-GFX Binary Output Configuration



Name	Type	Address	Poll Frequency	Conversion	Facets
FanCmd	BooleanOutputWritable	1	Normal	Default	trueText=Start,falseText=Stop

Name: FanCmd
Type: BooleanOutputWritable
Address: 1
Poll Frequency: Normal
Conversion: Default
Facets: trueText=Start,falseText=Stop

Figure 63 - JACE Binary Output Configuration

The BAS controller takes its onboard data points, schedules, data points from other controllers, and setpoints and processes the programmed logic. Once a condition or set of conditions is satisfied, the binary output is enabled. Once enabled, the isolation relay's coil is energized which causes its switched output contacts to actuate to their energized state to enable and disable the controlled equipment.

3.10.2 Dry Contacts

BAS controllers have two main types of binary outputs circuits. The first type uses a set of dry contacts that are opened and closed depending on the binary output command. Therefore, a separate source of electrical power is required to power the binary output control circuits. The binary output contacts of the BAS controller, a 24 VAC transformer, and the coil of the isolation relay typically form the control circuit that controls the switched contacts of the isolation relay. The hot lead of the power source is typically connected to one of the BAS controller's binary output terminals. The common lead of the power source is typically connected to a coil terminal of the isolation relay. The common of the BAS controller and the other coil terminal of the isolation relay are connected. This circuit is completed when the BAS controller's binary output contacts close to power the coil of the isolation relay. This results in the isolation relay's switched contacts actuating to their energized state.

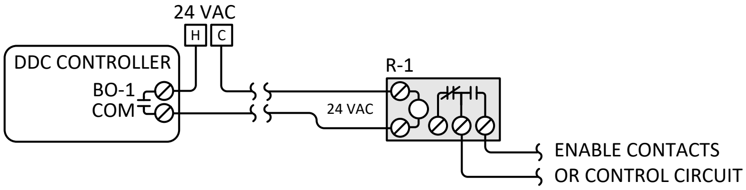


Figure 64 - Dry Contact Binary Output Wiring

3.10.3 Binary Triac Output

The second type of binary output is the triac output circuit. Binary triac outputs are solid-state relays that have no moving parts and provide high-speed current switching. They are a fully electronic form of a typical electromechanical isolation relay. As a result, their operation is completely silent. Nothing can be heard unless this binary triac circuit powers an intermediate isolation relay coil. These circuits utilize transistors to control the current flow through the binary output contacts. When used as a pair, binary triac outputs simulate the performance of an analog output with damper and valve actuators. This is typically called floating control because the position is not based on a zero reference. Its last position is the reference point or zero for the next actuator position command which is calculated based on the actuator stroke time and time of actuation. Hence, its zero or position reference floats.

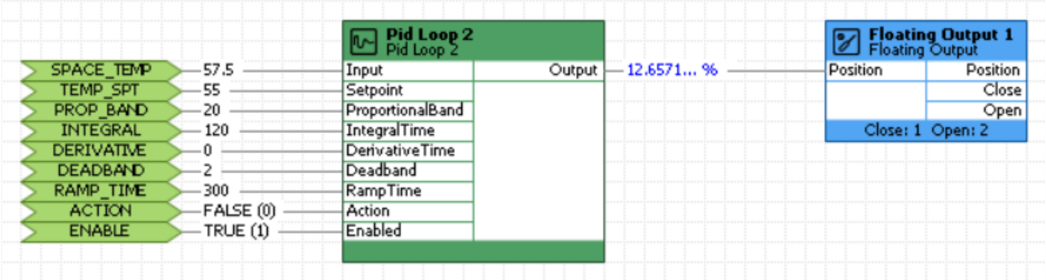


Figure 65 - Distech EC-GFX PID Loop and Floating Output

Over time, the difference between the actual position and the calculated actuator position can increase. Float synchronization resets this calculated position to improve its position accuracy by resetting the calculated position to zero. This typically occurs on change in occupancy or power cycle. The floating output block shown in Figure 65 uses binary outputs 1 and 2 to control the actuator position. Output 1 enables the actuator to move toward the closed position while binary output 2 enables the actuator to move towards the open position. If it is determined that the actuators move towards the incorrect position, the outputs can be switched in the program or the wires for binary outputs 1,2 can be switched. Either is acceptable. However, it is good practice to do the same for the entire installation to maintain consistency. The choice typically depends on whether this is a widespread issue or limited to just a few BAS controllers.

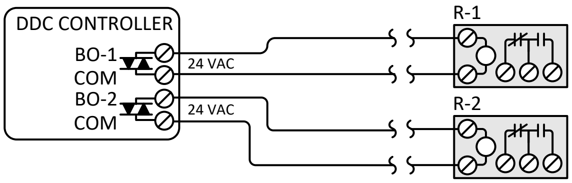


Figure 66 - Internally Powered Binary Triac Output

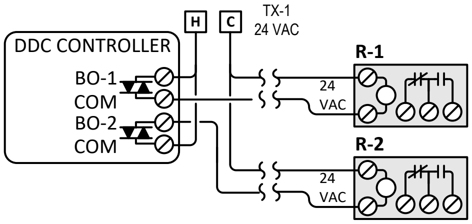


Figure 67 - Externally Powered Binary Triac Output

Binary triac outputs may be internally or externally powered. It is very important to review the manufacturer data sheets for the BAS controllers because they will differ between manufacturers and controller models. A dip switch, jumper setting, or switch determines whether the binary triac output is internally or externally powered. Alternatively, it may come as one or the other without the ability to adjust. If the triac output is configured for internal power, it will provide 24 VAC power from its own circuitry to the binary output terminals. If the binary triac output is configured for external power, then the power will come from an external (with respect to the controller) source and will pass through the binary triac contacts and the BAS controller will control the flow of current through the output contacts.

Binary outputs used for modulating control of dampers and valves are often called the "poor man's analog output" signal. Triac circuits can endure many times more on/off cycles than conventional electromechanical relays and are much more economical to produce. Many BAS controllers utilize the High-Side switching strategy to control the binary triac outputs. The binary triac output acts a gate and either allows current flow when it is enabled or prevents current flow when it is disabled. As such, the hot wire from the low-voltage transformer is connected to the common terminal of the binary output. When the binary output is enabled, it allows the current to pass from the common terminal to the binary output terminal. Figure 69 depicts the High-Side Switching strategy which controls the direction of actuator travel by energizing either the clockwise or the counter-clockwise terminals. This wiring strategy is typically applied to larger floating actuators. As you can see, four wires are required: two for power and two for control. This prevents the higher currents from flowing through the binary triac outputs. Smaller floating actuators typically used in terminal units, fan coil units, and unit ventilators will typically only utilize three wires because the current requirements are much lower (Figure 68).

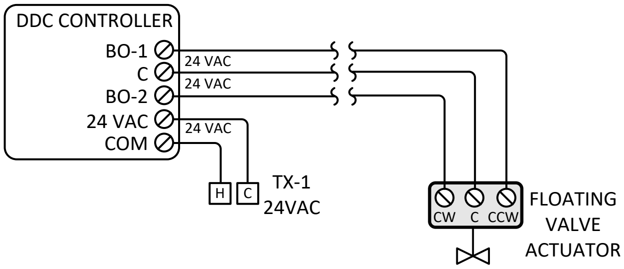


Figure 68 - Typical Terminal Unit Floating Valve Actuator Wiring

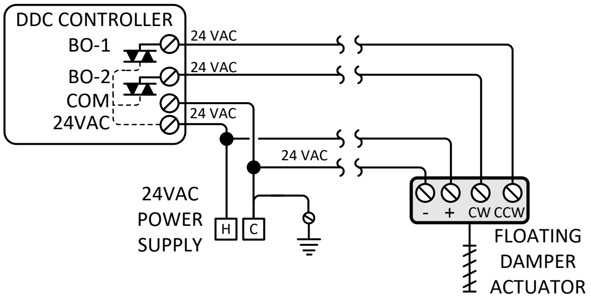
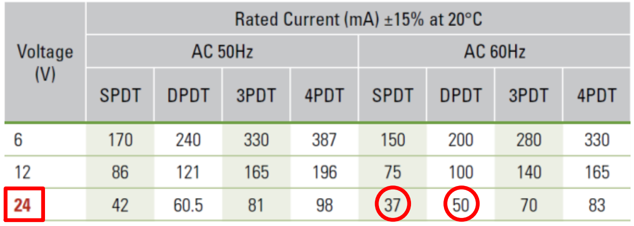


Figure 69 - Binary Triac Output (High-Side Switching) Directly Wired to Large Actuator

Binary triac circuits have strict current requirements. They require a minimum current load to operate reliably. If the minimum triac circuit amperage is not provided, they may not function at all or they may chatter if they do. Consult the BAS controller specifications to determine the acceptable current range for the binary triac outputs. If the minimum amperage rating of the binary triac circuit is 50 mA, then the current flow must be equal to or higher than this value when it is energized.



Voltage (V)	Rated Current (mA) ±15% at 20°C							
	AC 50Hz				AC 60Hz			
	SPDT	DPDT	3PDT	4PDT	SPDT	DPDT	3PDT	4PDT
6	170	240	330	387	150	200	280	330
12	86	121	165	196	75	100	140	165
24	42	60.5	81	98	37	50	70	83

Figure 70 - IDEC RH1B-UL Coil Ratings for Isolation Relays (IDEC Catalog)

The coil amperage rating for an IDEC RH1B-UL Single-Pole, Double-Throw (SPDT) relay (at 60 Hertz) operating with 24 VAC is 37 mA, so this isolation relay will not provide enough current flow (50 mA) to reliably operate the binary triac output. The coil amperage rating for an IDEC RH2B-UL Double-Pole, Double-Throw (DPDT) relay (at 60 Hertz) operating with 24 VAC is 50 mA. The Functional Devices RIBU1C isolation relay has a 24 VAC coil rating of 46 mA. With these isolation relays, the binary output triac circuit will reliably actuate the isolation relays which will, in turn, reliably control the end device or system. The need to satisfy the minimum Triac current requirement is the reason why double-pole and triple-pole isolation relays are often installed when the wiring only requires a single-pole isolation relay. You will surely observe this on older BAS controllers. The amperage readings provided in Photographs 47 & 48 agree with the manufacturer's current specifications (Figure 70). Photograph 49 shows that even when the binary triac output disabled, there is still a residual current of 1.63 mA.

Photo 47 - IDEC RH1B-UL with Binary Triac Output Energized

Photo 48 - IDEC RH2B-UL with Binary Triac Output Energized

Photo 49 - IDEC RH2B-UL with Binary Triac Output De-energized

If the triac current is too high, the triac circuit may fail catastrophically. Many controllers have a 500 mA to 800 mA maximum current rating on their binary triac outputs. As a result, replacement of the BAS controller, rewiring, configuration, programming, etc. may be required if the triac output fails and another is not available. To prevent this from occurring, some Controls Contractors install isolation relays between the actuator and BAS controller. Others will install a 1,000 Ohm 2-Watt resistor between the binary triac output terminals. These methods preclude excessive currents generated by the driven load (valve or damper actuator) from damaging the BAS controller's binary triac output circuits.

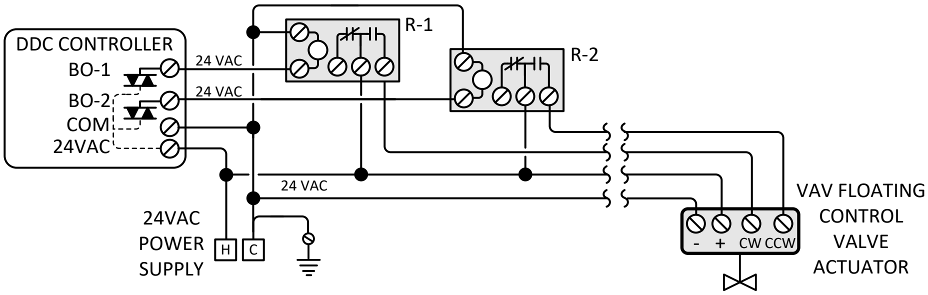


Figure 71 - Binary Triac Outputs with Isolation Relays

If there is any doubt whether the binary triac output is functioning correctly, do not bother to test it with a multimeter because it will be a waste of time. Even when the binary triac output is disabled, there is a residual voltage of 19.79 VAC across the terminals as shown in Photograph 50. This data is not helpful. Instead, connect a resistive load such as an IDEC isolation relay coil to the BAS controller's binary triac output terminals. The test isolation relay should have a coil amperage rating in excess of the binary triac circuit's minimum required current flow. Confirm this value with the BAS controller specifications. In most cases, a DPDT relay (IDEC RH2B-UL) may be used to test the operation of the binary triac outputs because it has a rated current flow of 50 mA. Enable the binary triac output and verify that it reliably actuates the switched contacts of the test isolation relay. At the same time, measure the voltage and current produced by the binary triac output circuit. Disable the binary triac output and record the same data.

Photo 50 - Testing Binary Triac Output with No Load (De-energized)

Photo 51 - Testing Binary Triac Output with DPDT Relay (Energized)

Photo 52 - Testing Binary Triac Output with DPDT Relay (De-energized)

If the binary triac output is unable to actuate the relay's switched contacts or they chatter, then it very likely has been damaged. Binary triac outputs tend to fail in the on state rendering them unable to stop current flow to the load (typically a relay or actuator). When a functioning binary triac output circuit is disabled, the switched contacts of the test relay should return to their normal position. If the binary triac output is unable to consistently actuate the isolation relay's switched contacts, select another binary triac output (if available). Test the new binary triac output with the test isolation relay to verify its operation prior to connecting the actuator or isolation relay.

3.10.4 Binary Output Control Logic

Schedules, setpoints, control logic, and manual overrides typically dictate the operation of binary outputs. Binary outputs enable or disable HVAC systems and components thereof. For example, consider an electric resistance unit heater in an equipment storage room. Space temperature is typically utilized to determine when the unit heater operates. The control programming will resemble following diagram. The room temperature is compared to the space temperature setpoint. The binary output will not be enabled until the zone temperature drops to 60°F. Once enabled, the unit heater will be enabled until the space temperature reaches 63°F (as indicated by the 3°F differential). In this example, a 3°F differential is used to prevent short-cycling of the heater.

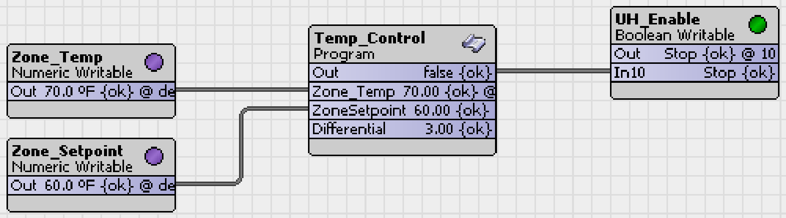


Figure 72 - Unit Heater Binary Output Control Logic Example

Air-handling units typically have several variables to consider before making the decision to enable its fan command. Operation of the air-handling unit may also be required during the unoccupied period if the occupancy override is activated or if the space temperature exceeds the unoccupied setpoints (night cycle). The control logic shown below indicates that if any of the occupancy status, night cycle status, or occupancy override status points are enabled and the low-temperature detector (LTD) and smoke detector status points are in their normal state, then the fan command will be enabled. Safety devices (smoke detector, freezestats, high static safety switches, etc.) are typically hard-wire interlocked to the motor starter or VFD to disable the supply fan should any of them actuate. In addition, they are often interlocked or at least monitored through software so that the operator will know what is preventing the air-handling unit from operating and thus know how to respond.

Some enable decisions require that several conditions be true before proceeding. To confirm these conditions, AND statements or logic blocks are utilized. The output of the AND statement or logic block is only true when all input conditions are true. Other enable decisions require only one of several conditions to be true to enable the binary output and this is where an OR statement or logic block is utilized. If any of the inputs are true, then the output of the OR statement or logic block will be true. The NOT block is used to negate or make opposite the monitored state. The supply fan enable point (binary output) will not be enabled until all prerequisite conditions dictated by the AND, OR, and NOT blocks are satisfied.

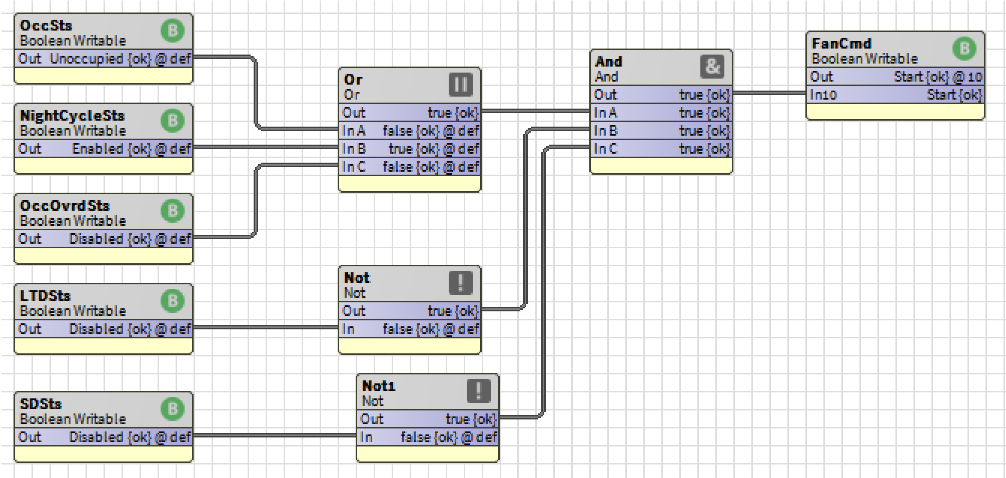


Figure 73 - Air-Handling Unit Binary Output Control Logic Example

3.10.5 Multiple Relays to Implement Binary Output Control

The isolation relays used to enable the controlled equipment are typically installed adjacent to the equipment or nearby electrical enclosure. When the controlled equipment is not within sight of the BAS controller (another room or floor), an additional relay is often installed in the local control panel. This additional panel-mounted isolation relay provides electrical isolation in case a high-power electrical source is inadvertently connected to the low-voltage control wiring and also provides visual confirmation (by LED status indicator) that the binary output is enabled. This first panel-mounted relay is typically an IDEC RH Series power relay because it is compact, has LED status indication, and is DIN rail-mountable.

When the BAS controller enables the binary output, it energizes the coil of the panel-mounted isolation relay causing its switched contacts to actuate which, in turn, energizes the coil of the second field-mounted interlocking isolation relay causing its output contacts to actuate to enable or disable the remote equipment. The interlocking isolation relay is located at or nearby the controlled equipment on or in an electrical enclosure and is typically a Functional Devices, Inc. model RIBU1C, RIBU1S, or similar device. The second field isolation relay may be installed outdoors to control the motor starter or VFD of roof-mounted exhaust fans, condensing units, rooftop air-handling units, or cooling towers. National Electrical Manufacturers Association which specifies the protection levels required by electrical enclosures based on their use, mechanical damage risk, expected moisture level, and location. Most components installed outdoors will have a NEMA rating. The RIBU1C-N4 is often used because it is constructed to NEMA 4X standards to withstand the potentially moist/wet environment.

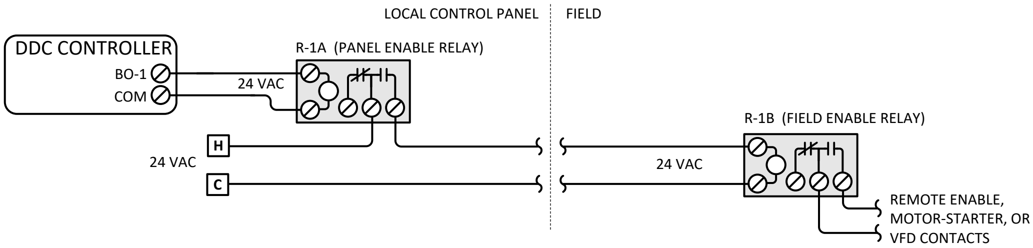


Figure 74 - Panel Relay Driving a Field Relay (Binary Triac Output)

If the BAS controller's binary outputs happen to be the dry contact type, this will require the inclusion of a voltage source in the binary output control circuit. The voltage to drive the isolation relays could come from the BAS controller terminals or a separate low-voltage transformer depending on how the VA loads have been distributed among the low-voltage power supplies.

Some Controls Contractors choose to use two isolation relays (panel and field) no matter what the distance as a standard. Relays are cheap insurance against damaging the BAS controller's binary outputs which may require BAS controller replacement, reprogramming, downtime, etc. if the incorrect voltage is applied. This may require a small increase in material and installation cost, but the reduction in troubleshooting time and risk is typically well worth the cost of the additional relays.

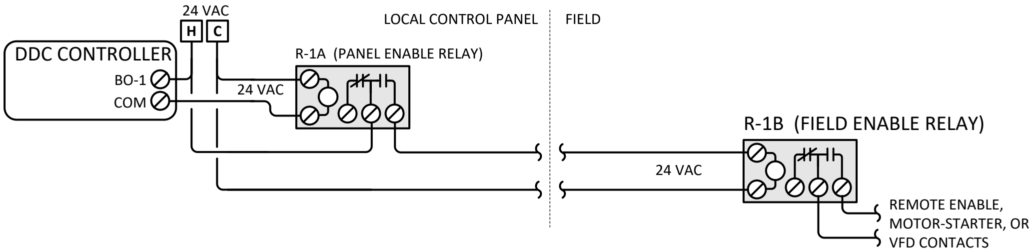


Figure 75 - Panel Relay Driving a Field Relay (Dry Contact Output)

The last variation of the binary output that may be observed in the field is the use of the multi-pole isolation relays to enable two or more devices. This is typically applied to supply and exhaust fan of an energy recovery ventilator or supply and return fans in an air-handling unit. Because these fans typically energize at the same time, a common enable command may be utilized for both fans. The binary output of the BAS controller enables and energizes the coil of the fan enable isolation relay (R-1). Its switched contacts send power to the coil of the remote interlocking relays (R-2,3) at the supply and exhaust fan motor starters and/or VFD enclosures. This wiring configuration saves binary outputs for control of other devices. Additional control logic may be required to disable the fan command if the operating status of either fan is lost. Without an operational supply fan, the return fan in an air-handling unit becomes an exhaust fan which will negatively pressurize the space. Hard-wired interlocking may also be used to prevent this situation.

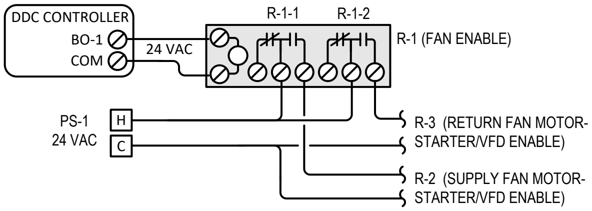


Figure 76 - Binary Triac Output Enables Two Fans Simultaneously

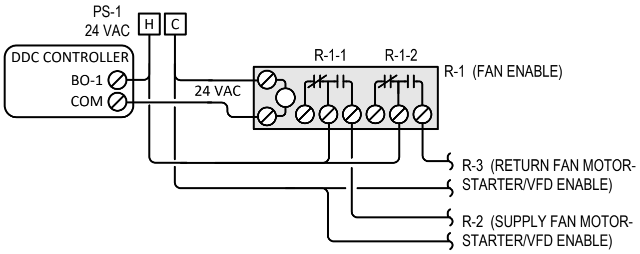


Figure 77 - Binary Dry Contact Output Enables Two Fans Simultaneously

3.10.6 Binary Output Device Calibration

Binary outputs are generated by the BAS controller for binary control of external components and systems. The binary output of the BAS controller is typically connected to an isolation relay whose switched contacts are wired to either the controlled equipment or an intermediate isolation relay. Calibration of binary outputs typically consists of verifying that the controlled isolation relays and/or controlled circuit or system correctly responds to changes in the command. Typically, only voltage and milliamp current measurements are required.

BO #	Point		State	BAS Command	Relay LED	Relay Contacts	Equipment State
1	SAFEnable		State 0	Stop	Off	Open	Off
			State 1	Start	On	Closed	On

Table 43 - Binary Output Device Calibration Results Example

3.11 Analog Outputs

3.11.1 General

After receiving, interpreting, and processing the input data, the BAS controller generates Analog Output (AO) signals to control modulating end devices such as valve and damper actuators, VFDs (speed), digital scroll compressors, electric resistance heaters, Electric-to-Pneumatic Transducers (EPTs), etc. This analog output signal may also terminate at equipment equipped with its own controls that use it to control one aspect of its operation. For example, Variable Frequency Drives (VFDs), boilers, and chillers are examples of equipment that utilize a remote analog signal to control either its output capacity or setpoint. The following table provides a summary of typical equipment that utilizes analog output signals from a BAS controller to control aspects of its operation.

Analog Output	Range	Percent Output					Units/Facets
		0%	25%	50%	75%	100%	
Control Damper Actuator	0-100	0	25	50	75	100	% Open
Control Valve Actuator	0-100	0	25	50	75	100	% Open

Analog Output	Range	Percent Output					Units/Facets
		0%	25%	50%	75%	100%	
VFD Speed	0-100	0	25	50	75	100	% Output
SCR Heat Output	0-100	0	25	50	75	100	% Output
Boiler Output	0-100	0	25	50	75	100	% Output or Setpoint
Chiller Output	0-100	0	25	50	75	100	% Output or Setpoint
Humidifier Output	0-100	0	25	50	75	100	% Output or Setpoint
Electric-to-Pneumatic Transducer	0-15	0	3.75	7.5	11.25	15	PSIG
BAS Controller Output #1	0-10	0	2.5	5	7.5	10	Volts DC
BAS Controller Output #2	2-10	2	4	6	8	10	Volts DC
BAS Controller Output #3	0-5	0	1.25	2.5	3.75	5	Volts DC
BAS Controller Output #4	1-5	1	2	3	4	5	Volts DC
BAS Controller Output #5	4-20	4	8	12	16	20	mA

Table 44 - Typical Analog Output Device and Signal Examples

Analog output signals are typically calculated by Proportional-Integral-Derivative (PID) control loops that maintain the process variable (temperature, static pressure, humidity, carbon dioxide concentration, etc.) at setpoint. In other words, they function to minimize the error between the process variable and the setpoint. PID loops will be discussed in greater detail later in this chapter. The following figure illustrates the signal conversion of a typical analog output.

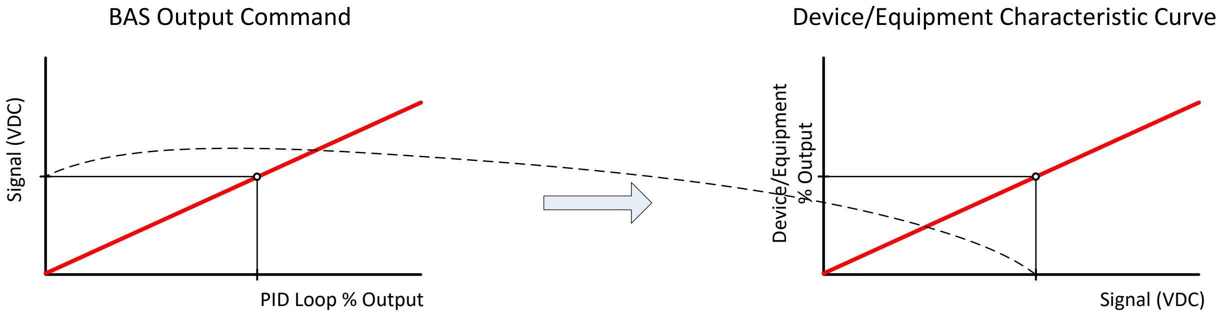


Figure 78 - BAS Analog Output and Device/Equipment Characteristic Curves (Output Signal)

The BAS calculates the required output command that is expressed in terms of percent output capacity, actuator position, or setpoint. This output command may control the position of a damper or valve, the speed of a VFD, or output capacity of a chiller, boiler, or humidifier. Therefore, the analog outputs of the BAS controller must be configured to produce an analog voltage signal (typically 0-10 VDC, 2-10 VDC, 0-5 VDC or 1-5 VDC) that corresponds to the calculated output command. The controlled equipment is then reviewed to verify that the voltage signal from the BAS controller is properly received and interpreted. This verification typically consists of setting the output command to several standard increments (typically 0%, 25%, 50%, 75%, and 100%) and verifying that the correct signals arrive at the controlled equipment and that it produces the correct response.

3.11.2 Analog Output Configuration

The PID loops calculate the valve and damper positions as well as equipment (boilers, chillers, VFDs, etc.) capacities required to maintain their respective process variables at setpoint. The position or capacity signals are converted to voltage signals for use by the controlled equipment. For example, a 0-100% open damper command is commonly implemented with a 2-10 VDC control signal from the BAS controller. Just as the analog inputs are configured to properly interpret the voltage and current signals from analog input devices, the signals generated by the BAS analog outputs must exactly match the signal type and range of the controlled devices or equipment.

Reading	Device Output (%)	Analog Output Signal (VDC)
Minimum	0	2
Maximum	100	10

Table 45 - Initial Output Configuration

In most cases, analog outputs are configured for either 0-10 VDC or 2-10 VDC signal ranges as show in the following figure. Occasionally, an odd signal range (1-5 VDC, 0-5 VDC, or other) is required by some pieces of equipment. Most actuators have the ability to select from several control signal ranges depending on wiring, terminals, or selector switch settings. There is often confusion at the lower end of the analog output signal range for control valve and damper actuators. When control actuators are configured for 0-10 VDC and the BAS controller analog output is configured for 2-10 VDC, the actuator will always be at least 20% open. When control actuators are configured for 2-10 VDC and the BAS controller analog output is configured for 0-10 VDC, the actuator will not move until the command reaches at least 20% open. These configuration errors are corrected during the calibration process.

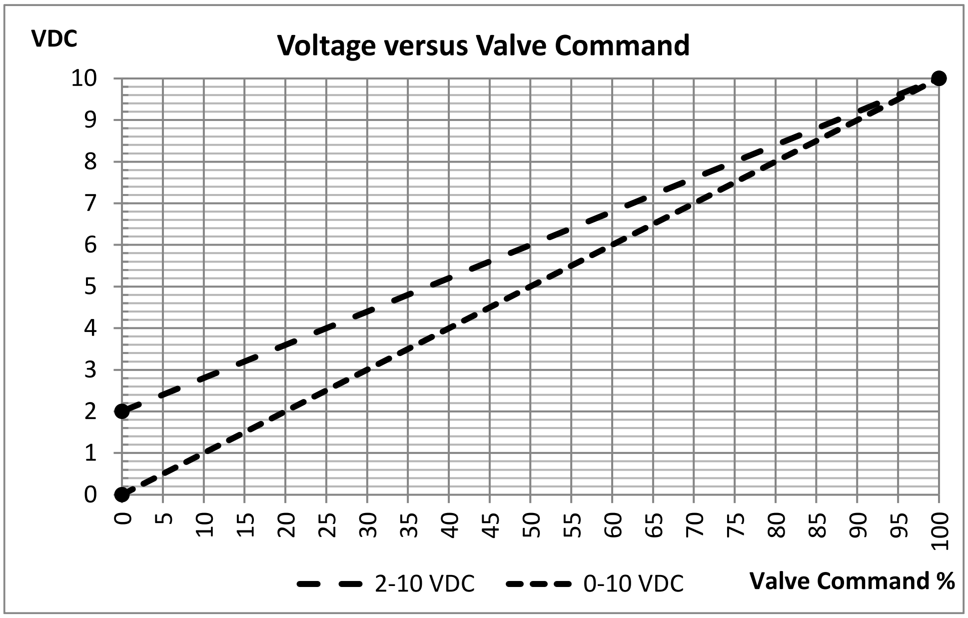
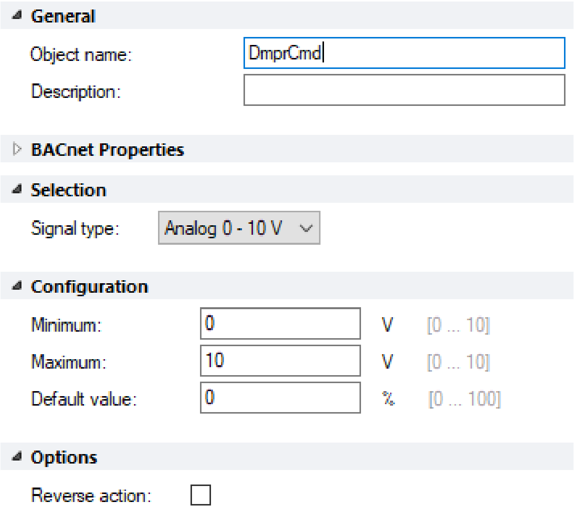


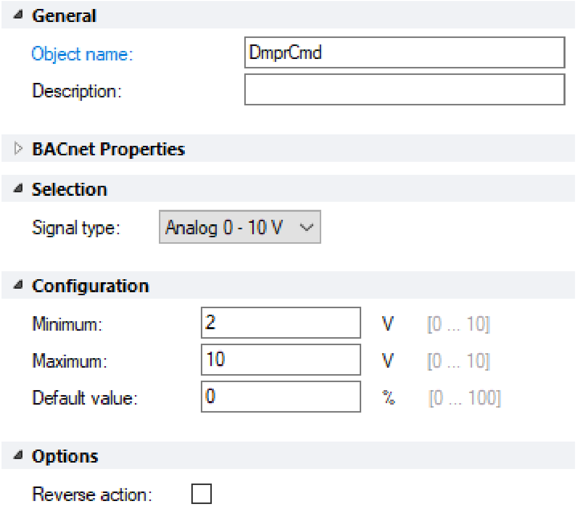
Figure 79 - Typical Analog Output Signals

The following figures show the analog output configurations for a Distech controller. One analog output is configured to provide a 0-10 VDC signal to an outdoor air damper actuator while the other is configured to provide a 2-10 VDC signal. The analog output is configured to provide these voltage signals to the damper assembly as the cooling demand (as indicated by the cooling PID loop) changes. Recall that the PID loops generate valve, damper, output capacity, and speed commands based on the error signal, so the analog output is configured internally to provide the translation between calculated commands and output voltages.



General
Object name: DmprCmd
Description:
BACnet Properties
Selection
Signal type: Analog 0 - 10 V
Configuration
Minimum: 0 V [0 ... 10]
Maximum: 10 V [0 ... 10]
Default value: 0 % [0 ... 100]
Options
Reverse action: ☐

Figure 80 - Distech EC-GFX 0-10 VDC Analog Output Configuration



General
Object name: DmprCmd
Description:
BACnet Properties
Selection
Signal type: Analog 0 - 10 V
Configuration
Minimum: 2 V [0 ... 10]
Maximum: 10 V [0 ... 10]
Default value: 0 % [0 ... 100]
Options
Reverse action: ☐

Figure 81 - Distech EC-GFX 2-10 VDC Analog Output Configuration

Like analog inputs, the configuration of the analog outputs for a JACE controller is defined by the entry of Scale and Offset values. The JACE uses the programmed signal range (0-10 VDC, 2-10 VDC, 0-5 VDC, 1-5 VDC, etc.) as the output signal by default. The Scale and Offset values are used to calculate the corresponding percent output (%) command which is more readily understood than the voltage signal. The output value displayed on the BAS graphics is typically the command in terms of % output (not control signal). This explains why the voltage signal (VDC) is the independent variable and the percent output is the dependent variable. Scale or m (also referred to as the Slope) is defined as the slope of the line and represents the change in the dependent variable ($\%_{\text{Output}}$) to the change in the independent variable (VDC). Offset is equivalent to the b value or "Y-Intercept" and represents the value of output command ($\%_{\text{Output}}$) when the analog output signal (VDC) is equal to zero.

$$\%_{Output} = m * VDC + b \qquad \text{(Equation 62)}$$

The scale is multiplied by the independent variable (VDC). Using the analog output parameters provided in Table 45, the scale is calculated as follows:

$$Scale = m = \frac{Rise}{Run} = \frac{Change\ in\ \%_{Output}}{Change\ in\ VDC} \qquad \text{(Equation 63)}$$

$$Scale = m = \frac{100\ \%_{Output} - 0\ \%_{Output}}{10\ VDC - 2 VDC} = \frac{100\ \%_{Output}}{8\ VDC} = 12.5\frac{\%_{Output}}{VDC} \qquad \text{(Equation 64)}$$

Once the slope of the line (m) or Scale has been determined, we solve for b or the offset. To do this, we substitute one of the known combinations of data points (100 $\%_{\text{Output}}$ at 10 VDC or 0 $\%_{\text{Output}}$ at 2 VDC) into the equation. It does not matter which point is chosen because the answer will be the same. We solve for the offset as follows:

$$(100\ \%_{Output}) = 12.5\frac{\%_{Output}}{VDC} * (10\ VDC) + b \qquad \text{(Equation 65)}$$

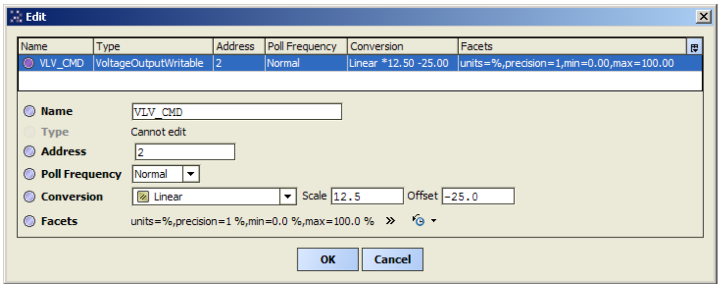
$$100\ \%_{Output} = 125\ \%_{Output} + b \qquad \text{(Equation 66)}$$

$$100\ \%_{Output} - 125\ \%_{Output} = 125\ \%_{Output} - 125\ \%_{Output} + b \qquad \text{(Equation 67)}$$

$$b = Offset = -25\ \%_{Output} \qquad \text{(Equation 68)}$$

Therefore, using the analog output configuration provided in Table 45, the equation of the line which represents the percent output command ($\%_{\text{Output}}$) based on the voltage signal (VDC) is as follows:

$$\%_{Output} = 12.5\frac{\%_{Output}}{VDC} * \text{VDC} - 25 \qquad \text{(Equation 69)}$$



Name	Type	Address	Poll Frequency	Conversion	Facets
VLV_CMD	VoltageOutputWritable	2	Normal	Linear *12.50 -25.00	units=%,precision=1,min=0.00,max=100.00

Name: VLV_CMD
Type: Cannot edit
Address: 2
Poll Frequency: Normal
Conversion: Linear Scale 12.5 Offset -25.0
Facets: units=%,precision=1 %,min=0.0 %,max=100.0 %

Figure 82 - JACE Controller 2-10 VDC Analog Output Configuration

With both the Scale and Offset calculated, these values can then be entered into the analog output configuration of the JACE controller. Most Control Technicians and programmers use a spreadsheet to quickly calculate the Scale and Offset parameters based on the analog output parameters.

Reading	Device Output (%)	Analog Output Signal (VDC)
Minimum	0	0
Maximum	100	10

Table 46 - Initial Output Configuration

When the analog output signal range starts at zero, as opposed to 1 VDC, 2 VDC, or 4 mA, or any other non-zero value, the calculation of Scale and Offset values is simplified. Following the same process outlined above, the Scale will simply be the maximum value of the output command divided by the maximum value of the control signal range. The Scale would be 10% Output/VDC and the Offset will be zero.

(Equation 70) $$\%_{Output} = m * VDC + b$$

(Equation 71) $$Scale = m = \frac{100\ \%_{Output} - 0\ \%_{Output}}{10\ VDC - 0VDC} = \frac{100\ \%_{Output}}{10\ VDC} = 10\frac{\%_{Output}}{VDC}$$

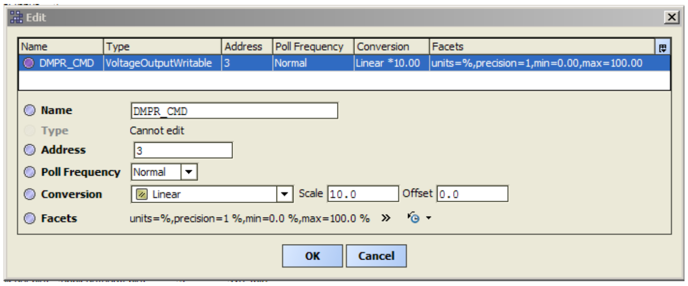
(Equation 72) $$(100\ \%_{Output}) = 10\frac{\%_{Output}}{VDC} * (10\ VDC) + b$$

(Equation 73) $$100\ \%_{Output} = 100\ \%_{Output} + b$$

(Equation 74) $$100\ \%_{Output} - 100\ \%_{Output} = 100\ \%_{Output} - 100\ \%_{Output} + b$$

(Equation 75) $$b = Offset = 0\ \%_{Output}$$

(Equation 76) $$\%_{Output} = 10 * VDC$$



Name	Type	Address	Poll Frequency	Conversion	Facets
DMPR_CMD	VoltageOutputWritable	3	Normal	Linear *10.00	units=%,precision=1,min=0.00,max=100.00

○ Name: DMPR_CMD
Type: Cannot edit
○ Address: 3
○ Poll Frequency: Normal
○ Conversion: Linear Scale 10.0 Offset 0.0
○ Facets: units=%,precision=1 %,min=0.0 %,max=100.0 %

Figure 83 - JACE Controller 0-10 VDC Analog Output Configuration

In other words, the equation of the line that provides the calculated %Output from the commanded control signal (voltage or amperage) passes through the origin of the graph (0 %Output, 0 VDC). After enough repetition, most Control Technicians can calculate or commit to memory the Scale and Offset factors required for a variety of sensor transmitters that they typically encounter.

3.11.3 Analog Output Device Calibration

An analog output signal (0-10 VDC, 0-5 VDC, 2-10 VDC, etc.) is generated by the BAS controller that is proportional to the PID loop output (damper position, valve position, VFD speed, etc.) controlling the process variable. In addition, the device or equipment receiving the BAS analog output signal must correctly interpret the control signal. Calibration of analog outputs typically requires that the calculated output command be overridden incrementally (typically 0%, 25%, 50%, 75%, and 100%). We then verify that the analog voltage signal is correctly generated, that it matches the analog signal expected by the controlled device/equipment, and that the signal is correctly interpreted and executed by the controlled device. The voltage signal at each increment can be verified with a multimeter and the response can be verified by observation of the device/equipment operation.

Calculated Command (%)	Output Voltage (VDC)	Device/Equip. Response (%)
0	2.0	0
25	4.0	25
50	6.0	50
75	8.0	75
100	10.0	100

Table 47 - Analog Output Calibration Readings

3.11.4 Proportional, Integral, Derivative Controller

Proportional-Integral-Derivative (PID) controllers, commonly called PID loops, are the most prevalent feedback (or closed loop) control algorithms in the world. Their only function is to calculate the signal that minimizes the Error which is defined as the difference between the Process Variable and Setpoint (Equation 77). By doing so, it maintains the process variable (feedback signal) at the desired setpoint. Process variable is the term commonly used to describe the parameter (temperature, humidity, carbon dioxide, etc.) that is controlled. Each PID loop controls a single process variable. PID control loops are configured by Proportional, Integral, and Derivative constants which control how they responds to the error. Their only function is to minimize the error signal.

(Equation 77) $$Error = Process\ Variable - Setpoint$$

Cruise control is a common closed loop controller or PID loop that most of us have used. Most vehicles are equipped with cruise control which maintains the vehicle's speed at the desired speed setting by controlling the engine output. While on flat land, the PID loop arrives at a throttle position that maintains the vehicles speed at setpoint. As we start to climb a hill, the vehicle's speed drops due to the increased incline. As a result, the PID loop controller increases the engine output to maintain the speed at the setpoint. As we approach the crest of the hill, the inclination decreases requiring less engine power to maintain speed. Therefore, the engine's power output is reduced, as required, to maintain the speed setting. Cruise control efficiently and effectively controls the speed of the vehicle resulting in increased fuel economy when compared to manual control of the vehicle speed.

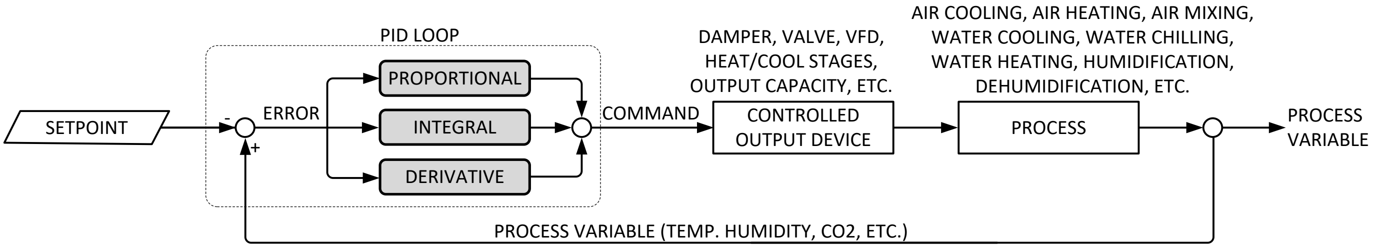


Figure 84 - Closed Loop PID Controller Schematic

The PID loop has the process variable (temperature, pressure, humidity, carbon dioxide, etc.) and setpoint as its main input data. Each PID loop is also configured with Proportional, Integral, and Derivative constants which determine how the output signal is calculated. At fixed time intervals defined in the PID controller, it calculates the output signal required to maintain the process variable at setpoint. Commissioning BAS components does not require an in-depth knowledge of PID control theory, but it is beneficial to recognize the source of the analog output signals and its appropriate behavior. This understanding helps us to recognize when the driven device (valve, damper, VFD, etc.) is not functioning correctly.

As the name implies, the PID loop control signal is composed of three components: Proportional, Integral, and the Derivative. Each controls a distinct aspect of the calculated response. The Proportional constant of the PID loop generates a signal that is proportional to the magnitude of the current error signal. The Integral time controls how much the PID loop responds to the error signal with respect to time. It impacts the steady-state error and works to minimize the offset that would exist if we only used proportional control. The integral component of the response accumulates over time and causes wind-up if the PID loop response is unable to produce a change in its process variable. Wind-up occurs when control actuators fail and when the system conditions (under sized coil, low flow, overloading, etc.) make it impossible for the PID loop to change the process variable. As a result, the integral correction continues to accumulate or "wind up" to a value that is so high that when the actuator is finally able to resume control, the PID loop command does not change. The Derivative constant affects how much the PID loop responds to the rate of change in the error signal. The derivative constant is not typically used in HVAC applications, but it may be used in steam and high-temperature, hot-water heating applications where the process variable can change very rapidly due to the intense energy available in these systems.

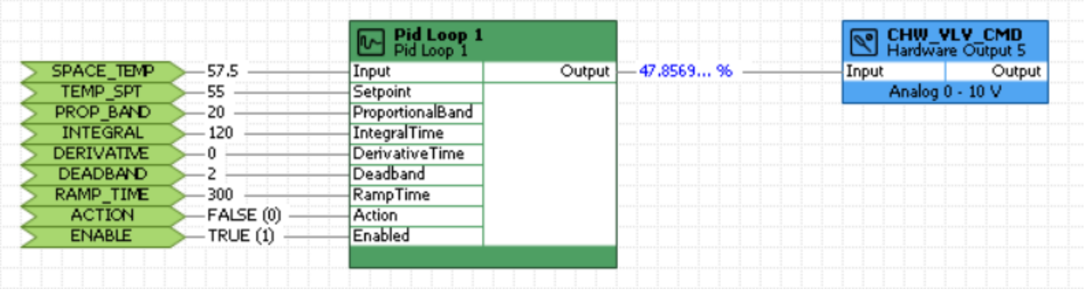
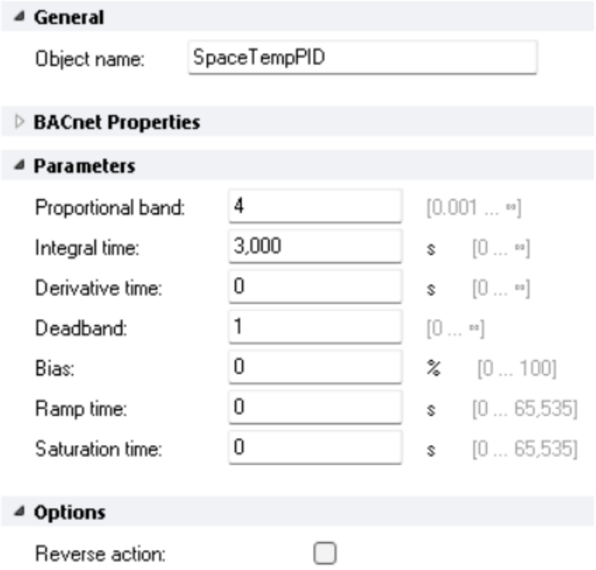


Figure 85 - Graphic of a Typical PID Controller

Instead of the proportional constant, the Distech EC GFX software uses the Proportional Band. It is another way to express the effect of the proportional constant. The Proportional Band is equivalent to the error that drives the PID loop output from 0% to 100%. The Proportional Band for space temperature control might be 2°F -6°F while the Proportional Band for discharge temperature control might be 10°F to 40°F. For example, in space temperature control PID loop, we might see a proportional band of 4°F. This means that when the error (difference between setpoint and space temperature) reaches 4°F, the PID loop will provide the controlled device with a 100% output signal. The proportional constant is related to the Proportional Band by the following equation.

(Equation 78) $$\text{Proportional Constant} = \frac{100}{Proportional\ Band}$$

In normal HVAC applications, it is typically only necessary to adjust the proportional band and integral time of the PID loop to achieve stable control of the process variable. For simplicity, the proportional response can be through of as the "push" or the initial effort to get the process variable moving in the right direction. The force of the push is proportional to the error value. The integral response can be thought of as the "nudge" that makes minor course corrections based on the amount of time that the error has existed (area below/above the performance curve). The nudges can be more or less forceful/frequent depending on the integral time setting. The derivative constant can be thought of as the "shove" as it looks at rate of change in the error and makes more drastic changes to the PID loop output to minimize overshoot. As previously stated, the derivative constant is seldom used in comfort conditioning applications (Figures 86 & 87).

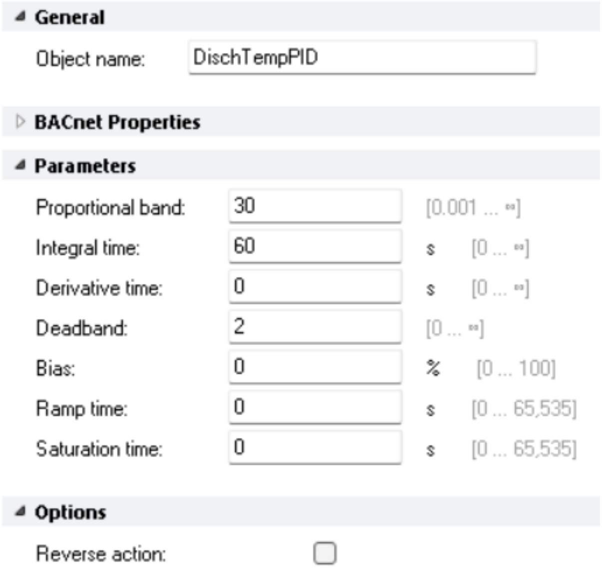


Object name: SpaceTempPID

Parameter	Value	Unit	Range
Proportional band:	4		[0.001 ... ∞]
Integral time:	3,000	s	[0 ... ∞]
Derivative time:	0	s	[0 ... ∞]
Deadband:	1		[0 ... ∞]
Bias:	0	%	[0 ... 100]
Ramp time:	0	s	[0 ... 65,535]
Saturation time:	0	s	[0 ... 65,535]

Reverse action: ☐

Figure 86 - Distech EC-gfx Space Temperature Control PID Loop Parameters (Slow Process)



Object name: DischTempPID

Parameter	Value	Unit	Range
Proportional band:	30		[0.001 ... ∞]
Integral time:	60	s	[0 ... ∞]
Derivative time:	0	s	[0 ... ∞]
Deadband:	2		[0 ... ∞]
Bias:	0	%	[0 ... 100]
Ramp time:	0	s	[0 ... 65,535]
Saturation time:	0	s	[0 ... 65,535]

Reverse action: ☐

Figure 87 - Distech EC-gfx Discharge Air Temperature Control PID Loop Parameters (Fast Process)

For example, the temperature of a room is controlled by modulating the flow of hot water through a control valve. The room is currently at 65°F and the setpoint is 70°F. The room temperature control PID loop will calculate a proportional response and an integral response and the sum of these commands is supplied to the hot water control valve actuator to raise the room temperature. Initially, there is only a proportional response and the integral response begins to accumulate. As the hot water control valve opens, it delivers heated air to the space and after some time, the space temperature begins to rise. As the temperature rises toward setpoint, the proportional response gets smaller and smaller. The integral response continues to accumulate, but at a rate that reduces as the space temperature approaches setpoint. When the space temperature reaches the temperature setpoint, the proportional response goes to zero, but the accumulated integral response is still active. As a result, the control valve remains open and heat continues to be delivered to the space. As a result, the space temperature continues to rise. As the space temperature exceeds setpoint, the proportional and the integral response begins to subtract from the accumulated PID loop signal modulating the control valve towards the closed position. The temperature begins to reduce and the temperature may undershoot the setpoint. Depending on the observed performance, adjustments of the proportional band and integral time may be required to achieve satisfactory control of the process variable. Achieving setpoint in a "reasonable" amount of time is the goal. This adjustment process is known as "Tuning" of the PID loop. Once the PID loop is tuned, it will be able to maintain the process variable at setpoint in a timely, stable, and accurate manner.

3.11.5 PID Loop Action

Consider a two-pipe hydronic system where unit ventilators are supplied with either chilled water or hot water depending on the season. When the central plant is in heating mode, hot water flows through the dual-temperature hydronic system. The control valves open to increase hot water flow through the dual-temperature coil of the unit ventilators as the space or discharge air temperature drops below setpoint. Consequently, this heating PID loop would be configured as reverse acting. Alternatively, consider the same scenario during cooling operation. As the space or discharge temperature exceeds setpoint, the control valve opens to increase the flow of chilled water through the dual-temperature coils. This cooling PID loop would be configured as direct acting. It is not uncommon to find PID loops with incorrectly defined output actions. It is easily corrected, once it is identified. A quick review of the setpoint, process variable (temperature, pressure, carbon dioxide concentration, humidity, etc.), and analog output command (valve actuator, damper actuator, VFD command) will typically reveal this issue. The following table provides examples of processes and their corresponding PID loop actions. For the application described above, two PID loops are required to control the dual-temperature control valve because the required valve actions are different and the P and I constants are typically different for heating and cooling control.

Device	Application	Action
Dual-Temperature Control Valve	Space Temperature Control (Heating)	Reverse-Acting
Dual-Temperature Control Valve	Space Temperature Control (Cooling)	Direct-Acting
Hot Water Control Valve	Discharge/Space Temperature Control (Heating)	Reverse-Acting
Chilled Water Control Valve	Discharge/Space Temperature Control (Cooling)	Direct-Acting
Chilled/Hot Water Control Valve	Minimum Flow Control	Reverse-Acting
Steam Control Valve	Space Heating	Reverse-Acting
Steam Control Valve	Space Humidification	Reverse-Acting
Control Damper	Space Temperature Control (Heating)	Reverse-Acting
Control Damper	Space Temperature Control (Cooling)	Direct-Acting
Outdoor Air Control Damper	Economizer Control (Cooling)	Direct-Acting
Outdoor Air Control Damper	Carbon Dioxide Control	Direct-Acting
SCR Electric Resistance Heater	Discharge/Space Temperature Control (Heating)	Reverse-Acting
Variable Frequency Drive	Cooling Tower Fan Speed Control	Direct-Acting
Variable Frequency Drive	Supply Duct Static Pressure Control	Reverse-Acting
Variable Frequency Drive	Hydronic Differential Pressure Control	Reverse-Acting

Table 48 - PID Loop Action

3.11.6 PID Loop Deadband

The deadband defines a range of process variable values where adjustment of the controlled device (damper/valve actuator, chiller, boiler, humidifier, variable frequency drive, etc.) is not required. In other words, if the process variable is within the deadband, the PID loop output is held constant. As a result, the controlled device remains at its current operating output (speed, position, capacity, etc.). When the process variable exceeds the deadband, the PID loop output resumes operation. For comfort cooling, it is not necessary for a central air-handling unit to provide exactly 55°F supply air. Anywhere from 53°F to 57°F is typically acceptable, so the controlling PID loop would typically have a deadband of 1°F to 4°F centered on the setpoint value. Start with something reasonable and adjust as required. Without a deadband, the controlled device will constantly make minute adjustments to the position, speed, or output command which will cause wear and shorten its service life.

3.11.7 PID Loop Ramp Time

Ramp time comes into effect only when the PID loop is initially enabled. Most air-handling unit PID loops are enabled when the supply air fan status has been proven. Likewise, most temperature and pressure control PID loops are enabled when the status of pumps and compressors are proven. If fan status is lost, the PID loops that depend on its status are disabled and their output goes to zero. On startup, most supply air fans with speed control are controlled to ramp up at a controlled, slow rate. This is typically accomplished with the Ramp Time parameter of the PID loop. In colder climates, the PID loop controlling the outdoor air dampers are commonly opened at a very slow rate. It is not uncommon to see ramp times of 10-30 minutes (600 seconds to 1,800 seconds) on outdoor air damper PID loops. This ensures that on start up the preheat coil control valve will have ample time to adjust to the outdoor air heating load thus preventing nuisance trips of the Low-Temperature Detector (Freezestat).

3.11.8 PID Loop Tuning

Understanding the HVAC process that is controlled is key to properly tuning the PID loop parameters. For example, the

PID loop parameters for the control of fast processes such as discharge air temperature, pre-heat coil discharge air temperature control, cooling coil discharge air temperature, and mixed-air low-limit control of an air-handling unit are different from the PID loop parameters for much slower processes like space temperature control, return air humidity control, and demand-controlled ventilation because the amount of time required to see a measurable change in the process variable per unit change in output signal is significantly higher.

Prior to tuning any PID loops, it is also important that the controlled output device be reviewed to determine that it has full control across its operating range. For example, an Electric-to-Pneumatic Transducer (EPT) may control the pneumatic pressure between 0-15 PSIG. However, if the connected pneumatic actuator only actuates between 3-8 PSIG, then there is a significant amount of control signal (0-3 PSIG and 8-15 PSIG) in which the commanded pressure change does not produce a corresponding process variable change. This results in poor control of the process variable. The controlled pressure range should more closely resemble the pressure range of the pneumatic actuator. In other words, at 0% output the pneumatic signal should be 3 PSIG and at 100% output, the pneumatic signal should be 8 PSIG. More detailed information on this issue is provided in Chapter 40: Modulating Pneumatic Actuators (AO).

Once the process or system is understood and the output device control is confirmed, it is time to move on to PID loop tuning. Most PID loops are initially configured with default PID loop parameters recommended by the controls manufacturer or parameters that have been proven to function well in similar applications. Once the system is energized and under normal operation, the process variable (space temperature, discharge air temperature, pressure, carbon dioxide level, etc.) and the action of the controlled output device (valve, damper, VFD speed, etc.) are observed over time. The main emphasis in PID tuning is to determine the parameters (P and I, typically) that provide timely and stable control of the process variable.

Open loop (no feedback) bump tests are performed to evaluate the response of the process variable to changes in the controlled output device. In its simplest form, it is typically implemented by initially overriding the output device (valve, damper, VFD speed, etc.) to the zero output (position, speed, or command) and noting the process variable value. If we had a chilled water control valve it would be overridden to the closed or 0% open position. After the supply air temperature stabilizes, note this temperature and command the chilled water control valve to 50% open. After the supply air temperature stabilizes, note this temperature and command the chilled water control valve to 100% open. After the supply air temperature stabilizes, note this temperature. This test provides an indication of the change in process variable that is possible with known changes in the controlled device speed, position, or output. It also provides an indication of the speed in which the process variable is changed per unit change in the controlled device speed, position, or output.

Closed loop bump tests are performed to evaluate the PID loop's ability to drive the process variable in a stable and consistent manner to a new setpoint. While operating at steady-state conditions, the setpoint is changed by a "reasonable" amount. The PID loop begins to calculate the new output signal commands required to reduce the difference between the setpoint and process variable. The speed at which the new setpoint is achieved depends on the process (space temperature control versus discharge air temperature control). The process variable should achieve setpoint in a "reasonable" amount of time. Once steady-state conditions are achieved (process variable tracks setpoint), the setpoint is returned to its original value and the process is observed. Documentation of these tests may require short-interval (seconds to minutes) trend data to capture the changes in the process variable. These tests should be performed under actual operational loads, if possible. The PID loop parameters established in an empty building with no load may not work as effectively under full-load conditions.

Short interval (seconds to minutes) trend data can also be collected and reviewed to determine how well PID loops perform under these tests. The trend data is also used to validate the control parameters, document stable control of the process variable, and identify signs of the poor PID loop performance. However, there is a much better way. Distech's EC GFX software has a PID loop visualization tool called Live Log that allows us to review a continuous graph of the PID loop parameters (setpoint, process variable, and PID loop output) in real time. The live view is a very efficient way to review and adjust PID loops without acquiring, processing, and reviewing mountains of raw data. Screenshots of the Live Logs window are typically enough to document proper PID loop operation, but the data points can also be exported as a *.CVS file for spreadsheet analysis. Distech's EC GFX software allows us to update the PID loop parameters without leaving the Live Log window or reloading the program.

The PID loop is only as good as its tuning and the stability of the process variable reading. The word "Hunting" is used to describe the situation where the process variable (green line) successively overshoots and undershoots the setpoint value (orange line) as the control device bounces between extreme position, speed, or output commands (blue line). Hunting is a sign of poor PID loop tuning and system instability. In variable volume pumping applications, hunting is exhibited by the speed of the pump(s) modulating up and down while the hydronic differential pressure reading successively overshoots and undershoots the differential pressure setpoint (Figure 88). In variable-air-volume applications, hunting is exhibited by the speed of the fan(s) modulating up and down while the supply duct static pressure reading successively overshoots and undershoots the duct static pressure setpoint. In damper/valve control applications, the actuator continuously opens and closes as the discharge temperature successively overshoots and undershoots the discharge air temperature setpoint. This could also be caused by other factors such as over-sized control dampers or valves and incorrect analog output signal range, but for now, let us assume that the PID loop tuning is the only problem. If not corrected, the process will not be under stable control and the control actuator for the damper/valve will eventually fail because of the constant cycling. Alternatively, the PID loop may react too slowly and the process variable may take too long to reach setpoint. Both of these situations can be improved with tuning of the PID loop parameters.

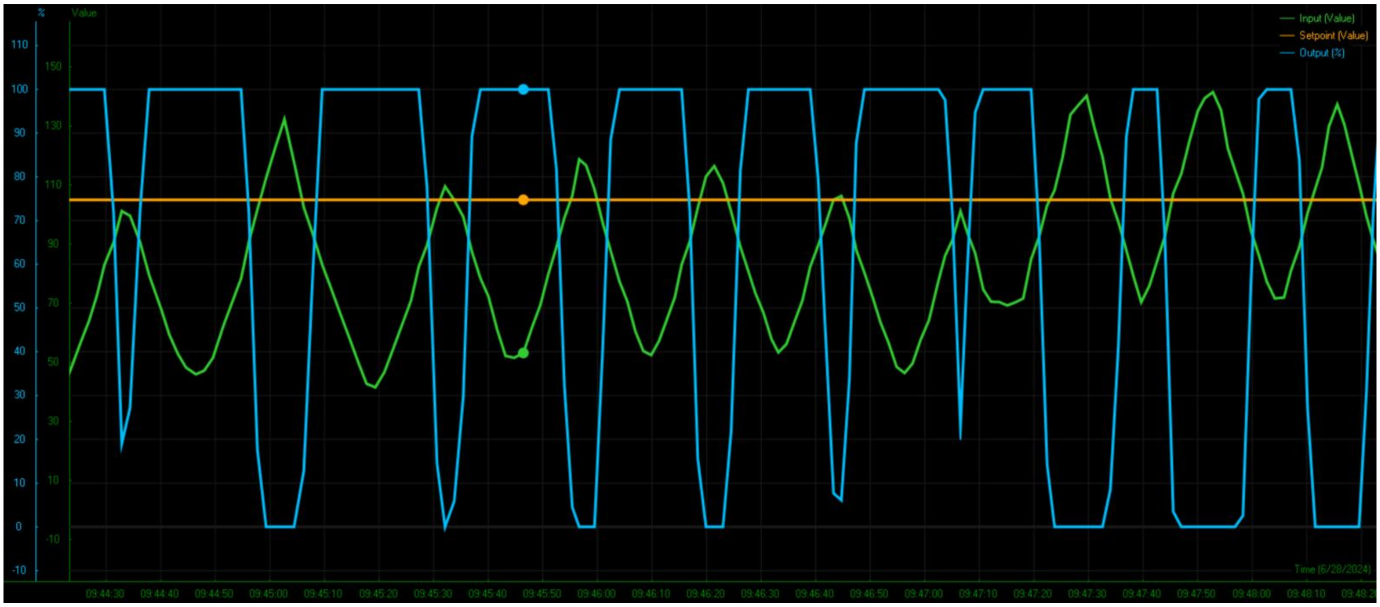


Figure 88 - Distech EC GFX Live Log View – Before PID Loop Tuning

Tuning typically requires adjustment of the proportional band until acceptable performance is rendered. Adjustments typically consist of doubling or cutting in half the current proportional band. As the response improves, smaller changes are implemented. The same is then done for the integral time. Once a PID loop is properly tuned, it is very effective at maintaining the process variable (i.e. temperature) at setpoint as the load changes. Fortunately, for comfort control applications, the sweet spot or target is typically large.

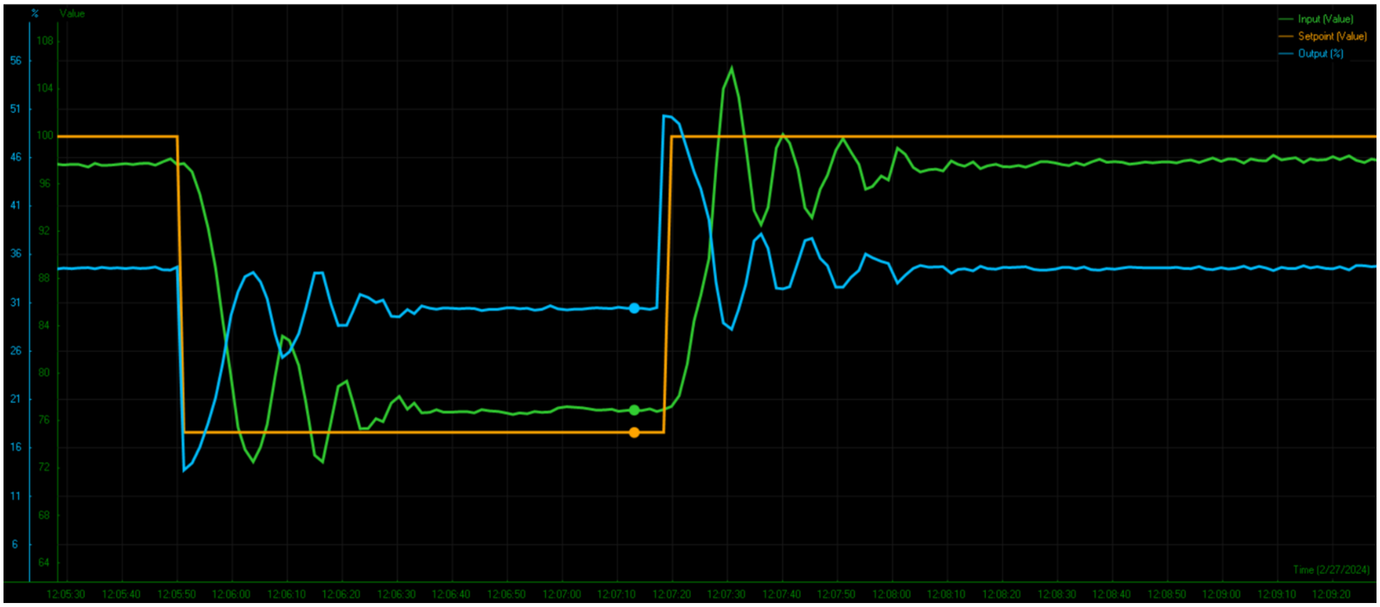


Figure 89 - Distech EC GFX Live Log View – After PID Loop Tuning

The example graph shown in Figure 88 was collected during the startup of a variable-volume condenser water pump system. Upon start-up, the pump immediately started to hunt as indicated by the rapid cycling of the differential pressure and pump speed up and down repeatedly. The PID loop Proportional Band was increased to reduce the magnitude of the pump speed signal changes. In addition, the Integral time was increased to reduce the reaction time of the PID loop. Favorable differential pressure control was achieved after additional PID loop adjustments which were made based on the observation of several step changes in the differential pressure setpoint. Following PID loop tuning, the differential pressure was able to quickly adjust to 5 PSIG setpoint changes (Figure 89).

3.11.9 Air-Handling Unit Damper Control

The following schematic shows a typical draw-through air-handling unit equipped with a control damper assembly, hot water pre-heat coil, chilled-water cooling coil, and supply fan. To control this air-handling unit requires at least four PID loops. The first PID loop controls the pre-heat coil flow through VA-1, the second PID loop controls the chilled water coil flow through VA-2, and the third PID loop controls the fan VFD. The final PID loop controls the control damper assembly (DA-1,2,3). The first three PID loops have already been discussed. The control damper assembly (shown below inside the red dashed line) typically includes the outdoor air, return air, and the exhaust (also referred to as relief) air dampers. Some air-handling units have exhaust/relief air dampers that are remotely located (in the roof or wall). The relief air (exhaust) dampers are used to control space pressurization, especially during economizer operation.

The control damper assemblies of most air-handling units are associated with various control strategies which can complicate the control sequence. Review of the sequences of operation is required to determine the required damper control strategies. Compare this to the installed damper assembly to verify that the required sequences of operation can be satisfied with the installed equipment and input and output devices. At a minimum, there will typically be alarm, unoccupied, morning warm-up, morning cool-down, economizer (dry-bulb or enthalpy), and minimum outdoor air control (damper position, flow control), demand-controlled ventilation, mixed-air low limit control, but also there may be others. A state table is helpful for visualizing the possible control strategies of the control damper assembly. Typically, the three control dampers (D-1,2,3) modulate in unison. The outdoor and exhaust dampers are typically modulated by the outdoor air damper PID loop. The return damper receives the same control signal, but it is wired so that it starts at 100% open and closes with increasing outdoor air damper command.

While in the occupied cycle, the outdoor air damper is opened to the minimum position or may be controlled to maintain minimum flow through an airflow measuring station. During economizer cycle, the BAS controller modulates the air-handling unit damper assembly beyond the minimum position or outdoor airflow setpoint to maintain the discharge air temperature or space temperature at setpoint. The PID loop defined to control this cooling process will increase its output signal as the discharge air temperature exceeds setpoint requiring a direct-acting PID loop. As the error signal (Error = $T_{DischargeAir}-T_{Setpoint}$) changes, the PID loop calculates the outdoor air damper assembly command necessary to maintain the discharge air or space temperature at setpoint. The same sequence of events occurs when the DCV (Demand-Controlled Ventilation) cycle is enabled, except the dampers are modulated to maintain the return/space carbon dioxide level below the DCV carbon dioxide setpoint.

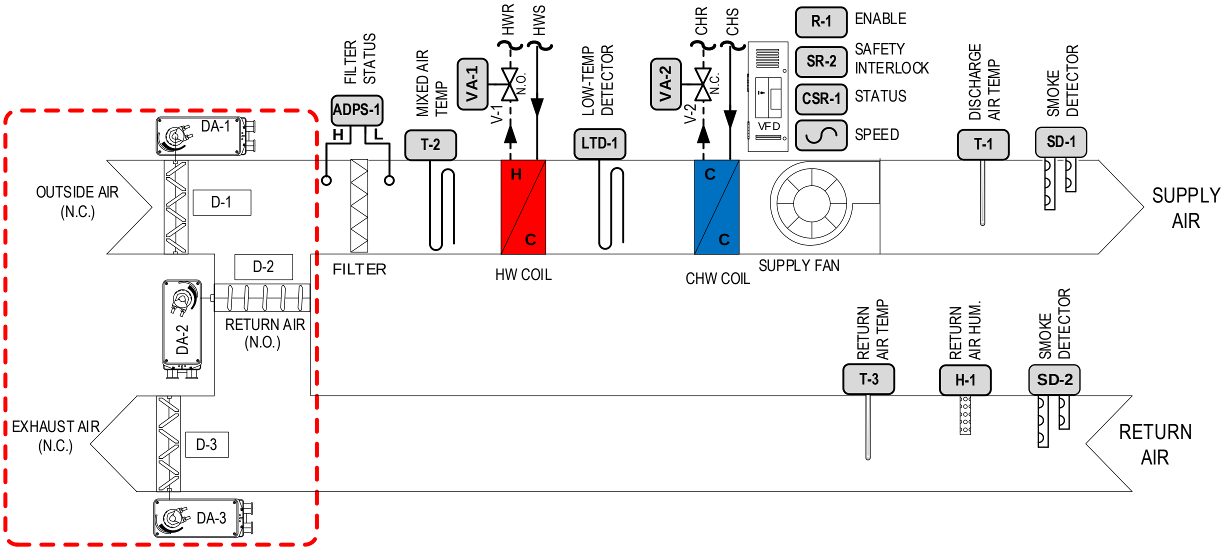


Figure 90 - Schematic of Mixed-Air Damper Assembly

3.11.10 Heating Coil Control

A BAS controller may be used to modulate the flow of hot water with a control valve actuator to maintain the preheat coil discharge air temperature at a setpoint of 50°F. The PID loop defined to control this heating process will increase its output signal as the coil discharge air temperature reading drops below setpoint. This example requires a reverse-acting PID control loop. As the error signal (Error = $T_{PreheatAir}$-$T_{Setpoint}$) changes, the PID loop calculates the new hot water control valve position necessary to maintain the preheat discharge air temperature at setpoint.

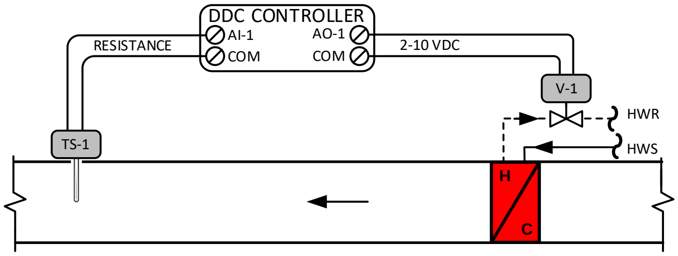


Figure 91 - PID Loop for Pre-Heat or Reheat Coil Control

3.11.11 Cooling Coil Control

In this example, a BAS controller is used to modulate the flow of chilled water with a cooling coil control valve actuator to maintain the cooling coil discharge air temperature at a setpoint of 55°F. The PID loop defined to control this cooling process will increase its output signal as the discharge air temperature exceeds setpoint. This example requires a direct-acting PID control loop. As the error signal (Error = $T_{DischargeAir}$-$T_{Setpoint}$) changes, the PID loop calculates the new chilled water control valve position necessary to maintain the cooling coil discharge air temperature at setpoint.

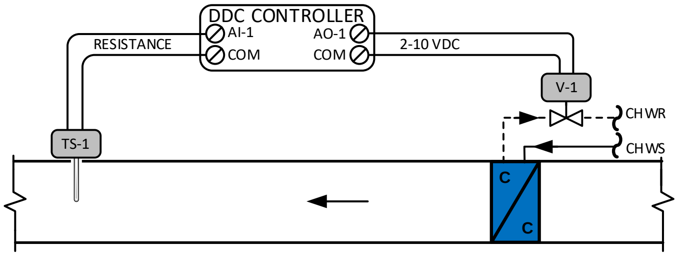


Figure 92 - PID Loop for Cooling Coil Control

3.11.12 Duct Static Pressure Control

In the next example, a BAS controller is used to modulate the fan VFD speed to maintain the supply, return, or exhaust duct static pressure in a variable-air-volume system at setpoint. As the connected load changes throughout the day, the duct static pressure varies. The PID loop defined to control the duct static pressure increases the fan VFD speed as the static pressure drops below setpoint. Therefore, this example requires a reverse-acting PID control loop. As the error signal (Error = SP_{Duct}-$SP_{Setpoint}$) changes, the PID loop calculates the new VFD fan speed necessary to maintain the duct static pressure at setpoint.

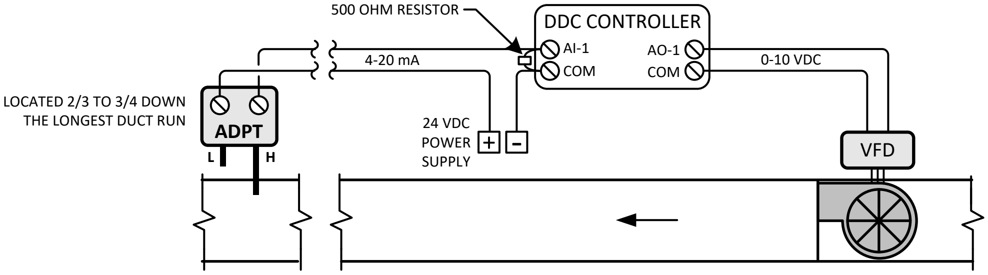


Figure 93 - PID Loop for Supply Duct Static Pressure Control

3.11.13 Digital to Analog Conversion

Once the programmed control logic has executed, the analog output signals are generated by the BAS controller. The outputs of the various PID loops are connected to an assigned analog output. Before the control signal arrives at the analog output terminals, it passes through a Digital to Analog Converter (DAC). Consult the manufacturer's data for the

BAS controller to verify the bit level of the DAC. The DAC may be at the same bit level as the ADC or it may be at a lower level depending on the BAS controller manufacturer. The bit level of the DAC determines the output signal resolution or the smallest increment of output signal change that can be achieved. In this 12-bit example, the smallest position change in terms of percent open is 0.024% or 24 thousandths of a percent. This is a very small increment of actuator movement and could be interpreted as excessive because this amount of change in actuator position may not produce a detectable change in the process variable. Many BAS controllers have a 12- or 16-bit ADC for their analog inputs and 8- or 10-bit DAC for their analog output signals.

(Equation 79) $$Increments = 2^{12} = 4{,}096$$

(Equation 80) $$Resolution_{Voltage} = \frac{10\ VDC}{4{,}096\ Increments} = \frac{0.00244\ VDC}{Increment}$$

(Equation 81) $$Resolution_{Actuator} = \frac{100\ \%}{10\ VDC} X \frac{0.00244\ VDC}{Increment} = \frac{0.0244\ \%}{Increment}$$

If the same DAC were based on 10-bit resolution, the smallest actuator position change would be 0.1%. This seems like a more reasonable level of output signal resolution and exemplifies the reason why many controllers have a DAC bit level that is lower than the ADC bit level.

(Equation 82) $$Increments = 2^{10} = 1{,}024$$

(Equation 83) $$Resolution_{Voltage} = \frac{10\ VDC}{1{,}024\ Increments} = \frac{0.00977\ VDC}{Increment}$$

(Equation 84) $$Resolution_{Actuator} = \frac{100\ \%}{10\ VDC} X \frac{0.00977\ VDC}{Increment} = \frac{0.0977\ \%}{Increment}$$

Accuracy and stability of control depends not only on the accuracy of the sensor/transmitter, but also on the resolution of the analog output signal. The bit level of the DAC determines the minimum step size that a BAS controller can provide to the controlled equipment and actuators. The following figures provide graphical examples of the differences in output signal resolution. Higher bit levels provide an output signal that very closely resembles an analog output signal and provides tighter control of the process variable.

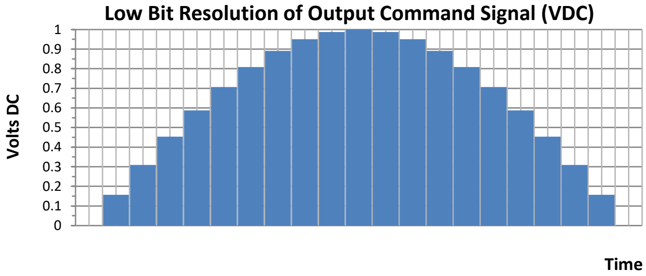


Figure 94 - Low Bit Resolution Example of an Analog Output Signal

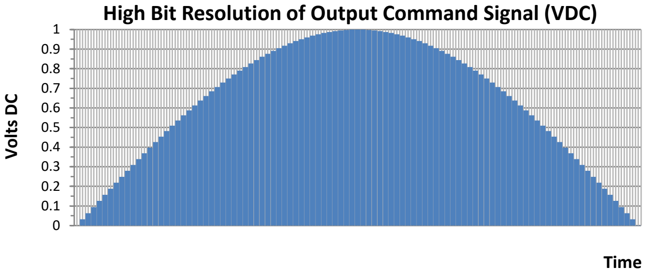


Figure 95 - High Bit Resolution Example of an Analog Output Signal

3.11.14 Transformer Loading

Most sensor transmitters, actuators, controllers, and relays will not have dedicated low-voltage transformers (also called power supplies). LVTs will typically serve several devices of similar voltage ratings and/or use. The capacity of a LVT is rated in units of Volts-Amps (VA). Typical controls specifications require Class 2 transformers for control systems and require that the connected load be limited to 80 percent of its rated capacity to prevent overloading the transformer with transient voltage and amperage spikes. Therefore, a 24-VAC class 2 transformer rated for 100 VA is limited to 80 VA (0.8 * 100 VA) of connected load. Controls Contractors group similar devices and power them with a common 24 VAC transformer. For example, electric actuators are typically grouped because they typically have higher VA capacities than other components (controllers, relays, transmitters, etc.). To ensure that the transformer is adequately sized, it is necessary to sum the VA loads of all its connected devices.

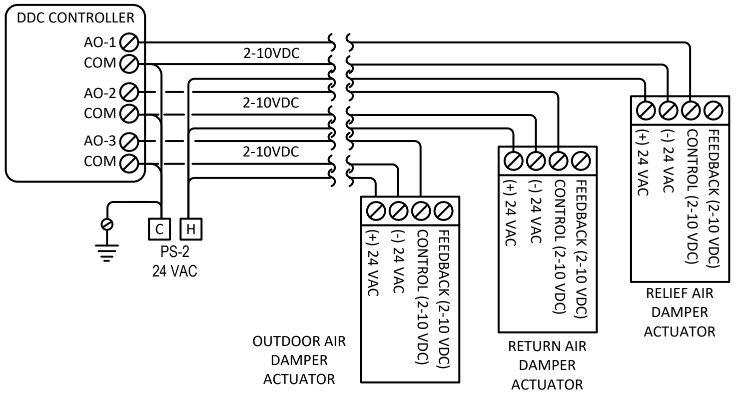


Figure 96 - Power and Signal Wiring for Multiple Actuators

If several controllers, transmitters, and actuators are powered by a common transformer and there are issues with actuators not opening and/or closing fully or strange readings, check the voltage at the connected terminals. If a transformer is overloaded, the voltage available to each powered device may be low (less than 24 VAC). When BAS controllers are underpowered, they may exhibit strange behaviors (unreliable communication, strange transmitter readings, intermittent float synchronization, etc.). The installation of additional transformers is typically required to provide adequate power for the actuators and controllers. This issue emphasizes the importance of carefully planning transformer sizes and maintaining the connected loads below 80% of the transformer VA capacity. This is typically done by entering each powered device, its quantity, and its associated VA load into a spreadsheet similar to that shown in following table.

When the control system is designed, the Controls Contractor typically provides a low-voltage ladder logic diagram that shows what is powered by each low-voltage transformer. This diagram clearly shows what is powered by each transformer and is also used as a basis for calculating the transformer VA load. If the connected transformer load exceeds 80% of the transformer capacity, then additional transformers are required to remain below the maximum-specified transformer load. The following diagram shows an air-handling unit that required a Class 2 control transformers (TX-1) to power its input and output devices (BAS controller, sensors, relays, and damper and valve actuators). The VA loads for each transformer were totalized and its transformer selected to ensure that the connected VA load did not exceed the 80%.

LOW-VOLTAGE TRANSFORMER LOAD SUMMARY							
MAXIMUM LOAD:			**80%**	POWER SUPPLY:	**TX-1**	UNIT:	**LCP-1**
#	**TAG**	**QTY**	**DEVICE**	**DESCRIPTION**	**ACTION/TORQUE**	**UNIT VA**	**TOTAL VA**
1	UC-1	1	ECB-403	DISTECH	N/A	22	22
2	R-1,2,3,4	4	RIBU1C	FDI	N/A	1.1	4.4
3	ADPT-2	1	PRESSURE TRANS.	SETRA	N/A	0.6	0.6
4	H-1	2	RH TRANS.	ACI	N/A	0.6	1.2
5	DA-1,2	2	MS7510W2008	HONEYWELL	88	14	28
6	SR-1	1	RIBMNLB	FDI	N/A	24	24
						TOTAL LOAD (VA)	**80.2**
						MINIMUM TRANSFORMER RATING (VA)	**100.3**
						SELECTED POWER SUPPLY RATING (VA)	**PSH100A**

Table 49 - Transformer Load Summary

Some Controls Contractors make the mistake of exceeding this convention with the rationale that all connected actuators will never be driven at the same time. That is very true under normal operating conditions. However, if balancing and commissioning are part of the project requirements, actuation of all valve and damper actuators simultaneously is very likely. Global overrides are typically used to posture the air and water systems for maximum load during testing, adjusting, and balancing of the air and water systems. In addition, global overrides are also commonly used for testing and calibration of BAS input and output devices as well as control logic verification.

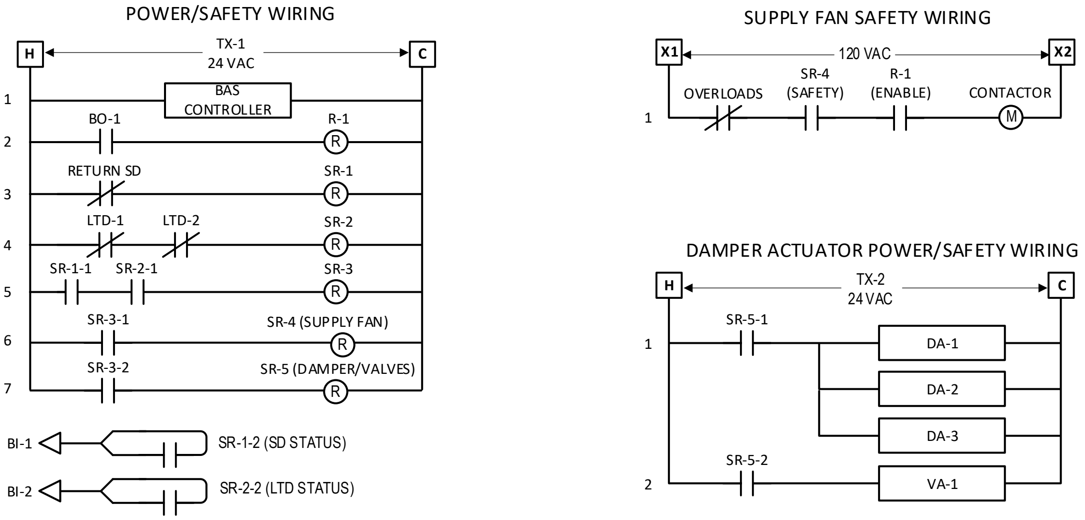


Figure 97 - Air-Handling Unit Ladder Logic Example

3.12 Review

1. ________________________ utilize the setpoint and process variable to calculate control signal for the modulating output device.
2. BAS controllers are typically installed inside a ____________________________ for protection from mechanical damage.
3. Air differential pressure switches, smoke detectors, and current-sensing relays are examples of devices that provide ____________________ input signals to the BAS controller.
4. ______________________ provide electrical isolation and control of circuits of much higher power ratings.
5. A ______________________ is a type of solid-state relay that has no moving parts and can provide millions of cycles.
6. ______________________ control requires at least two binary outputs to simulate the performance of a modulating output.
7. Two-wired sensor transmitter circuits are typically referred to as _____________________ transmitter circuits.
8. When the PID loop increases its output signal as the process variable drops is an example of __________________________ control action.
9. A 250 Ohm resistor installed across the terminals of an analog input receiving a 4-20 milliamp signal provides a _________ VDC to _______ VDC signal.
10. The VA load on a control transformer is typically limited to ___________ percent of the transformer capacity.

3.13 References

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Chapter 4 - BAS Component Testing and Verification

4.1 BAS Components:

The performance of any system is dependent on the proper functioning of each and every one of its components. Therefore, it makes little sense to jump right into system level functional performance testing of the BAS if its inputs and outputs have not been thoroughly reviewed and tested. Many hours of confusion, questioning, and uncertainty will be wasted on determining why system level tests did not function properly when the root cause was one or more of its components that had not been selected, installed, wired, configured, calibrated, programmed, and bound to the BAS graphics correctly. With the various parties involved in the installation of the BAS, there are many opportunities for things to go wrong or to be missed and this fact underscores the importance of component level testing and verification prior to system level and intersystem level testing. The following figure provides a conceptual distribution of issues typically found during the commissioning of any HVAC building automation system. An estimated one-third to two-thirds of the issues encountered on most commissioning projects are related to the inadequate, incomplete, or incorrect installation or configuration BAS input and output devices. Therefore, it is well worth the effort to validate the performance of the input and output devices to ensure that the subsequent tasks are not interrupted.

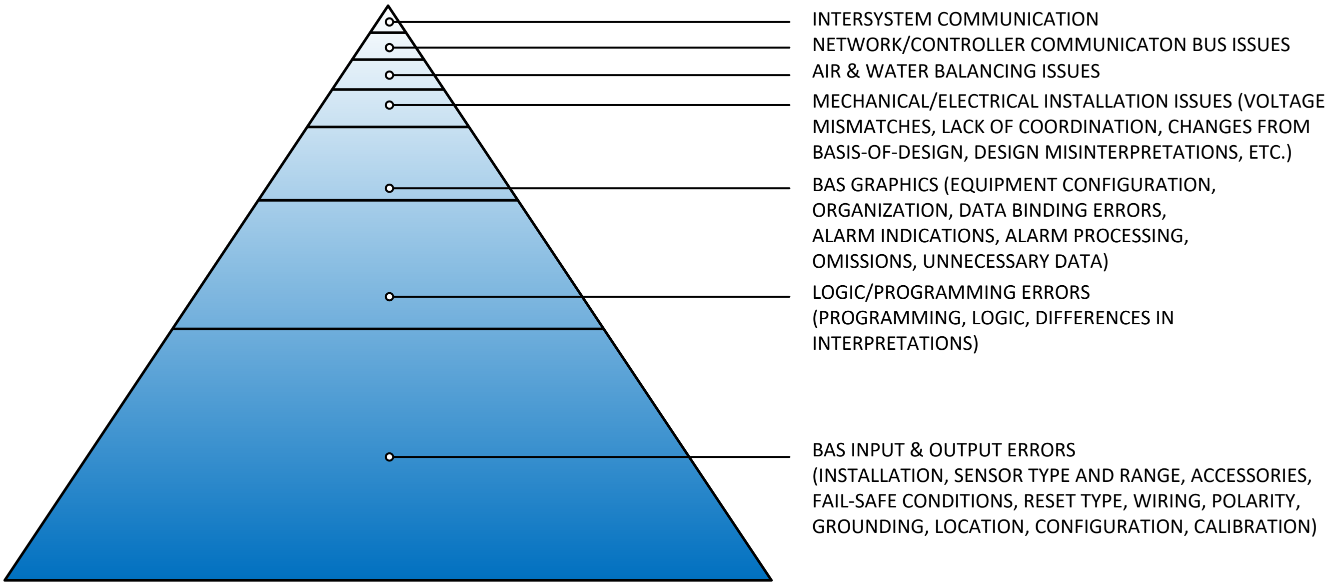

Figure 98 - Graphical Distribution of Commissioning Issues

4.2 Barriers to Proper BAS Installation and Calibration:

It is typically assumed that the Controls Contractor has properly selected, installed, configured, and calibrated the BAS input and output devices. Controls Contractors, like any other business, exist to provide quality products and services that satisfy a market demand – Building Automation Systems. They also have competing demands, responsibilities, goals, and resources that must be managed to ensure their survival. Successful installation of a BAS requires the involvement of many people each with their own unique combination of knowledge, skill, and experience. These variations must be assessed and addressed as time permits so that the appropriate personnel are assigned to each project. Four of the top barriers to a properly installed and calibrated BAS are explained herein.

4.2.1 Lack of Time

A significant portion of the BAS commissioning issues are related to the inadequacy of time allotted to do the job correctly and completely. When there is not enough time to perform the required tasks, they are executed in a hurried fashion resulting in errors and/or incomplete work. Unfortunately, the BAS installers, technicians, and programmers are often expected to complete the work within a project schedule or the labor estimates produced months or years before by sales staff or estimators. We have to keep in mind that these are "estimates" and were very likely adjusted to lower values to win the project. The validity of the man-hour estimates is typically not questioned, but they need to be calibrated just like BAS input and output devices based on the actual man-hours used to complete the included tasks. This is the only way that the estimates will ever approach a reasonable level of accuracy. It unreasonable to expect BAS installers, technicians, and programmer to perform their work within overly aggressive and often unrealistic man-hour estimates. Expectations must be adjusted to account for the actual project conditions and knowledge, skills, and training of the assigned personnel.

4.2.2 Lack of Education

Every person in the BAS industry must have a minimum level of education to manage and process the data that they will be dealing with. Building automation is a technical field that requires mental horsepower and attention to detail. In addition to basic math skills, the installers and programmers must also be familiar with the devices they are installing and the mechanical and electrical systems in which they are installed. Knowing the operating characteristics of various air and hydronic system types is a huge advantage to installers and programmers. They must also know several programming and graphics packages to properly configure, calibrate, and bind the data points to the BAS graphics. In short, building automation systems are constantly advancing and we have to continually educate ourselves to keep up with the ever-changing technology and applications.

4.2.3 Lack of Training

Training is an area where many BAS practitioners and their employers fall short. Most people need and want training, but there is only so much time and money to go around. Good employers will invest in their staff by providing targeted training to the employees that need it. Many HVAC and control concepts are better communicated by hands-on demonstrations rather than brief verbal or written explanations (with no demonstration). Telling someone to "figure it out" is not a recipe for success or professional development. It is extremely frustrating and time-consuming to do a task that you are not properly trained or equipped to handle. Instructions are better understood and retained when there is an opportunity to apply the lessons to an actual project. Learning by trial-and-error is not a particularly effective or economical way to learn because some errors can be very expensive. Having a seasoned veteran of the trade as your coworker, teacher, or mentor offers the employer an opportunity to provide in-house classroom training as well as on-the-job training to the less-experienced staff. These individuals are a valuable resource to the staff and employer.

4.2.4 Availability of Proper Tools and Instruments

Proper tools and instruments are also required to properly install, test, and calibrate the BAS input and output devices. The readings of calibrated instruments and meters are compared to the readings provided by the BAS to verify its accuracy. Controls Contractors have a responsibility to equip their staff with the proper tools, supplies, equipment, PPE, and calibrated instruments to properly install, test, and calibrate the BAS input and output devices. Humidity transmitters require a calibrated humidity meter for calibration. Carbon dioxide transmitters require a calibrated carbon dioxide meter. Calibrated reference instruments are required to calibrate the analog input and outputs devices. Control Contractors should have at least one set of calibrated instruments that are kept at the shop and are used on their various BAS projects as needed. TAB Contractors are often used to assist in the calibration of air and water flow meters by providing reference flow measurements. Some specifications require the TAB Contractor to provide the calibration readings for the control system sensors and transmitters. However, they need the Controls Contractor to update the controls system configuration because they typically don't have access to the control system or the programming knowledge to make the required changes.

4.3 Component Testing and Verification:

The integrity of the BAS controller input and output devices is critical to the successful testing and verification of the HVAC control system and the reliability of the systems they control and monitor. The programmed logic may be 100% correct, but if the wires for the devices were landed on the wrong controller input/output, then the program will not provide the intended control. Likewise, the wiring may be accurately landed, but the control logic may reference the incorrect points also resulting in poor control. Each input/output device has a range of jumpers, dip switches, wiring, tubing, terminations, and other options that impact their operation and each BAS input/output must be configured to accept/provide that same signal. For example, if a hot water valve actuator is configured for a 0-10 VDC signal, but the BAS has been configured for a 2-10 VDC signal, the control valve will always be at least 20% open.

Poor control could be the result of errors and/or omissions in the control logic. We often reuse control logic for efficiency, but there may be missing or unnecessary steps that impact the current application. The operation of controlled systems must be observed and tested to ensure that it provides the intended sequences of operation. Distech's ECgfx software (and others) provides a debug mode that allows review of the live program either connected or unconnected to the controller. Often unexpected actions are encountered that require control logic modifications to provide the sequences of operation.

If the bindings for the BAS graphics reference the incorrect point, the indicated data will be incorrect. If the point name has changed since it was originally configured and bound to the BAS graphics, the binding will be broken and no data will be displayed on the BAS graphic. The installation, configuration, wiring, and binding of each device must be correct in order for the controlled systems to function correctly and efficiently and for the data displayed on the BAS graphics to be accurate. In summary, there are a multitude of potential failure points and testing is absolutely required to identify and correct them and provide a properly functioning system.

The following sections of this chapter provide a general test procedure for each of the input and output types of a typical BAS controller – Binary Input, Analog Input, Binary Output, and Analog Output. The goal of this book is to provide a framework around which the building automation industry and its practitioners may coalesce to arrive at standard testing and verification procedures that are consistent. With "standard" testing procedures, we all can have the same foundation from which to direct our efforts. There are a myriad of component testing and calibration strategies used by Control Technicians and Programmers to achieve the same goal – a properly functioning BAS. The wide variation in testing and verification procedures is related to the various levels of experience, training, and education and the availability of the proper tools and instruments. With standard procedures, we will all have the same knowledge, perform the same steps, use the same tools, instruments, and arrive at the same results with the same documentation.

These procedures are based on the assumption that the BAS graphics will also be tested and verified. The most efficient way to test and verify the graphic bindings is to do it as each input and output device is being reviewed, tested, and calibrated. Verifying the BAS graphics after the testing and verification of the individual input and output devices ensures the unnecessary duplication of work. Many of the steps performed during the testing and verification will have to be repeated in order to verify the graphical bindings of the data points. If your BAS installation project does not include graphics, these steps can be ignored. In addition, your project may require additional steps not listed. These general procedures provide a guideline that may change with the addition or subtraction of steps depending on time and/or budget constraints. These procedures are considered to be the basic steps necessary to ensure that each BAS component is properly installed, wired, configured, calibrated, and bound to the BAS graphics. These generic Testing and Verification procedures are applied to the typical BAS input and output devices described in Sections 2, 3, 4, and 5.

4.4 Binary Input Testing and Verification

The general test procedures for BAS controller binary inputs include the following:

1. Verify that the binary input device has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal requirements. The mounting, orientation, operating range, number of output contacts, normal position of the available contacts, and type of reset (manual or automatic) are some of the features that should be verified.
2. Verify that the binary input component has been installed at the correct or optimum location.
3. Verify that the binary input device has been installed per the manufacturer's installation recommendations. In addition, verify that the selected device is appropriate for the intended service.
4. Verify that the BAS controller's binary input has been properly configured to match the specifications of the binary input device contacts. This typically consists of verifying whether the binary input device contacts are maintained or momentary and whether they are normally-closed or normally-opened.
5. Verify that the binary input component has been correctly wired. The device may have multiple sets of normally-open and normally-closed contacts which must be properly landed and coordinated to provide the desired control logic.
6. Verify that the pneumatic and hydronic tubing, piping, probes, valves, and thermal traps are correctly located and tightly fitting. The high-pressure port of the pressure sensing transmitters should be connected to the high-side of the system and the low-pressure port should be connected to the low-side of the system.
7. Verify that the binary input device is connected to the correct BAS controller binary input. Simulate the binary input signal by making or breaking the electrical circuit at the device contacts (not at the BAS controller). This step may require the removal of a wire from a terminal or the use of a jumper wire or Magjumper to make electrically continuous a set of normally-open contacts. If the monitored contacts are normally-closed, then loosening one of the terminal screws and lifting the signal wire from its contacts will be required. When the electrical connection is made or broken, the status of the binary input point in the BAS controller should also change.
8. At the same time that the electrical contacts are opened and/or closed, verify and document that the data point bound to the BAS graphics also changes. Binary inputs that are used as safety devices should also display a color change to clearly and prominently indicate its status.
9. If a binary input device is used as a safety device (smoke detectors, low-temperature detectors, high/low static pressure

switches, low/high temperature switches, etc.), verify how it is interlocked with fans, damper actuators, and valve actuators. Refer to Chapter 6: Wiring Practices for Safety Devices for more information on this subject. Update the control logic ladder diagrams that are typically included with the controls submittal. Drawings or sketches are typically best for documenting the wiring strategies used.

10. Verify that the binary input devices that are used as safeties generate an alarm in the alarm console upon activation.
11. Verify that the binary input device and its wires at the BAS controller end have been labeled. For example, air-handling units may have multiple air differential pressure switches that monitor supply fan status, return fan status, filter status, high-static safety, low-static safety, etc. The BAS binary input may be wired to the binary input device contacts or an intermediate relay or fan alarm safety circuit contact so labeling is an important part of conveying the purpose and defining which system it is connected to.
12. Verify that the facets of the binary input device are correctly displayed for each state. The facets should be consistent with the binary states of the monitored equipment. Equipment such as fans, pumps, and electric resistance heaters whose operating status was monitored by binary input devices typically display "On/Off," "Enabled/Disabled," "Running/Stopped," or "True/False" facets. Valve and damper actuators monitored with a position feedback switch typically use "Opened/Closed" facets. Safety devices typically display "Normal/Alarm" facets and typically display a color change (typically red) when the alarm condition is initiated.
13. If status or alarm delays are used, then they should be verified and documented. Equipment (fan, pump, compressor, electric resistance heaters, etc.) operating status points are typically given a status alarm delay of 30, 60, 90, or 120 seconds, depending on the application, prior to generating the status alarm. This is done to ensure that the alarm condition is true and to minimize nuisance alarms. Safety devices such as smoke detectors, low-temperature detectors, and high/low-static safety switches typically have no delays. For consistency, they should be the same for similar devices and applications.
14. Verify that the binary input device functions by making it actuate by the appropriate means. Measure or simulate the test media that causes that actuates the binary input device contacts. For example, use a low-pressure calibration pump and manometer to test and verify that the setpoint of the Air Differential Pressure Switch is properly set. Determine the current setpoint of the binary input device and adjust it to the setpoints required by the project contract documents or application. Some binary inputs are not readily verified by a measurable parameter. They may actuate by presence or detection of media or are actuated by a physical input. Document the test method, equipment used to actuate the status contacts of the binary input device, and the results.
15. Upon resetting the binary input device (if required), verify that all system components restart as expected and resumes normal operation. Occasionally, resetting a virtual reset button on the BAS graphics may also be required in order to restart the system.
16. Once the binary input has been proven to function and display properly, verify and document any collateral sequences of operation that initiate as a result of its activation. For example, in addition to disabling the supply fan, closing the outdoor and exhaust damper, and opening the return air damper, the coil freeze protection pump may also energize if a low-temperature detector activates.
17. Review the trend data to verify that the binary input device reliably and consistently reports to the BAS controller. Change-of-State trends are typically utilized to minimize memory requirements. Be aware that some binary input devices such as smoke detectors and low-temperature detectors will not alarm during the course of a typical day. They will have to be manually activated to verify the alarm generation.
18. Document the results of all testing. Screenshots of the binary input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the binary input device.

4.5 Analog Input Testing and Verification

Analog input devices have the highest degree of variability in the types of devices and signals that can be monitored. The following is a general test procedure which is applicable to most analog input devices. To avoid unnecessary duplication, steps that are specific to certain analog input devices will be provided in the test procedures for that device in the appropriate chapter.

1. Verify that the analog input device has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The operating conditions, sensor range, mounting, output contacts, manifolds, wiring, and output signals are some of the features that should be verified.
2. Verify that the analog input component has been installed at the correct or optimum location. The location of the

device can significantly affect the accuracy, stability, and reliability of the acquired data. Unfortunately, there often is no "ideal" location and the "best" of several poor locations must be selected. In these situations, document the issue and do the best you can to complete the testing and calibration of the analog input device.

3. Verify that the analog input device has been installed per the manufacturer's installation recommendations. If the analog input device has temperature and humidity limitations, the installation should prevent temperature and moisture from reaching their limits. If the analog input device has multiple operating ranges, verify that the appropriate range has been selected. The lowest range that encompasses the normal operating conditions should be used. In addition, minimum clearance requirements to duct or pipe fittings must be observed.
4. As applicable, posture the HVAC system or the required components (damper, control valves, fans, VFD speeds, etc.) to prevent unwanted system changes (modulation, staging, cycling) during the sensor/transmitter calibration. For example, overriding the air-handling unit for either 100% outdoor airflow or 0% outdoor airflow (depending on the outdoor air conditions) typically improves air temperature sensor calibration accuracy because this minimizes/eliminates the negative effects (stratification) of incompletely mixed air streams. It also allows our single-point field temperature-measuring instruments to be used as reference readings (as opposed to temperature traverses) because the air streams are homogenous during either full-recirculation or 100% outdoor air operation. Equipment (boilers, chillers, humidifiers, heaters, cooling towers, coils, heat exchangers, etc.) can also be disabled, isolated, or bypassed to limit changes in air and hydronic systems.
5. Verify that the pneumatic and hydronic tubing, piping, probes, valves, and thermal traps are correctly located and tightly fitting. The high-pressure port of the pressure sensing transmitters should be connected to the high-side of the system and the low-pressure port should be connected to the low-side of the system.
6. Verify that the analog input device has been correctly wired. The analog input device may have multiple sets of contacts which must be properly landed and coordinated to provide the required signal type and range. Temperature sensors only require a pair of wires. Sensor transmitters require two or three wires and a power supply to generate the analog input signal. Refer to Chapter 3: BAS Inputs and Outputs for detailed information on the typical wiring configurations. Verify and document all adjustable
7. dip switches, selector switches, and jumper settings to ensure the correct signal type and range are generated. If a resistor has been utilized to convert the 4-20 mA current signal to direct current voltage, document the resistance of the resistor (typically 500 Ohm or 250 Ohm). If any manipulation of the resistor or wiring is required, be sure to remove power from the sensor transmitter and BAS controller prior to loosening these terminals. Catastrophic damage to the BAS controller is possible if this is not followed. Drawings or sketches are typically best for documenting the wiring strategies used.
8. Verify that the analog input device is connected to the correct BAS controller analog input. This step requires the removal of the signal or power wire from the analog input device terminals (not the BAS controller). With no signal, the reading for the associated data point will change to a value consistent with an open circuit thus identifying it from the other data points.
9. At the same time that the analog input device's electrical contacts are opened, verify and document that the data point bound to the BAS graphics also changes.
10. Verify that the analog input device and its wires at the BAS controller end have been labeled to indicate their purpose. For example, air-handling units typically have multiple temperature sensors (supply air, mixed air, return air, bypass air, cooling coil discharge, discharge air, etc.). A label makes it clear to all that follow what each temperature sensor was intended to monitor, what system it is associated with, and to which analog input it is connected. The local control panel should also be furnished with a set of control drawings so that future operators and Control Technicians will have an idea of what the control system was designed to accomplish.
11. Verify that the units/facets are correctly displayed. The facet should be consistent with the units of measure for the analog input device. The control program must correctly interpret the resistance (Ohms), amperage (4-20 mA), or voltage signals (0-5 VDC, 1-5 VDC, 0-10 VDC, 2-10 VDC) it receives and translate them to the correct units or "facets" used by the control program and displayed on the BAS graphics. Refer to Table 19 for the typical facets used with typical analog input devices.
12. Verify that the precision of the analog input reading is appropriately set. Setpoints, carbon dioxide, and most flow readings should be whole numbers. The precision of most other analog input readings should be no more than one decimal place for most applications. Duct static and space static pressures are an exception because the values are much smaller. Duct static pressures are typically displayed with one or two decimal places while space static pressures are typically displayed with two or three decimal places. Setpoints for duct and space pressurization are typically at

one decimal place lower than the precision of the duct and space static pressure readings.

13. Verify that the BAS controller's analog input point has been properly configured to interpret the analog signal type and range from the installed analog input device. Most input devices have markings, tags, or labels indicating at least the manufacturer, sensor range, and signal range. Many sensor transmitters have multiple ranges and the selected range should be the lowest range that encompasses the normal operating conditions. It is critical that the configuration of the analog input of the BAS controller exactly match the sensor/transmitter output signal. If the analog input signal is from a temperature sensor, verify that the analog input point of the BAS controller has been properly configured to interpret the temperature sensor type. A decade resistance box or variable resistor is useful for this task. In this example, an ADPT produces an output signal that ranges from 4-20 mA and a 500 Ohm load resistor is placed across the BAS controller analog input terminals to convert it to a 2-10 VDC voltage signal. A signal generator may also be used as a second method of validating whether the analog input has been correctly configured. Ramp the simulated voltage or current signal up and down to verify that the BAS controller properly interprets the analog input signal.

Operating Point	Static Pressure (Inches W.C.)	Volts (VDC)
Minimum	0	2
Maximum	10	10

Table 50 - Initial Analog Input Configuration

If the analog input configuration of the BAS controller is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs. The scale and offset values are used to calculate the static pressure reading from the voltage signal provided by the ADPT.

Volts (DCV)	Inches (W.C.)
2	0
10	10

Calculated Scale= 1.25
Calculated Offset= -2.50

Table 51 - Initial Scale-Offset Calculation for Analog Input Configuration

14. Verify that the analog output signal generated or transmitted by the sensor or transmitter is accurate for its sensor reading. This step verifies that the sensor transmitter produces or transmits an accurate output signal which will be monitored by an analog input of the BAS controller. If the sensor transmitter does not produce the appropriate output signal or does not report across its full range, then it should be calibrated by modifying its zero and span adjustments. If accurate results cannot be attained through adjustment, then it should be replaced. Ideally, this step is performed with at least two calibration points. If the full range of the sensor transmitter can be simulated or observed, this will confirm that this device provides an output signal across its full range. The following table shows the initial calibration test data of an air differential pressure transmitter.

Reading	Test/Instrument (Inches W.C.)	Output Signal (VDC)	Calculated Output (Inches W.C.)
1	0.0	2.03	0.04
2	5.0	5.98	4.98
3	10.0	9.83	9.79

Table 52 - Initial Transmitter/BAS Calibration Check

15. Update the configuration of the analog input of the BAS controller and retest to confirm the calibration of the analog input device. Some analog input devices come with zero and span adjustments. Adjustment of the analog input device should only be implemented in compliance with the manufacturer's instructions. Adjust them until acceptable calibration readings can be attained at 0%, 50%, and 100% of full pressure range. If the analog input readings still appear to be inaccurate or the analog input device does not provide readings across its full range, then replacement of the analog input device is recommended. Record the final analog input calibration and correction factors.

Operating Point	Static Pressure (Inches W.C.)	Output Signal (VDC)	Calculated Output (Inches W.C.)
Minimum	0	2.03	0.0
Maximum	10	9.83	10.0

Table 53 - Updated BAS Controller Configuration

If scale and offset factors are used to configure the parameters of the BAS controller analog input, update them accordingly using the same methodology explained in Chapter 3: BAS Inputs and Outputs.

Volts (DCV)	Inches (W.C.)
2.03	0
9.83	10

Updated Calculated Scale= 1.28
Updated Calculated Offset= -2.60

Table 54 - Updated Scale-Offset Calculations

16. Release all overrides used to posture the system for testing and calibration.
17. Review the trend data to verify that the analog input device reliably and consistently reports to the BAS controller. Keep in mind that trend data at 10-15 minute intervals can hide transient conditions. Shorter intervals (5 seconds-5 minutes) should be used initially and then increased as the trends prove accurate, reliable, and stable operation. There should not be any gaps or omissions in the trend data.
18. Document the results of all testing. Screenshots of the analog input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the analog input device.

4.6 Binary Output Testing and Verification

The general test procedures for BAS controller binary outputs include the following:

1. Verify that the binary output device has the capabilities, capacity, and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The mounting (DIN rail, base plate, knockout, snap track, etc.), fail-safe damper and valve positions, normal equipment state, wiring requirements, contacts, output signals are some of the features that should be verified. Verify with the equipment wiring diagram and equipment literature whether the closure of the remote enable contacts enables or disables the equipment.
2. Review the sequences of operation to verify how the UUT should be controlled and its fail-safe state.
3. As applicable, posture the HVAC system or the required components (damper, control valves, fans, VFD speeds, etc.) to prevent unwanted system changes (modulation, staging, cycling) during the device calibration.
4. Verify that the binary output device and controlled equipment have been installed per the manufacturer's installation recommendations.
5. Verify that the binary output component and its connections to the controlled equipment have been correctly wired. The devices may have multiple sets of normally-open and normally-closed contacts which must be properly landed and coordinated to provide the desired control logic. Also verify that any unused isolation relay wires are secured to prevent clutter and confusion. Also, verify and document how all hardware interlocks associated with the binary outputs are implemented. Update the ladder logic diagram that is typically included in the controls submittal. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify that the binary output device is connected to the correct BAS controller binary output. This step is typically performed by overriding the BAS controller binary output and verifying whether the output device follows the command. Measurements may also be performed at the terminal strip of the controlled equipment. For example, suppose a binary output point controls the operation of a constant-volume hot-water pump that is currently off or de-energized. If overriding the pump start/stop command to start causes the pump to energize and disabling the same point causes it to de-energize over multiple cycles, this provides a clear indication that the overridden binary output controls the hot-water pump. In noisy and/or dark areas, a clamp meter or continuity tester is often helpful for verifying motor control in small loads (inline pumps, fans, relays, and contactors) when they cannot be readily seen or heard.
7. As the BAS controller binary output is overridden, verify and document that the corresponding data point bound to the BAS graphics also changes as the controlled equipment is enabled and disabled. Also verify that the binary output data point bound to the graphic changes color to indicate that it has been overridden. While the binary output is overridden, the programmed control logic no longer controls the binary output and it will remain in the overridden state until the override is released.
8. Using the binary output field bound to the BAS graphics (not the binary output data point) associated with the binary output, verify that the controlled equipment (chiller, boiler, humidifier, rooftop air-handling units, VFD, etc.) energizes and de-energizes on command. Override the binary output data point to the opposite state and verify that the controlled equipment follows the command.
9. Verify the fail-safe position or operating state of the controlled equipment (relay, electrical circuit, chiller, boiler, VFD, packaged air-handling unit, damper or valve actuators, etc.). This can be done by removing power from the BAS controller or entire control panel. This simulates both the loss of BAS controller power and the loss of control signal

from the binary output of the BAS controller. All binary outputs of the BAS controller will be affected so it is typically more time efficient to verify the fail-safe state of all binary outputs at the same time.

10. Verify that the LED status indicator of the isolation relays illuminate to indicate their commanded state with each cycle of the binary output. If it does not illuminate, replacement is recommended. If the relays did not come with LEDs, then measurements at the relay contacts will be required to determine the current state and confirm proper operation of the relays.
11. Verify that the binary output devices have been labeled to indicate what data points and what equipment or system they are associated with. For equipment wired to the normally-closed switched relay contacts (instead of the normally-open), Controls Contractors typically make a note with permanent marker or a label on or near the isolation relay to indicate that its coil is enabled to disable the controlled equipment.
12. If the isolation relay controlled by the binary output is equipped with an H-O-A switch, verify that it functions in all positions. If it does not, troubleshoot the wiring, correct, replace (if applicable), and retest. The Functional Devices, Inc. model RIBU1S and RIBU1S-NC are often used for this application. In the Hand position, the controlled equipment is enabled permanently. In the Off position, the controlled equipment will not operate at all. In the Auto position, the binary output signal from the BAS controller (or time clock) controls the operation of the controlled equipment.
13. If the motor starter is equipped with an H-O-A switch, verify that it functions in all switch positions. If it does not, an electrician should be consulted to troubleshoot the high-voltage wiring. The position of the H-O-A switch should function as described above. Isolation relays with H-O-A switches are not recommended if an H-O-A switch is already provided with the motor starter. This will only cause confusion for the field personnel.
14. Verify that the facets are correctly displayed. The facets are typically consistent with the operating states of the controlled equipment. Equipment controlled by binary outputs, like fans, pumps, and electric resistance heaters typically display “Start/Stop” or “Run/Stop” facets. Valve and damper actuators typically use “Open/Close” facets. Equipment with its own packaged controls such as chillers, boilers, humidifiers, and rooftop units are typically given the facets of “Enabled/Disabled.”
15. If the status of the controlled equipment is monitored by a status monitoring device (air differential pressure switch, hydronic differential pressure switch, end-switches, position feedback contacts, current-sensing relay, etc.), this is an ideal time to test that device as well.
16. Verify binary output control over time by reviewing trend data. If the binary output can be verified by another sensor, trend that point as well. For example, if a pump enable point is trend, also trend the pump status to confirm that the command was executed. Trending the command only does not confirm that the command was followed. It is also a good idea to trend the occupancy schedule if that is what causes the pump to be enabled.
17. Document the results of all testing. Screenshots of the binary output point data as well as the BAS graphics are useful for documenting the ability of the BAS to control the binary output device.

4.7 Analog Output Testing and Verification

The general test procedures for BAS controller analog outputs include the following:

1. Verify that the analog output device has the capabilities, capacity, and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The operating range, mounting, fail-safe position, wiring requirements, contacts, output signals are some of the features that should be verified.
2. Verify that the analog output device has been installed in the correct or optimum location.
3. Verify that the analog output device has been installed per the manufacturer’s installation recommendations.
4. Review the sequences of operation to verify how the UUT should be controlled and its fail-safe state
5. As applicable, posture the HVAC system or the required components (damper, control valves, fans, VFD speeds, etc.) to prevent unwanted system changes (modulation, staging, cycling) during the device calibration.
6. Identify and document the process variable, setpoint, its output signal range, and action (direct-acting or reverse-acting) of the PID loop that calculates the control signal to be used by the end device (VFD, boiler, chiller, humidifier, electric resistance heat, etc.).
7. Verify that the analog output device is connected to the correct BAS controller analog output. This step is typically performed by overriding the analog output and measuring the analog output signal at the BAS controller and at the controlled device and verifying that the controlled equipment responds correctly to the analog output signal override commands. If the readings are not identical, troubleshoot the wiring and all connections.

8. Verify that the analog output component has been correctly wired. The device may have multiple contacts which must be properly landed and coordinated to provide the desired control signal. Drawings or sketches are typically best for documenting the wiring strategies used. Be sure to verify that the polarity is correct.
9. Verify that the analog output device and its wiring at the BAS controller end have been labeled to indicate what data point and what equipment or system it is associated with.
10. Verify that the facets are correctly displayed. Most analog output signals that control damper and valve positions will have percent open (% Open) facets. Equipment whose speed or capacity is controlled such as VFDs, compressors, boilers, humidifiers, etc. typically use percent sign (%). Analog outputs that control equipment setpoints will utilize the units relevant to the parameter being controlled. Temperature (°F or °C) is perhaps the most commonly used setpoint in HVAC control.
11. Verify that the precision of the analog output reading displayed on the BAS graphics is appropriately set. Setpoints should be whole numbers and the precision of the analog output should be no more than one decimal place for most applications.
12. Verify that the BAS controller's analog output point has been properly configured to transmit the commanded output capacity or damper/valve command. In this example, the 2-10 VDC signal produced by the BAS controller is proportional to the commanded damper or valve position (0-100% Open).

	Output (%)	Volts (VDC)
Minimum	0	2
Maximum	100	10

Table 55 - Initial Analog Input Configuration

If the output configuration is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs.

Volts (DCV)	% Output
2	0
10	100

Calculated Scale= 12.5000
Calculated Offset= -25.00

Table 56 - Initial Scale-Offset Calculation for Analog Output Configuration

13. Using the analog output data point (not the BAS graphics), verify that the controlled equipment responds to the analog output signal. Override the analog output signal to 0%, 25%, 50%, 75%, and 100% and verify that the equipment properly interprets and responds appropriately to the signal. If it does not, review the configuration of the controlled equipment, the BAS controller analog output, wiring, and the tightness of all wiring terminals. At each increment of commanded output, record the voltage signals at the BAS and equipment terminals and the actual output or setpoint indicated at the controlled equipment. If there is a difference between the voltage readings, troubleshoot as required. Look for signs of induced voltages that may have been imparted to the conductors that transmit the control signal.

Field Measurements/Observations			
Command	BAS Analog Output Signal (VDC)	Equipment Signal (VDC)	Equipment Output/Setpoint
0	2.06	2.06	25%
25	4.11	4.11	25%
50	5.94	5.94	50%
75	7.95	7.95	75%
100	10.09	10.09	100%

Table 57 - Control Signals versus Equipment Output State Table

14. Update the configuration of the analog output of the BAS controller, if required, and retest to confirm proper control. When the valve shaft has not been exactly aligned with the valve actuator, the zero and the full open positions may not be attained. Instead of stopping at the true zero position, the valve may pass the zero point and begin to open again. Most ball and plug valves do not have mechanical stops. The same can issue can occur in butterfly dampers as well. Opposed-blade and parallel-blade dampers do not reopen if their shafts are over-rotated. It binds and eventually the damper blades, shaft, or linkages prematurely fail if the actuator continues to drive past the true zero position. The solution is to either correct the alignment of the damper/valve and actuator, adjust the actuator stops, or to adjust the control signal so that the damper/valve stops at zero. Using the true zero and fully open positions and their corresponding voltage signals, the control signal range can be rescaled so that the damper/valve stops at zero and reaches the fully open position.

	Output (%)	Volts (VDC)
Minimum	0	1.95
Maximum	100	9.91

Table 58 - Updated BAS Controller Configuration

If scale and offset factors are used to configure the parameters of the BAS controller analog input, update them accordingly using the same methodology explained in Chapter 3: BAS Inputs and Outputs.

Volts (DCV)	% Output
1.95	0
9.91	100

Calculated Scale= 12.5628

Calculated Offset= -24.50

Table 59 - Updated Scale-Offset Calculations

15. As the BAS controller analog output is overridden, verify and document that the corresponding data point bound to the BAS graphics also changes. The color change provides a visual indication that this point has been overridden. While the analog output is overridden, the programmed control logic no longer controls the analog output and they will remain in the overridden state until the overrides are released.
16. Using the analog output field bound to the BAS graphics (not the analog output data point), verify that the controlled equipment responds appropriately. Also, verify that the BAS graphic provides a visual indication that these analog output points are currently overridden. While the analog output is overridden, the programmed control logic no longer controls the analog output and it will remain at the overridden command until the override is released.
17. Verify that the analog output controls over time by reviewing trend data. If the analog output can be verified by monitoring other sensors, trend those points as well. For example, if the supply fan speed is trended, also trend the supply duct static pressure to confirm that the fan speed is modulating to maintain the supply duct static pressure at setpoint. Trending the speed command only does not confirm that the speed command was followed. Keep in mind that trend data at 10-15 minute intervals can hide transient conditions. Shorter intervals (5 seconds-5 minutes) should be used initially and then increased as the trends prove accurate, reliable, and stable operation.
18. Document the results of all testing. Screenshots of the analog output point data as well as the BAS graphics are useful for documenting the ability of the BAS to control the analog output device.

4.8 Review

1. The ________________ display the state or units of measure for a data point.
2. A ________________ may be used to simulate an analog voltage signal to verify the configuration of an analog input of a BAS controller.
3. Errors with the installation and setup of the BAS system __________________ are responsible for a significant portion of BAS commissioning issues.
4. A ________________ may be used to simulate an analog resistance signal to verify the configuration of an analog input of a BAS controller.
5. What color is typically associated with alarm conditions? Answer: _________
6. How many decimal places should be used to display the carbon dioxide concentration? Answer: _________
7. What is the maximum number of decimal places that should be used to display operating temperatures?

   Answer: _________
8. True or False: It is not important that the analog input of the BAS controller and the analog signal from the sensor transmitter match if it was factory calibrated. Answer: _________
9. True or False: Verification of the data points bound to the BAS graphics is not required. Answer: _________
10. True or False: Verification of the data points used in the programmed logic is not required if a point-to-point checkout has occurred. Answer: _________

4.9 References

1. Tridium, Inc. 2009. Niagara AX NRIO Guide

Chapter 5 - Relays, Contactors, and Starters

5.1 General

This chapter focuses on Relays, Contactors, and Motor starters because a thorough understanding of each is required to safely test and troubleshoot these devices and the systems they control. These devices allow a low-voltage BAS controller to control high-power equipment and circuits. While they are all basically electrical switches, they each are unique and have different capabilities, limitations, and applications. They are used to implement relay logic through hard-wiring, so an understanding of relay logic diagrams is also essential. Relay logic diagrams will be discussed at the end of this chapter.

5.2 Electromechanical Relays

5.2.1 IDEC Relays

The low-power binary outputs of BAS controllers typically control equipment circuits with much higher voltage and current ratings. To protect the binary output contacts and avoid possible BAS controller damage, an isolation relay is typically used. It provides electrical isolation between the two circuits and allows low-power circuits (24 VAC) to provide binary control of high-power circuits (120 VAC and higher). The electromagnet is the heart of this device. The coil of the electromagnet is powered by the low-voltage source and when activated by the BAS binary output, the current flow through the electromagnet creates a magnetic field that attracts the spring-loaded armature and actuates the high-powered switched contacts. The isolation relays used in HVAC controls are typically the double-throw type that has a set of normally-open and normally-closed switched contacts.

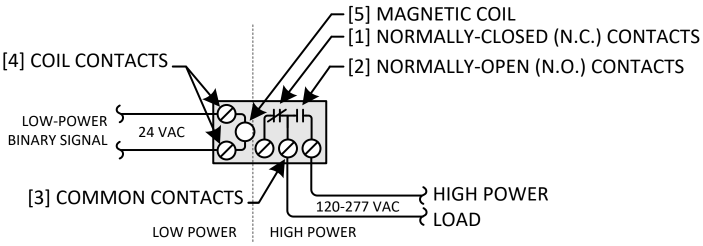

Figure 99 - Schematic of a Single-Pole, Double-Throw Relay

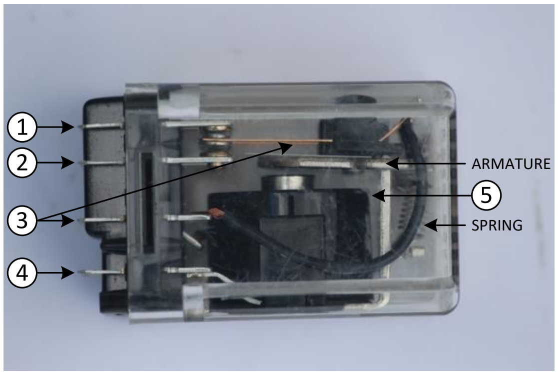

Figure 100 - Electromechanical Isolation Relay Labeled

An isolation relay has two states – Energized and De-energized. Relays are constructed with and without LEDs (Light Emitting Diodes) to indicate whether the coil is energized. Relays with LEDs are recommended for BAS installations because they provide a quick indication of its status. Graphical depictions of relays show the relay contacts in their normal or fail-safe state with its coil de-energized. When the coil is energized, the armature is pulled to the electromagnet causing the normally-open contacts to close (or make) and the normally-closed contacts to open (or break). Depending on the required relay logic, the controlled circuit can either be connected to the normally-open (powered closed) or the normally-closed contacts (powered open). When the isolation relay's coil is de-energized, the spring causes the armature to return to its normal, de-energized state where the normally-open contacts are open and the normally-closed contacts are closed.

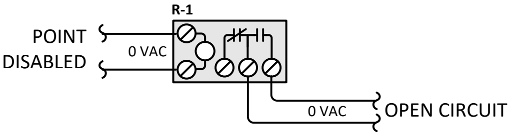

Figure 101 - Disabled Single-Pole, Double-Throw Relay

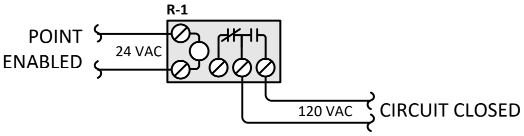

Figure 102 - Enabled Single-Pole, Double-Throw Relay

The type of isolation relay shown in Figure 100 is often called an "ice cube" relay because of its resemblance to an ice cube. This relay has a base to which the isolation relay is mounted (Photograph 53). When the relay is removed from the base, none of the switched relay contacts are connected. The contacts of the base are connected to the relay contacts through blade contacts. The base can either be mounted with screws or it can be attached to DIN rail. DIN rail is a metal rail system commonly used for mounting circuit breakers and controls components in an LCP. DIN stands for Deutsches Institut für Normung and was developed in Germany. This type of relay is often used in local control panels to provide electrical isolation and its switched contacts are connected to the controlled device or interlocking field relay located at the controlled equipment.

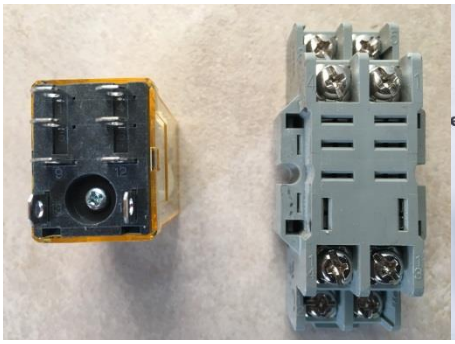
Photo 53 - IDEC RH Series Relay and Base

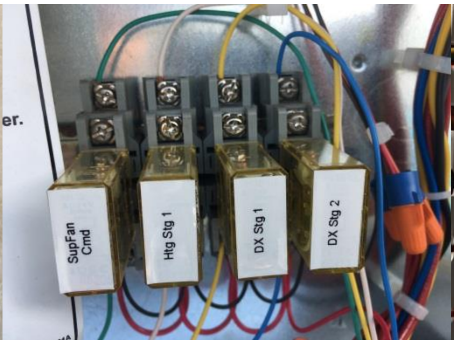

Photo 54 - Air-Handling Unit Enable Relays

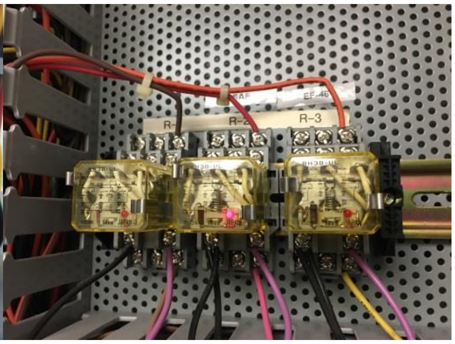

Photo 55 - Air-Handling Fan and Exhaust Fan Enable Relays

5.2.2 RIB® Relays

Functional Devices, Inc. manufactures a line of enclosed isolation relays that can be observed on most BAS installations. Their Relay in a Box RIB® line of control relays provide on/off control for electrical loads (motors, lights, heaters, etc.) and come with a variety of useful, time-saving features that simplify BAS installations which include, but are not limited to, the following:

1. Integral Hand-Off-Auto (H-O-A) switch for manual override of the driven load. This is a very nice feature for smaller single-phase equipment without a motor starter. If the equipment is driven by a three-phase contactor or motor starter with an H-O-A switch, this feature is not recommended as it tends to cause confusion.
2. Current Sensing Relay (CSR) for monitoring the operating status of the controlled equipment. This feature precludes the need to install a separate CSR to monitor the operating status. An LED is also provided to indicate the operating status of the controlled equipment.
3. Current transducer to monitor the instantaneous current flow.
4. Additional SPDT relays in the same enclosure for control of additional circuits
5. RIB relays have the ability to monitor and control field equipment and additional binary and analog points through various communication protocols (BACnet, Lonmark, and Modbus) minimizing wiring requirements.

Photo 56 - RIBU1C-N4 on a Rooftop Exhaust Fan Motor Starter Enclosure

Photo 57 - RIBU1S in a Chiller Control Panel

Photo 58 - RIB24P for Electric Resistance Heater Control

RIB relays are typically mounted through a knockout or through a hole drilled in the electrical enclosure. They have an LED that illuminates when the BAS has activated the coil of the relay. Typically, activation of the relay's coil enables the controlled equipment. However, some designs require that the central plant equipment be wired to the normally-closed contacts instead of the normally-open contacts so that they can be operated manually should the BAS controller fail in some way. In these installations, the binary output and connected isolation relay are energized to disable the equipment. The RIBU1S and RIBU1S-NC are often utilized in these situations to provide manual override capability should the binary control signal from the BAS controller fail.

RIB relays are generally a binary output device, but they can also serve as an input device when the isolation relay's coil is wired across a 120 VAC circuit. When the 120 VAC circuit is energized, the switched status contacts of the RIB relay actuate to their energized state. When it is de-energized, the status contacts return to their de-energized or fail-safe position. Electric resistance heaters are often installed in rooftop air-handling unit coil sections and pipe chases to maintain a minimum air temperature to prevent freezing of the hydronic pipes and coils during unoccupied periods. The circuit breakers for these electric heaters are turned off for one reason or another and are not energized when the next heating season returns. Those who have suffered ruptured pipes and coils because of this issue have learned to wire the coil of the RIBU1C across the 120 VAC circuit and monitor the switched contacts through the BAS controller. An alarm is generated when the outdoor air temperature is below some minimum threshold (40°F) and the electric heater circuit status indicates that it is de-energized.

5.3 Magnetic Contactors

A magnetic contactor is essentially a relay, but with higher current ratings. Contactors are typically used to control electrical circuits that handle more than 15 Amps. Relays and contactors function in the same manner. The electromagnet coil and switched contacts may be either exposed or enclosed depending on its design. Enclosed contactors shield the electromagnet and electrical contacts to increase safety and longevity by preventing the introduction of tools, fingers, debris (insects, webs, dust, etc.) in these areas. Most magnetic contactors have a visual indicator to identify whether it is energized and its high-voltage contacts are designed to minimize arcing when the contacts are opened and closed.

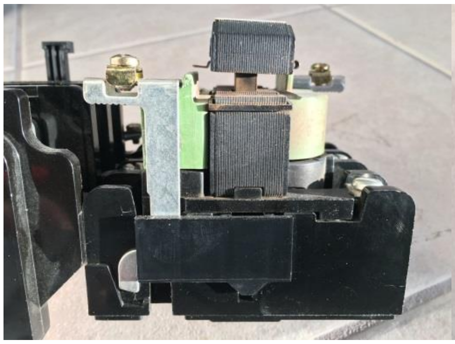

Photo 59 - View of Electromagnet

Photo 60 - Enclosed Contactor Design

Photo 61 - Auxiliary Contacts of a Supply Fan Contactor

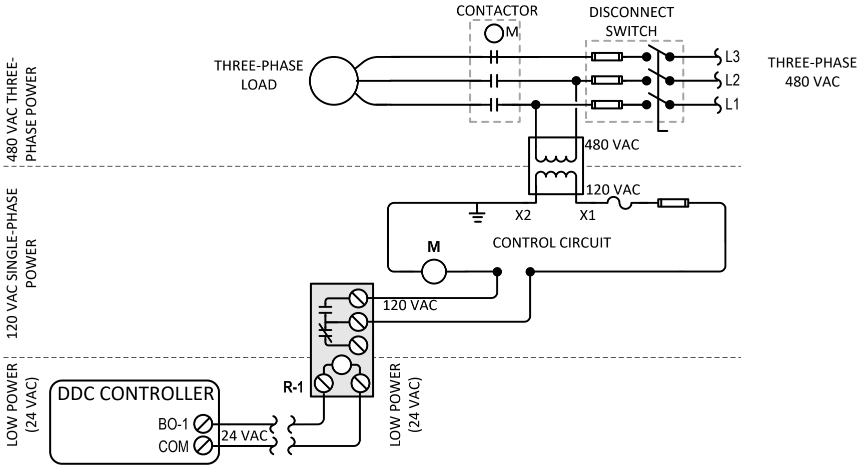

Figure 103 - Typical Contactor Wiring Diagram

Magnetic contactors allow low-voltage (24 VAC) and medium-voltage (120 VAC) power circuits to control high-power electric loads including, but not limited to motors, compressors, electric resistance heat, and lighting. When the BAS enables the binary output controlling the isolation relay coil, its switched contacts actuate to energize the coil of the contactor which powers the controlled equipment on command. The above figure shows the three voltage levels in the three-phase load control circuits. It also shows the wiring and components of a typical contactor control assembly. Nearly all of the conductors within the enclosure are high voltage (>50 VAC) with exception of the isolation relay coil that is controlled by the BAS controller. Be sure to use all appropriate electrical Personal Protective Equipment (PPE) and Lock-Out/Tag-Out procedures when working inside live electrical enclosures.

5.4 Combination Motor Starter/Disconnect Switch

Motor starters are essentially contactors with overload protection and are typically used when inductive loads are controlled. Electric motors operate on the principle of induction. By alternating the magnetic fields in the stator of the motor, the rotor rotation is induced in the direction of the rotating magnetic field. To induce this rotary motion, there is an initial inrush of current that is required to begin to turn the rotor and the connected load. This initial inrush of current is reported on the nameplate data as the Locked Rotor Amps (LRA) of the motor. As the magnetic field is established and the speed of the rotor increases, the current flow drops off substantially and stabilizes at the normal operating current requirements which is typically below the Full Load Amps (FLA) rating. FLA represents the motor amperage when it is fully loaded.

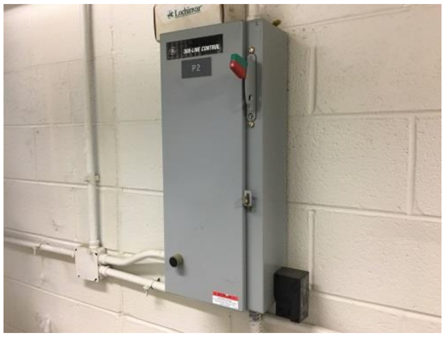

Photo 62 - Pump Combination Motor Starter/Disconnect Switch

Photo 63 - Air-Handling Unit Combination Motor Starter/Disconnect Switch

Photo 64 - Rooftop Exhaust Fan Combination Motor Starter/Disconnect Switch

Motor starters are typically housed in an enclosure that provides several supplemental components. They are part of an assembly called a combination motor starter/disconnect switch and typically abbreviated to just "motor starter" or simply "starter." Combination motor starter/disconnect switches are typically used in HVAC applications to provide manual and automatic control (through the Hand-Off-Auto Switch), Lock-out/Tag-out capability, overload protection, power disconnection means, and BAS integration. Depending on the environment in which they are installed, they may have various NEMA (National Electrical Manufacturers Association) enclosure ratings. Combination motor starters typically consist of the following main components:

1. Manual disconnect switch.
2. Short circuit and ground fault devices
3. Control transformer
4. Magnetic contactor
5. Motor overloads
6. H-O-A Switch

The following diagram shows the wiring and components of a typical motor starter assembly. Nearly all of the conductors within the enclosure are high voltage (>50 VAC) with exception of the isolation relay coil that is controlled by the BAS controller. Be sure to use all appropriate electrical Personal Protective Equipment (PPE) and Lock-Out/Tag-Out procedures when working inside live electrical enclosures. The main high-power conductors are typically either three-phase 208 VAC or 480 VAC. The control circuit, powered by the control transformer, is typically 120 VAC, but other voltages are possible. Therefore, in order for the BAS to control a three-phase load, the switched contacts of the isolation relay must be part of the contactor's coil control circuit. An isolation relay is connected to the Automatic leg of the H-O-A switch. Therefore, the BAS controls the relay's coil (24 VAC) which, in turn, controls the 120 VAC contactor coil control circuit through its switched contacts. The contactor's switched contacts, in turn, control the 208/480 VAC, three-phase load.

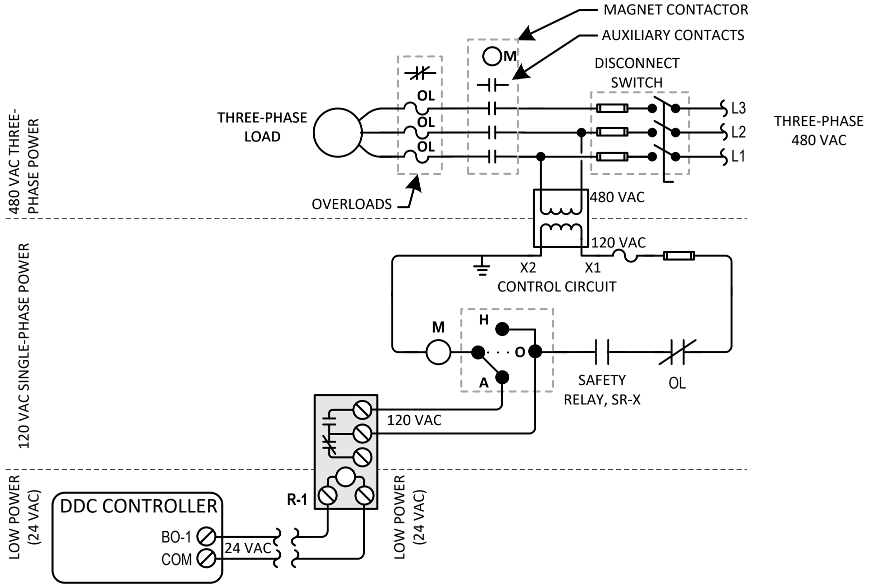

Figure 104 - Typical Air-Handling Unit Motor starter/Disconnect Switch

5.4.1 Manual Disconnect Switch

The manual disconnect switch (Photograph 65) provides the means to manually de-energize the motor starter. The handle also includes a means to lock the handle down to implement Lock-Out Tag-Out procedures. While de-energized, there should be no electrical potential downstream of the disconnect switch. The electrical wires are still live on the line side of the disconnect switch. Verify with voltage readings that the conductors are de-energized. If you have to install or check the installation of current sensing relays or current transmitters inside the enclosure, be sure to de-energize and lock-out the manual disconnect switch prior to opening it. If you have to work in a live enclosure, be sure to use the proper PPE and implement the relevant electrical safety precautions.


Photo 65 - Disconnect Switch & Fuses


Photo 66 - Magnetic Contactor


Photo 67 - Enable & Safety Relays

5.4.2 Control Transformer.

The control transformer provides the power for the contactor coil control circuit and is typically a lower voltage than the controlled circuit. Single-phase control transformers rated for 120 VAC are commonly used, but other voltages are possible. The controls transformer terminal contacts are often designated X1 and X2 and provide the power for the contactor control circuit which includes the enable contacts (typically controlled by a binary output of a BAS controller or time clock), overload contacts, magnetic contactor coil contacts, and additional safety device contacts (or safety interlock relay contacts).

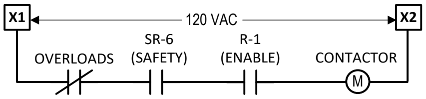

Figure 105 - Typical Motor Starter Control Circuit

As long as the overloads and the safety interlock relay are in their normal state, this circuit may be enabled by the BAS controller's binary output which controls the switched contacts of enable (or start/stop) relay R-1. If the overload device or any safety devices activate, then the contactor control circuit opens breaking the current that holds the contactor in the closed or energized position. This, in effect, disables the motor starter until the overloads and/or safety devices are reset. This control circuit is also called the "safety circuit" because it includes the safety device contacts or their safety interlock relay contacts.

5.4.3 Short Circuit and Ground Fault Devices

Short circuits and fault currents can damage motor controllers (failure of starter or heater elements). It is important that these protective devices are properly selected and installed. A current-limiting fuse can cut off the short-circuit current before it reaches damaging levels. Several conditions including, but not limited to phase loss, overloading, and locked rotor conditions, can also result in excessive motor currents resulting in damage to the windings.

5.4.4 Magnetic Contactor

The magnetic contactor is basically a high-power relay and its magnetic coil is powered by the control transformer. When the control circuit is energized, the magnetic field created by the coil pulls the high-voltage contacts together completing the electrical circuit that powers the high-powered electrical load. The load is only energized under a specific set of conditions. The overload status contacts and the safety interlock relay status contacts (SR-X) must be in their normal state before the enable relay (R-1) can enable the magnetic contactor coil circuit. This safety relay is used to interlock the operation of the three-phase load with the status of monitored safety devices (low-temperature detector, smoke detector, high static safety switch, etc.) either directly or through a fan safety alarm circuit. Should any of the safety devices actuate, the safety relay's switched contacts open de-energizing the contactor's coil control circuit thereby disabling the three-phase load until the safety relay circuit is restored to normal status. This safety circuit and interlocking relay will be discussed in greater detail in Chapter 6: Wiring Practices for Safety Devices.

Magnetic contactors have optional auxiliary contacts that close when its coil circuit is energized and open when it is de-energized. These are useful when the interlocking of other high-power loads is necessary. Return fans are often interlocked using the auxiliary contacts of the supply fan's magnetic contactor. Should the supply fan overload or safety relay activate, the return fan will also be disabled. If the return fan operates without the supply fan, it becomes an exhaust fan which can negatively pressurize the zone or building and lead to a host of humidity-related issues. Photographs 60, 61, and 66 show magnetic contactors with auxiliary contacts. The supply fan auxiliary contacts are included in the contactor control circuit of the return fan motor starter as shown in the following figure. Therefore, the return fan can only operate while the magnetic contactor of the supply fan motor starter is energized. This eliminates the need to wire the safety devices to the return fan safety circuit and ensures that the return fan only runs when the supply fan is operating.

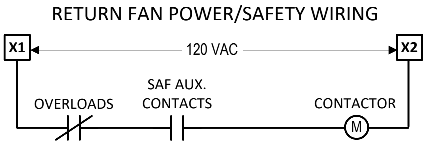

Figure 106 - Return Fan Motor Starter Interlock with Supply Fan Auxiliary Contacts

5.4.5 Motor Overloads

The initial inrush of current is required to energize the windings of the induction motor and get the load (motor and connected fan, pump, or compressor) turning. Overload protection allows the initial inrush of current which may be many times the FLA and then monitors the electrical current flow to ensure that it does not exceed safe levels. Motor overloads protect the electrical motor from overheating by interrupting the control circuit that powers the magnetic contactor coil when the motor current flow gets too high. These overloads are also called "heaters." Overload protection consists of a current sensing device, a means to break the contactor control circuit, and a mechanism to reset the device when the overload condition has been corrected. Overload protection is typically either bimetallic or electronic. Bimetallic overloads utilize the differences in thermal expansion of two dissimilar metals to actuate the overload status contacts which are part of the contactor control circuit. Electronic overloads perform the same function, but they rely on a current sensing device and circuitry that monitors the current level and actuates its status contacts when the current exceeds its setpoint (Photograph 68). Electronic overloads typically provide an adjustable setpoint and reset button.

5.4.6 Hand-Off-Auto Switch

The Hand-Off-Auto (H-O-A) switch allows the Operator to manually select the source of the control signal. This switch has three options: Hand, Off, and Automatic as shown in Photograph 69. When the H-O-A selector switch is set to the Hand position, the control circuit powering the magnetic contactor is manually energized and under the control of the operator (not the BAS). The magnetic contactor will remain energized as long as the H-O-A switch is in this position. Typically, the Hand position is used for temporary testing to check motor rotation, to verify that the operation of a current sensing relay, or to temporarily energize the equipment when it is scheduled by the BAS to be off. When the H-O-A switch is set to the off position, the motor starter will not energize and will remain de-energized as long as the switch is in this position. When the H-O-A selector is set to the Auto (short for Automatic) position, the magnetic contactor is under the control of an external isolation relay that is controlled by either a time clock, interlock relay, or a BAS controller. The H-O-A switch can be a source of aggravation for some Owners and Operators that are very aggressive in the management of their energy costs. When equipment is put in Hand mode, it does not de-energize and this can significantly impact energy use, maintenance frequency, and energy costs. Some energy managers remove all H-O-A switches ensure that only the BAS controls when the equipment runs.

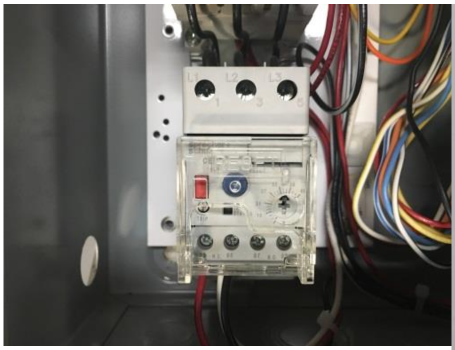

Photo 68 - Electronic Overload Protection

Photo 69 - Hand-Off-Automatic Switch

Photo 70 - Control Transformer and Fuses

5.5 Relay Logic Diagrams

Relay logic diagrams or ladder diagrams are used to indicate the hard-wired relay logic and show how the BAS controller's low-voltage binary outputs interface with the isolation relays and ultimately, the high-voltage circuits. If we visualize a typical ladder, the vertical rails represent the two electrical conductors that provide the power for all included circuits. The left rail is typically connected to the hot terminal of the 24 VAC control transformer and the right rail is typically the common terminal.

Each step or rung of the ladder represents a control circuit. In the HVAC controls field, the components typically found on the rungs of relay logic diagrams include: BAS controller, binary output contacts, relay contacts, relay coils, contactor coils, manual switch contacts, overload contacts, safety relay contacts, temperature-actuated contacts, pressure-actuated contacts, smoke-actuated contacts, etc. To construct and to read relay logic diagrams, we observe the following general rules:

1. Each rung represents an operation or logical step in the control sequence.
2. The current in each rung flows from the left to the right.
3. The relay logic progresses from the top towards the bottom.
4. Each rung starts with an input at the left side and ends with at least one output at the right side.
5. Relays can have multiple sets of switched contacts, so their switched relay contacts may appear in several places in the same ladder diagram or in different ladder diagrams.
6. Output devices cannot be connected in series.
7. Output devices appear only once in a ladder diagram.
8. Each power level or location requires a new ladder diagram.

Relay logic diagrams show the installer (Control Technician or Electrician) how to assemble the control devices and wire them according to the required control and load distribution strategy. The following relay logic diagram indicates the BAS controller's binary outputs and how they are wired to control a supply fan and an exhaust fan. Relay logic diagrams are also used to determine the loads on each low-voltage transformer. All loads (controllers, relays, transmitters, actuators, etc.) connected to each transformer are totalized so that the total VA load does not exceed 80% of the transformer VA rating. Safety interlock relay SR-6 contacts are normally open, but are powered closed while power is available and the safety relay(s) are in their normal state.

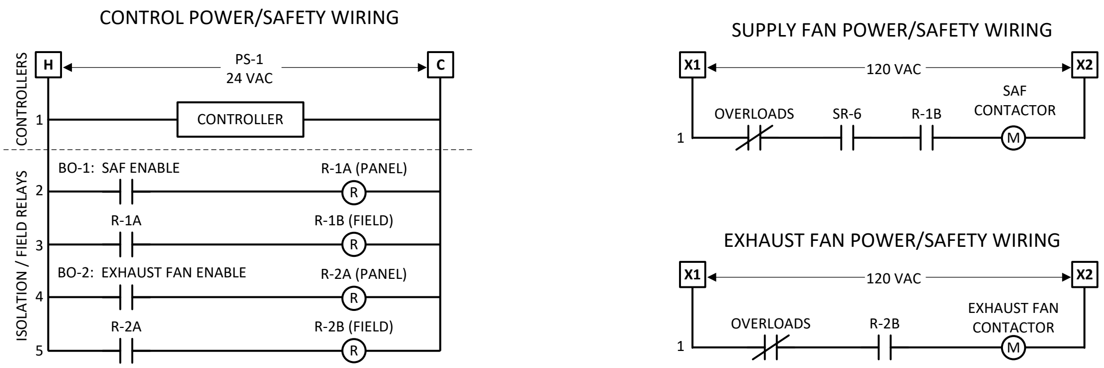

Figure 107 - Relay Logic Diagram Example

As the diagram above indicates, the first rung of the ladder logic is used to power the BAS controller. The second rung includes the normally-open binary output contacts BO-1 of the BAS controller and the panel-mounted isolation relay coil R-1A. When operation of the supply fan is required, the binary output (BO-1) is enabled which powers the coil of the panel-mounted isolation relay R-1A. When the normally-open R-1A switched contacts close (third rung), it energizes the coil of the field-mounted isolation relay R-1B which is located at the controlled equipment (supply fan). The R-1B contacts are part of a separate relay logic diagram because this circuit operates at 120 VAC. Closure of the switched contacts of the field-mounted isolation relay (R-1B) completes the 120 VAC contactor coil control circuit which energizes the supply fan motor as long the safety interlock relay contacts (SR-6) and the overload contacts are closed (Normal state).

The fourth rung of the low-voltage relay logic diagram is composed of the normally-open binary output contacts BO-2 of the BAS controller and the panel-mounted isolation relay coil R-2A. When operation of the exhaust fan is required, the binary output (BO-2) is enabled which powers the coil of the panel-mounted isolation relay R-2A. When the normally-open R-2A switched contacts close (fifth rung), it energizes the coil of the field-mounted isolation relay R-2B which is located at the exhaust fan starter. These contacts are part of a separate logic diagram because this circuit operates at 120 VAC. Closure of the switched contacts of the field-mounted isolation relay (R-2B) completes the 120 VAC control circuit which energizes the exhaust fan motor. The panel mounted relays (R-1A,2A) are typically the IDEC RH series isolation relays with LED indicators and the field-mounted isolation relays (R-1B,2B) are typically the Functional Devices, Inc. RIBU1C relays or similar.

5.6 Review

1. The part of the typical electro-mechanical isolation relay that actuates the armature is the __________________.
2. RIB stands for _________________________.
3. ________________ is another term used to describe motor overload devices.
4. _____________________ contacts of a contactor are used to interlock one fan control circuit with another.
5. When the H-O-A switch is in the __________________ position, the motor starter will be energized continuously resulting in elevated energy use.
6. Each rung in the ______________________represents a control circuit which executes an operation or logical step in the control sequence.

5.7 References

1. https://www.eaton.com/us/en-us.html
2. https://www.schneiderelectricrepair.com/square-d-products-repair-exchange-remanufacturing/
3. https://www.functionaldevices.com/products/building-automation/relays/
4. https://www.idec.com/language/english/catalog/Relays/RHSeries.pdf
5. https://instrumentationtools.com/what-is-din-rail/

Chapter 6 - Wiring Practices for Safety Devices

6.1 Equipment Safety Devices

Safety devices are a special class of field devices (smoke detector, key switch, high static safety, freezestat, end switch, etc.) that detect unsafe conditions to protect the equipment, the building, and lives. When the monitored condition is detected by the safety device, its binary status contacts actuate resulting in the immediate shutdown of the interlocked system. The status contacts of the safety devices are typically wired directly to the control circuits of motor starters and VFDs to implement equipment shutdown without BAS involvement. The shutdown signal may also be interlocked with control dampers and valves such that upon activation of a safety device, power to the spring-return actuators is interrupted which causes them to return to their fail-safe positions. The same strategy can be applied to any other system. This chapter explains how most hard-wired safety devices are configured when they are used on air-handling units. The most common safety devices are reviewed in later chapters. Air-handling units are typically equipped with multiple safety devices such as smoke detectors, low-temperature detectors (freezestats), and high/low static safety switches to protect the equipment and the building from collateral damage. Activation of safety devices typically results in the disabling of the air-handling unit supply and return fans and the closure of the outdoor dampers. Safety devices are also used in hydronic systems to disable the plant equipment should the discharge pressure and/or temperature exceed their predetermined high-limit or low-limit setpoints.

The building automation system is powerful, but it should not be included in the processing or transmission of the equipment shutdown signals. It is highly susceptible to human error and there are many other things that can go wrong with the BAS. If the communication bus is down or impaired, the sending and receiving of the shutdown signal can be interrupted. If the programmed logic is ever changed, erased, or otherwise modified to the point that the alarm condition detected by the safety device (smoke detector, high static safety, freezestat, end switch, etc.) is not received, properly interpreted, and communicated to the systems that require immediate shutdown, then the safety of the occupants, equipment, and building may be compromised.

The components included in the alarm signal processing should be single-purpose and reliable, so that they are not confused with another process or subject to inadvertent programming, software, or hardware changes. Isolation relays are commonly used in the processing, delivery, and execution of the alarm signal because of their binary nature and multiple switched contacts. Isolation relays with LEDs are very reliable and easy to interpret. Hard-wiring is always preferred over programming. Only in special situations should the BAS be used to transmit the equipment shutdown signal. Fan coil units are often shutdown upon an alarm event through the BAS. These units are small and condition a limited area, so the consequence of a communication failure is much lower when compared to a central air-handling unit.

6.2 Hard-Wired Equipment/System Shutdown

Extensive building, equipment, and property damage as well as injury and loss of life can occur when the activation of a safety device goes undetected. When the contract documents require the immediate shutdown of HVAC equipment upon activation of any safety device, it should always be implemented through hard-wired connections utilizing the normally-closed safety device status contacts (as opposed to the normally-open status contacts) to ensure the detection of activated safety devices and any future failure of this circuit. Because the monitoring circuit utilizes the normally-closed status contacts, the normal state is verified by electrical continuity across its status contacts. These contacts are wired directly to either the safety circuit of the motor starter or the VFD safety contacts. When an alarm condition is detected, the status contacts open and the interlocked equipment/system is immediately shut down. The use of the normally-closed status contacts also allows any inadvertent damage or disconnection of the monitoring circuit to be immediately detected by activation of the alarm state. If the status monitoring wiring was ever cut or otherwise interrupted during a subsequent construction project, the opening of this circuit would initiate an immediate equipment shutdown. This allows the operating staff the opportunity to make the necessary repairs and restore system operation. Although dealing with the resulting equipment shutdown may be inconvenient and annoying, it is still preferred to finding out during a real smoke, fire, or water damage event that the status monitoring wires of the safety device had been cut during a previous construction project. It is preferable to identify and correct any interruptions in the status monitoring circuit as soon as it occurs and utilizing the normally-closed safety device contacts allows this to happen.

6.3 BAS Monitoring of Safety Device Status

When safety devices are monitored by the BAS, the BAS controller's binary inputs typically monitor the normally-open status contacts of the safety device or intermediate safety relay. The equipment/system shutdown occurs automatically through hard-wired interlocking. Therefore, it is not critically important whether the normally-closed or the normally-open status contacts of the safety device are monitored by the BAS controller. Most of the Controls Contractors monitor the normally-open status contacts through the BAS controller. If the normally-closed status contacts were monitored, it would allow us to detect any future breakage or opening of this status monitoring circuit.

6.4 Direct Wiring of Safety Devices

There are two principal schools of thought on the wiring of safety devices such as low-temperature detectors (freezestats), smoke detectors, etc. Control purists require direct wiring of the safety device status contacts to the motor starter or VFD safety contacts and they believe that there should be no intermediate devices in the status monitoring circuits. The prevailing argument is, "What if the safety device actuates, but the intermediate device fails?" The intermediate device could be an isolation relay or a BAS controller that receives the alarm signal then disables the system or transmits the shutdown signal to another controller to implement the shutdown. If the intermediate device were to fail (by whatever means), the alarm signal would not reach the end device or system that requires the shutdown. As previously discussed in Chapter 5: Relays, Contactor, and Starters, isolation relays have a potential for failure because they are electro-mechanical devices. Failures in the BAS are also very possible due to the reliance on hardware, software, programming, electrical power, and signal communications. For this faction of people, only safety devices with at least two sets of status contacts are acceptable for BAS monitoring. One set of status contacts (normally-closed) is connected directly to either the VFD safety contacts or the motor starter control circuit to initiate the equipment shutdown upon actuation. The other set of status contacts is monitored by the BAS controller. This is absolutely the most direct implementation of a hard-wired equipment shutdown while providing safety device status monitoring by the BAS.

The following wiring diagrams for a typical three-phase load (typically a fan motor) protected by smoke detector and low-temperature detector show that each safety device has two sets of status contacts. The first set of normally-closed contacts of each safety device is wired in series with the 120 VAC motor starter control circuit or VFD safety circuit. As long as the included safety device contacts are in their normal state (closed), then the status contacts will be closed permitting operation of the three-phase load. It is important to note that this status circuit is live and the voltage could potentially be much higher depending on the magnetic contactor's coil voltage rating. This is why all safety circuit devices must be treated with respect. It cannot be assumed that they are 24 VAC circuits. The second set of normally-closed (or normally open) safety device status contacts is connected to the BAS for status monitoring. No isolation relays or intermediate controllers are required.

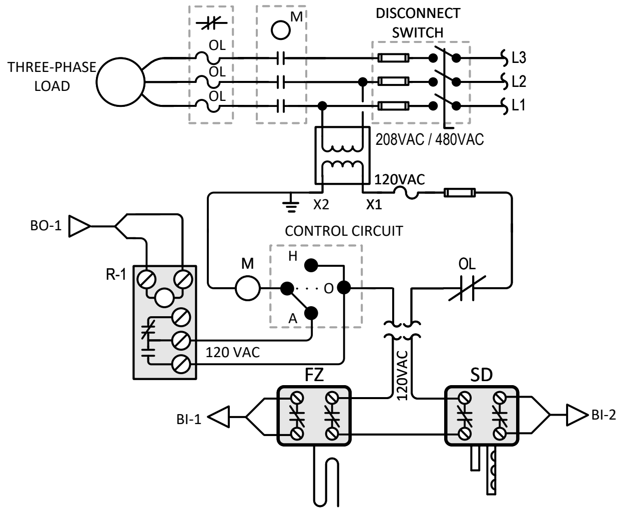

Figure 108 - Motor Starter Wiring with Interlocking Safety Devices

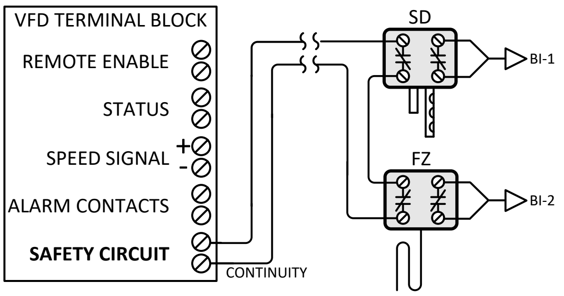

Figure 109 - VFD with Interlocking Safety Devices

6.5 Safety Circuits

The “Newer School” of thought recognizes that the use of isolation relays, fan safety alarm circuits, and even the BAS in specific applications is acceptable. The use of electromechanical and solid-state relays to transmit emergency signals is acceptable as long as their function has been proven and their failure can be detected. These devices are single purpose, reliable, and provide nearly instantaneous communication of the alarm signal over long distances to the equipment/systems that require shutdown upon initiation of the alarm condition. We have to keep in mind that safety circuits are not cycling all of the time. They remain in one position as long as the safety devices status contacts are in the same state and actuate only when alarm state is detected or the circuit power source is disabled. The use of relays makes sense because of their inherent binary nature and it maximizes the low-voltage wiring which makes the control system wiring safer to test and troubleshoot. The voltage on the terminals of any safety devices should be verified with a voltmeter prior to handling its terminals and wiring.

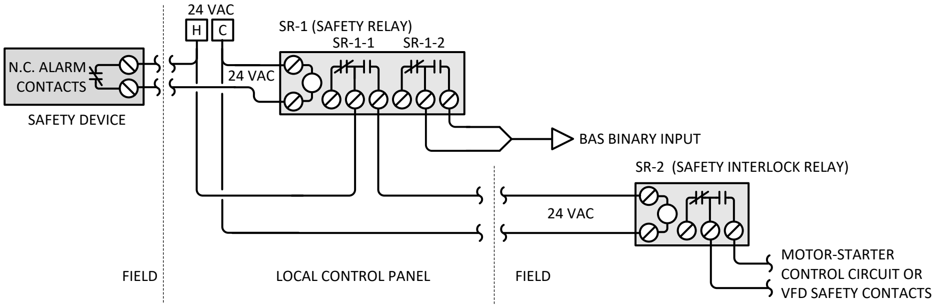

Figure 110 - Single Safety Device Wiring with Interlocking Isolation Relay

The above figure shows how a single safety device (smoke detector, low-temperature detector, high static, etc.) might be wired to the coil of a typical Double-Pole, Double-Throw (DPDT) isolation relay, and a 24 VAC transformer. For clarity, isolation relays used to transmit safety/alarm conditions are designated as “SR,” while regular isolation relays that transmit normal Open/Close, Enable/Disable, and Start/Stop commands use the “R” designation. The circuit formed by the power supply, coil of the DPDT safety interlock relay, and safety device status contacts will be energized as long as power is available and safety device contacts remain in their normal state. While energized, the isolation relay’s (SR-1) normally-open contacts are closed and its normally-closed contacts are open. The BAS interprets the closed (Normally open, powered closed) isolation relay status contacts (SR-1-2) as the normal state and the other set of switched relay contacts (SR-1-1) allow operation of the interlocked equipment either directly or indirectly through an interlocking relay (SR-2). Upon either a power loss or activation of the safety device, the switched contacts of the safety relay and its safety interlock relay return to their fail-safe, de-energized positions. This, in effect, causes an open circuit in the motor starter control circuit or VFD safety circuit which disables its operation. As a result, the power circuit of the interlocked load is disabled until the power is restored, the alarm condition is corrected, and the safety device is reset.

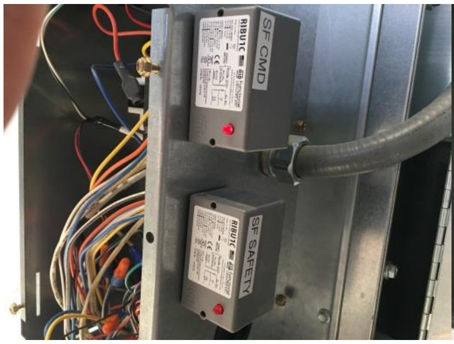

Photo 71 - Enable and Safety Relays Example #1

Photo 72 - Enable and Safety Relays Example #2

Photo 73 - Enable and Safety Relays Example #3

Where electrical loads (typically air-handling unit supply fans) are both controlled by a binary output signal and interlocked with safety devices, two enclosed isolation relays (RIBU1C or similar) are typically mounted at its electrical enclosure as shown in photographs above. One is for normal binary (On/Off) control of the three-phase load (supply fan motor starter or VFD) and is typically labeled “Start/Stop,” “S/S,” or “Enable/Disable.” The second isolation relay is used to disable its operation in the event that one of its monitored safety devices actuates and is typically labeled “Safety.” This interlocking safety relay (SR-2 & SR-6) receives its signal from either an intermediate safety relay (as shown in Figures 111 and 112) or a fan safety alarm circuit that monitors the status of all included safety devices. Instead of two separate isolation relays, the same function could be implemented with a single RIBU2C which incorporates two isolation relays in a single enclosure which minimizes installation costs. There are two types of fan safety alarm circuits that are used by Controls Contractors and they will be discussed in the following sections. This wiring convention is used by most Controls Contractors to disable air-handling units when a safety device is activated because it is safe, simple, and reliable. The interlocking safety relay is located at the motor starter or VFD enclosure, so the high-voltage (120 VAC) wiring does not extend beyond its electrical enclosure. This wiring method increases safety because it reduces the amount of high voltage wiring that personnel are exposed to.

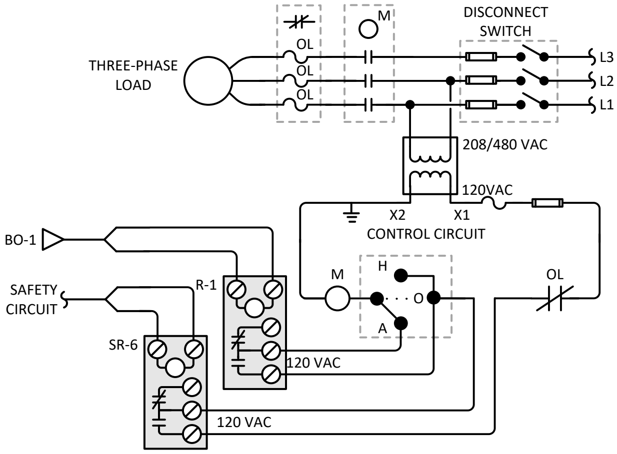

Figure 111 - Motor starter Wiring with Interlocking Safety Relay (SR-6)

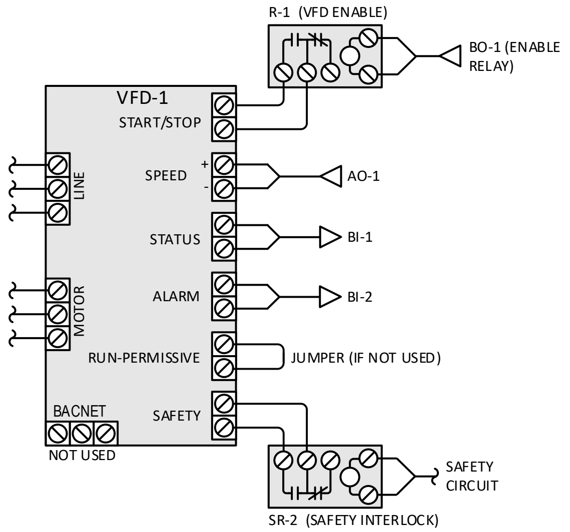

Figure 112 - VFD with Interlocking Safety Relay (SR-2)

6.6 Traditional Fan Safety Alarm Circuit

The traditional Fan Safety Alarm Circuit (FSAC) is composed of multiple isolation relays whose relay logic has been arranged to incorporate the contacts of the included safety devices, provide individual status contacts for BAS monitoring, and disable the interlocked air-handling unit should any of the safety devices activate. The number of required isolation relays is typically equal to the number safety devices plus one master safety isolation relay. Additional safety interlock relays are often installed at the controlled equipment motor starter or VFD. Some of the potential safety devices include, but are not limited to, smoke detectors, high-static safety switches, low-temperature detectors, low-static safety switches, emergency shutdown switches, etc.

This FSAC is manually constructed of individual DPDT isolation relays mounted on a piece of DIN rail and strategically wired according to the ladder logic diagram. The status contacts of each safety device are part of a circuit that powers the coil of its corresponding safety relay coil (SR-1,2,3,4) and are represented by rungs 3 through 6. Figure 113 indicates that the current passes from the hot wire of the 24 VAC transformer passes through the normally-closed contacts of each safety device before terminating at the coil of its corresponding safety relay (SR-1,2,3,4). The common wire of the 24 VAC transformer connects to the other side of the safety relay coils to complete these circuits. It is difficult to fully appreciate the function, ingenuity, and simplicity of the FSAC until you have constructed one with your own hands. Rungs three through nine (within the red dashed line) make up the FSAC.

As long as 24 VAC power is available and all safety device contacts are in their normal position (closed), its corresponding DPDT safety relay coil contacts (SR-1,2,3,4) will be energized and their normally-open switched relay contacts (SR-1-1, SR-1-2, SR-2-1, SR-2-2, SR-3-1, SR-3-2, SR-4-1, SR-4-2) will be in their energized position (closed) and their LEDs will be illuminated. The first set of switched status contacts (SR-1-1, SR-2-1, SR-3-1, SR-4-1) is wired in series to provide power to the master safety relay coil contacts (SR-5) only when all safety devices are in their normal state as represented by rung 7. The other set of switched safety relay contacts (SR-1-2, SR-2-2, SR-3-2, SR-4-2) are each wired to the corresponding binary input of the BAS controller to provide status monitoring of each safety device.

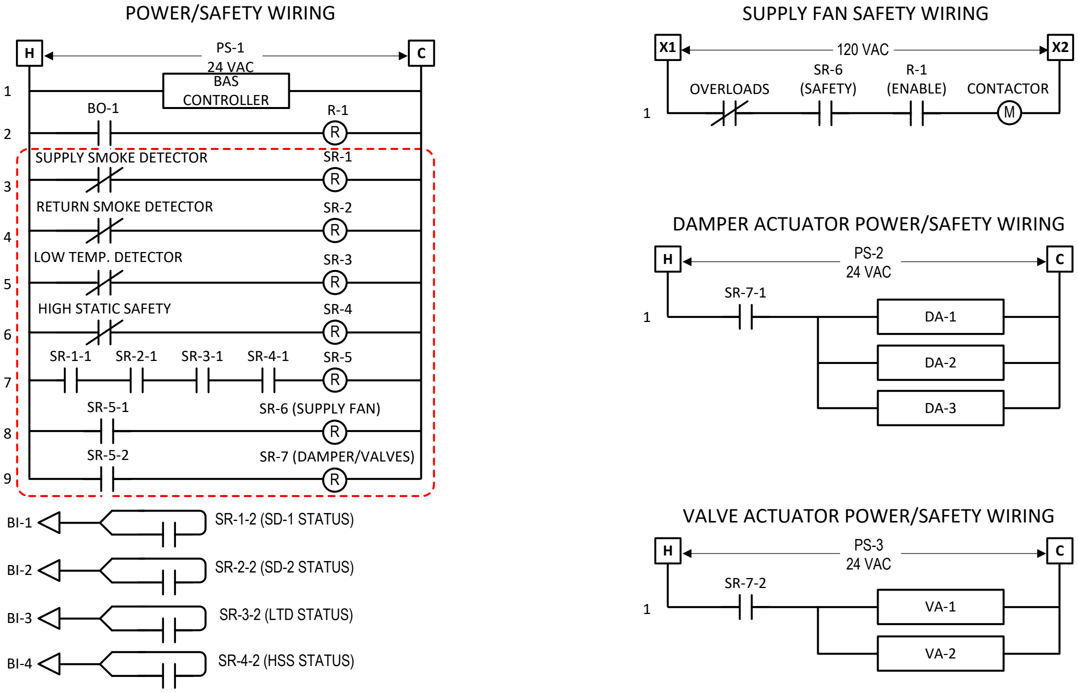

Figure 113 - Traditional Fan Safety Alarm Relay Wiring

The position or state of the switched status contacts and its LED indicate the status of the master relay (SR-5). The normally-open switched relay contacts of the master safety relay SR-5 are closed which powers safety interlocking relays SR-6,7 allowing operation of the supply fan and providing power to the damper/valve actuators. If any safety device is actuated, its status contacts open de-energizing power to the coil of its associated safety relay and the master safety relay coil (Rung 7). With no power to the master relay coil SR-5, the interlocked fan starter and damper/valve actuators are disabled through the opening of the switched status contacts of the interlocking safety relays SR-6,7.

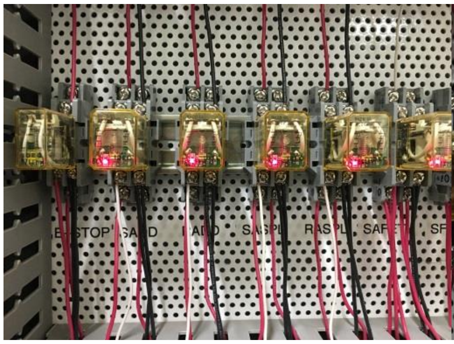

Photo 74 - Fan Safety Alarm Circuit Example 1

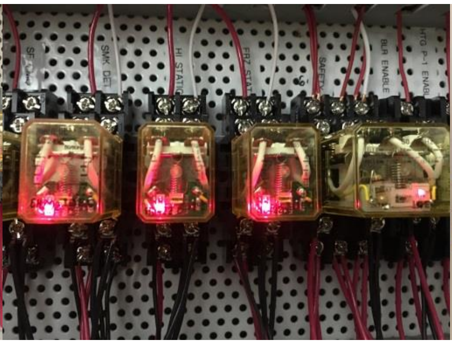

Photo 75 - Fan Safety Alarm Circuit Example 2

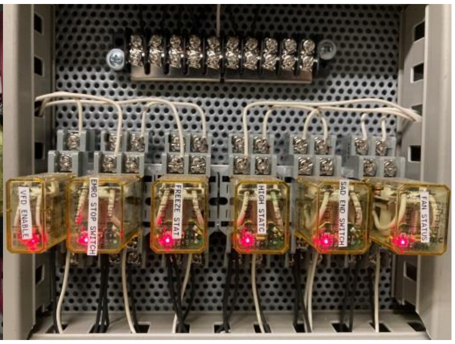

Photo 76 - Fan Safety Alarm Circuit Example 3

The LEDs of the safety relays provide a quick indication of the state of the circuit. When all safety devices are in their normal state, all LEDs will be illuminated as shown above. If any of the included safety devices activates (creating an open circuit), its corresponding LED will not be illuminated. In addition, the LED of the master relay SR-5 also will not be illuminated. With the master relay SR-5 disabled, the interlocking safety relay coils of SR-6,7 will also be disabled. In Figure 113, isolation relay SR-6 (rung 8) is mounted at the supply fan motor starter or VFD. Safety relay SR-7 (rung 9) is used to interrupt power to the damper and valve actuators if any safety device has activated. This fan safety alarm circuit allows the Owner and/or Control Technician to quickly determine which safety device has activated and respond accordingly.

The following photographs show a test FSAC that was constructed to illustrate how the LEDs are used by Control Technicians and Operators to determine which device has activated. The safety device contacts are simulated with toggle switches. When all safety devices are in their normal state, all isolation relay LEDs will be illuminated. If the low-temperature detector actuates, its LED and the LED of the master safety relay will not be illuminated. Likewise, if the

Estop (Emergency Stop) is activated, its LED and the master relay's LED will not be illuminated. When all safety devices are returned to their normal state, all LEDs will be restored.

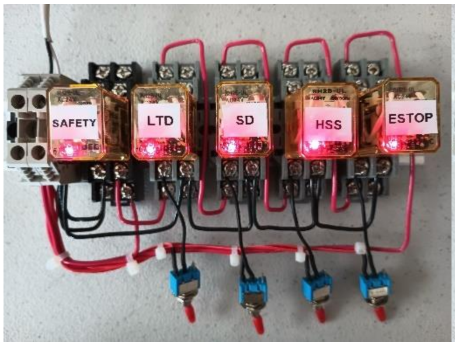

Photo 77 - Fan Safety Alarm Relay Assembly (Normal State)

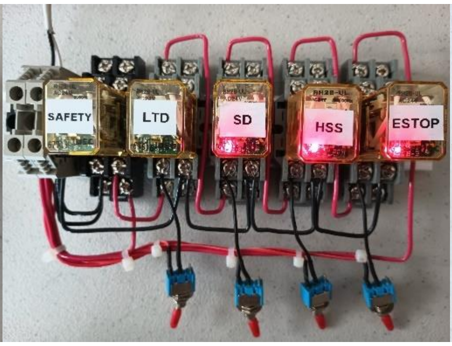

Photo 78 - Low-Temperature Alarm Simulation

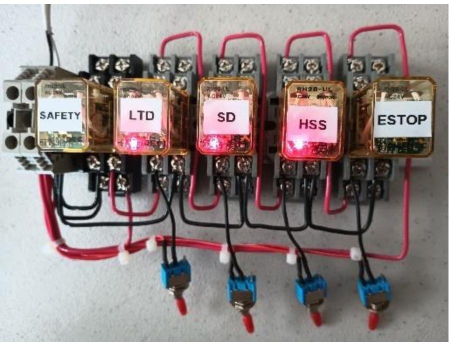

Photo 79 - Estop Alarm Simulation

With this wiring strategy and the use of ladder logic, it does not matter if the safety device has more than one set of status contacts because only one set is required. The DPDT relays provide the status contacts necessary to shut down the equipment and notify the BAS of the actuated safety device. It also simplifies the safety and interlocking wiring, increases safety, and reduces diagnosis and troubleshooting time allowing the responding staff to quickly identify the activated safety device and get the air-handling unit back on line as soon as possible.

6.6.1 Solid-State Fan Safety Alarm Circuit

A new, integrated, solid-state fan safety alarm circuit (Functional Devices, Inc. model RIBMNLB) is being used on controls projects with increasing frequency. It provides the same function as the traditional arrangement of individual isolation relays, but it comes completely assembled as an integrated circuit board and ready to use, minimizing the potential for wiring errors. It was immediately obvious that it vastly simplifies the LCP panel wiring and the time required to assemble and wire individual isolation relays in the traditional fan safety alarm circuit is completely eliminated.

Photo 80 - RIBMNLB-4 in Normal State

Photo 81 - RIBMNLB-6 in Normal State

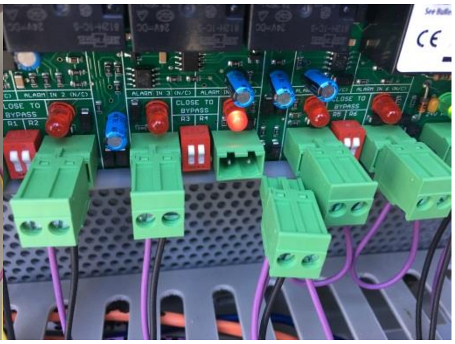

Photo 82 - Safety Device Terminal Lifted to Simulate an Alarm Condition

The onboard circuitry of the RIBMNLB monitors two, four, or six alarm input devices and opens the master alarm contacts if any of the monitored circuits open. As the RIBMNLB-4 is shown in Photograph 80, the four safety device contacts are connected to the input terminals along the bottom of the circuit board from left to right. The bottom far right terminals are where the 24 VAC power is connected. A green LED indicates the presence of 24 VAC power. Binary inputs of the BAS controller are connected to the four safety device status outputs along the top of the board from left to right. These contacts are normally-closed with no power and open while its corresponding safety device is in the normal state. The two sets of terminals at the top right are powered status contacts of the master relay which can be used to power interlocking safety relays. Power to these contacts is de-energized while an alarm condition exists. The terminals at the center along the right side of the circuit board are the master safety relay status contacts which remain closed until any of the monitored safety devices are activated. These are dry contacts with no power output and can also be used to interlock to motor starter and VFD safety circuits.

Although each input of the RIBMNLB can be individually removed from the relay logic with a dip switch, installers typically prefer to leave all safety device inputs enabled and install a jumper wire across the contacts of the unused inputs.

This provides a more conspicuous indication that this input is not currently monitoring a safety device. This solid-state FSAC provides exactly the same functions as the traditional FSAC, but is contained in a single pre-assembled circuit board. With exception of the safety devices themselves, all of the components included inside the dashed line are included in this integrated relay circuit board (Figure 114). It is not unusual to see jumpers installed across safety device input contacts whose devices have not yet been installed, powered, or wired. This is often done to allow temporary operation of the air-handling units during construction until the safety devices are installed and wired to the FSAC. However, when construction is complete there should only be jumpers on the inputs that are not used and they should be labeled as such.

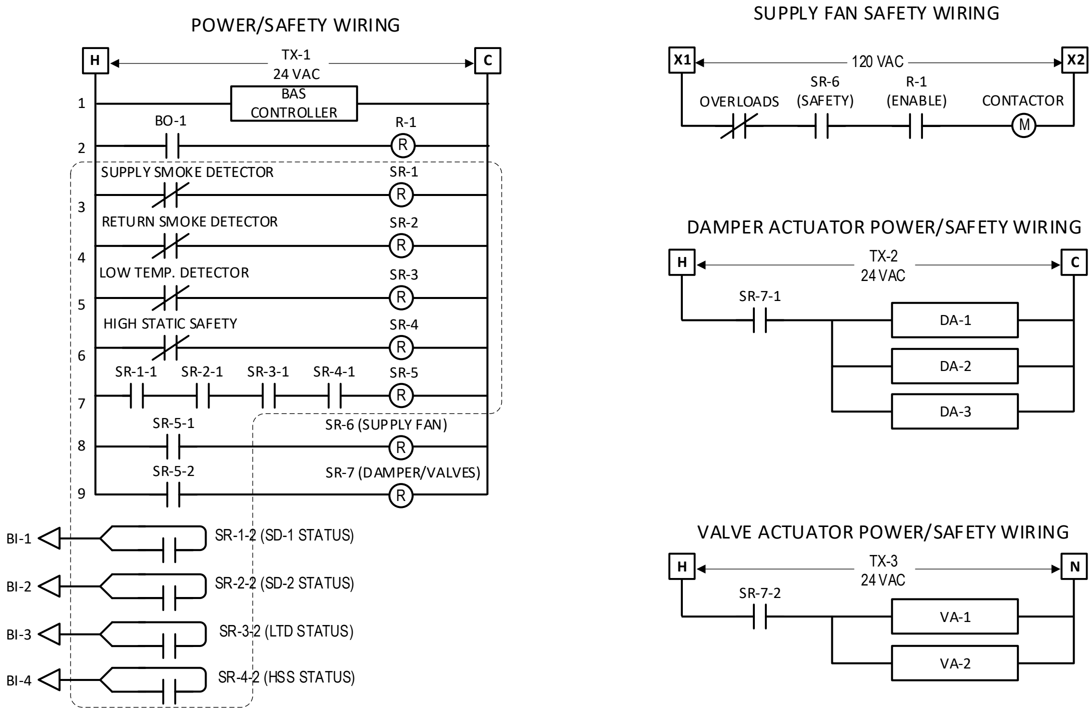

Figure 114 - Functional Devices, Inc. Fan Safety Alarm Circuit

Instead of multiple relays and the wiring between them, the RIBMNLB provides a single, integrated fan safety alarm circuit which vastly simplifies the local control panel wiring and significantly reduces assembly, installation, testing, and troubleshooting time. Operationally, it is exactly the same at the traditional safety alarm assembly. The main differences are the way the LEDs illuminate to indicate which safety device has tripped.

Prior to conducting any testing of this device, it is critical that each safety input device be identified and labeled. To do this requires that the status circuits of each included safety device be opened one by one to simulate the alarm condition. The opening of the status monitoring circuits should be performed at the safety device (not at the RIBMNLB). Do not lift the terminal blocks to perform device identification. As each status monitoring circuit is opened, this will cause the corresponding alarm status LED on the RIBMNLB board to illuminate providing positive identification of each input. As each safety device input is identified, it should be labeled.

The RIBMNLB is useful for preliminary testing of collateral sequences of operations testing, troubleshooting, and verification. Each input terminal block lifts out of its socket causing an open circuit which simulates the activation of the monitored safety device. For example, tripping a low-temperature detector typically causes the supply fan to be disabled, hot water control valve to open fully, coil pump to energize, and outdoor air damper to fully close. Lifting the terminal blocks can be used to perform preliminary testing of the collateral sequences of operation. Once the hard-wired and programmed control logic has been verified, the actual low-temperature detector can be tested to verify its operation.

The following photographs show a test FSAC using the RIBMNLB-4 that was constructed to illustrate how the LEDs function. When all safety devices are in their normal state, only the green LED will be enabled on the RIBMNLB circuit board to signify the availability of 24 VAC power. In addition, none of the red LEDs on the RIBMNLB will be illuminated and the two powered outputs will be energized to power interlocking safety relays. If the #1 safety device circuit is opened, its LED and the LED of the master safety relay will be illuminated to indicate the alarm condition. Likewise, if the #4 safety device contacts are opened, its LED and the master relay LED will be illuminated. When all safety devices are returned to their normal state, only the green LED will be illuminated. Some Controls Contractors do not like the RIBMNLB's LEDs indications because they are different from the traditional FSAC. However, they cannot deny the time savings, simplicity, and safety that they provide.

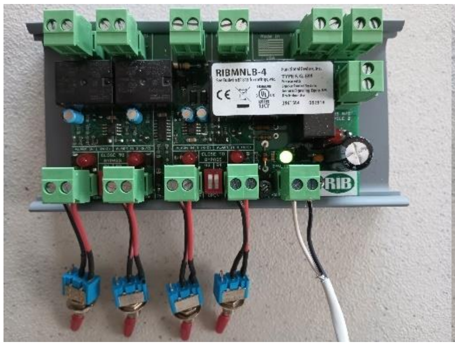

Photo 83 - Normal State (No Device Status LEDs Illuminated)

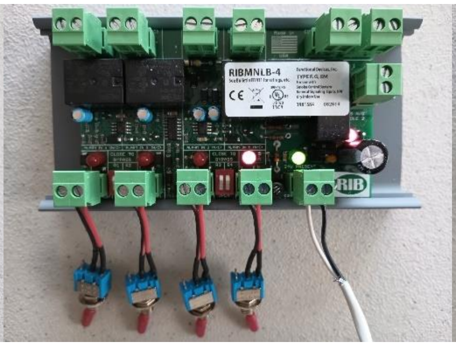

Photo 84 - Input #1 in Alarm and Master Relay LEDs Illuminated

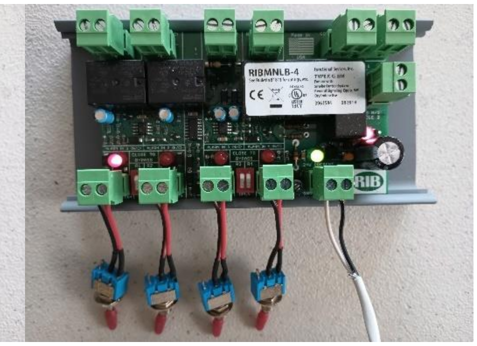

Photo 85 - Input #4 in Alarm and Master Relay LEDs Illuminated

Functional Devices, Inc. has further improved this innovative product by incorporating BACnet connectivity into the model RIBMNWLB-7-BC fan safety alarm circuit. Up to six hard-wired binary alarm circuits can be monitored and their status communicated to the BAS through a BACnet MS/TP (Master-Slave Token Passing) communication link which frees up to six binary inputs to monitor other devices. The seventh binary input (BI-7) is for monitoring the operating status of a monitored load (typically a supply fan) through a binary input device such as a current sensing relay or differential pressure switch. Either a dedicated low-voltage transformer or a diode is recommended to avoid electrical issues. This unit has two sets of switched 24 VAC contacts to power interlocking safety relays and two sets of dry DPDT switched status contacts that are used for interlocking with the motor starter control circuits or the VFD safety contacts. This unit provides hard-wired shutdown of interlocked equipment (typically air-handing units) as it always did, but it also has the ability to communicate the status of the monitored devices over BACnet MS/TP.

After addressing the board and setting the baud rate through dip switches, the BACnet link is established. The available BACnet points are then discovered and the select points added to the proxy points folder in Niagara. At this point, the proxy points are renamed to reflect the various connected alarm input devices. Jumpers are typically installed across the input contacts that are not used, but they can also be bypassed by using the dip switches. The RIBMNWLB-7-BC also has the ability to latch any or all alarm status indications and require either a physical or virtual input to release the latch. The physical latch release is activated by an onboard button associated with binary input eight (BI-8). The latch can also be released virtually through the "Clear Latches" BACnet point (BV-1). The master relay status is indicated by virtual binary output BO-1. The monitored fan status is indicated through BACnet by a virtual binary output (BO-2). This solid-state relay reduces the installation cost, vastly simplifies the wiring, and declutters the local control panel. The only notable difference in operation between this and the original RIBMNLB is that there is a delay (2-5 seconds) in the update of the BACnet point status. There is less delay at higher baud rates. However, this is not an issue because the physical outputs activate instantaneously to shut down the interlocked equipment.

6.7 Review

1. The ________________________ contacts of the safety device are included in the interlock wiring to allow the detection of open status-monitoring circuits.
2. How many individual double-pole, double-throw isolation relays are required in a traditional fan safety alarm circuit to monitor three safety devices? _______________.
3. How many isolation relays will be observed at an air-handling unit that is enabled by the BAS as well as disabled by any of its safety shutdown devices? _______________.
4. True or False: When a safety device actuates in a traditional fan safety alarm circuit, the master isolation relay LED will be illuminated Answer: _________
5. True or False: In a solid-state fan safety alarm relay, when a monitored device has actuated, its LED status indicator light is illuminated. Answer: _________
6. The RIBMNWLB-7-BC uses the ________________________ communication protocol to transmit the status of its monitored safety devices which allows BAS controller with smaller point counts to be used.

7. Which instrument will be the most useful when testing and troubleshooting fan safety alarm circuits?
   Answer: ________

   A. Ultrasonic flow meter
   B. Electron Telescope
   C. Electrical Multimeter
   D. Laser distance measuring tool

8. The RIBMNLB solid state fan safety alarm circuit has the following advantages: Answer: ________

   A. Minimizes local control panel clutter
   B. Simplifies the control wiring
   C. Reduces panel construction time.
   D. Facilitates testing and troubleshooting
   E. All of the above.

6.8 References

1. https://www.functionaldevices.com/support/downloads/datasheet-generator/?SKU=RIBMNWLB-7-BC
2. https://www.functionaldevices.com/?pagename=products/details&SKU=RIBMNLB
3. https://www.functionaldevices.com/support/downloads/datasheet-generator/?SKU=RIBU1C
4. https://www.functionaldevices.com/products/building-automation/relays/
5. https://www.idec.com/language/english/catalog/Relays/RHSeries.pdf

Chapter 7 - Essential Equipment, Tools, and Instruments

7.1 Occupational Safety and Health Administration (OSHA)

OSHA was formed in 1970 by the Occupational Safety and Health Act to ensure safe and healthful working conditions by setting and enforcing safety and health standards. There are a great number of regulations, so it is prudent to determine which are applicable to the activities that we routinely conduct. OSHA defines anything over 50 VAC as "high voltage" and this designation governs most electrical safety requirements in the construction industry. Most of the BAS infrastructure operates on 24 VAC, so it is considered a low-voltage system. However, this system is connected to high-voltage circuits and systems, so we must be cognizant of the safety requirements relevant to the high-voltage OSHA requirements. When access or measurements are required in any electrical enclosures that is considered high-voltage, the use of Personal Protective Equipment (PPE) and the appropriate safety precautions are required.

7.2 Personal Protective Equipment (PPE)

7.2.1 Hard Hat

BAS testing and troubleshooting typically takes place in mechanical equipment rooms, chases, ceilings, inside air-handling units, on the roof, in service tunnels, or any other place where the controlled HVAC equipment and its BAS input and output devices may be located. This often includes active construction sites where hard hat use is mandatory. We are often looking at our electronic devices, checklists, sequences of operations, drawings, submittals, etc. while walking in poorly lit locations. It is very easy to walk into a low-hanging beam, duct, pipe, all-thread, or structural supports. Of all the PPE, my hard hat has saved me from injury the most often. Full brim hard hats offer extra protection from the rain and sun when testing is required outside of the building. They tend to be heavier because they are larger than conventional hard hats. Fiberglass hard hats are lighter than typical high-density polyethylene hard hats. Carbon fiber hard hats are even lighter. Klein Tools© manufacturers hard hats with integral lamp holders for hands-free lighting that has proven to be very convenient and effective. An extra light is recommended. To be used at active construction sites, head protection must comply with American National Standards Institute (ANSI) Z89.1, "American National Standard for Industrial Head Protection." More information can be obtained by reviewing the OSHA Standard for Head Protection, Title 29 Code of Federal Regulations Parts 1910.135 & 1926.100.

Photo 86 - Klein Hard Hat with LED Head Lamp

Photo 87 - Lock-Out Tag-Out Accessories

Photo 88 - Half-Mask Elastomeric Respirator

7.2.2 High Visibility Safety Garments

The American National Standard for High-Visibility Safety Apparel and Headwear (ANSI/ISEA 107) is a standard established by American National Standards Institute, Inc. Most active construction sites will require the use of Class II safety garments (typically vests) for quick visual identification of all workers during low-light conditions. It is also very handy for carrying pens, pencils, earplugs, calculators, safety glasses, etc. in its pockets. Review the requirements of your work sites to be sure that your safety apparel complies.

7.2.3 Safety Glasses and Goggles

Most active construction sites will require the use of safety glasses. At times, we are testing and calibrating after the real construction has concluded. Therefore, safety glasses may not be mandatory, but they are still recommended. If you are working around moving or rotating equipment, the use of safety glasses is highly recommended. If you have to enter an operating air-handling unit, safety goggles are recommended because they provide better protection against debris and dust carried by air currents. Be especially careful when access to positively pressurized sections of air-handling units is required. The outward force produced by the internal pressure against the door can generate great forces. When access to these sections is required, either de-energize the unit or lower the operating speed of the fans to a safe level.

Goggles cover the eyes and are secured by a strap around your head. When opening doors in the positively pressurized sections of an air-handling unit, you should be especially careful. Debris is disturbed and agitated by the air currents and can easily end up in your eyes. Drilling holes in insulated supply ducts is another activity that poses a threat to the eyes from airborne debris. Insulation and metal shavings are blown out of the freshly drilled duct and air-handling unit penetrations. Protective eyewear must comply with ANSI/ISEA Z87.1, Occupational and Educational Personal Eye and Face Protection Devices. More information can be obtained by reviewing the OSHA Standard for Eye and Face Protection, Title 29 Code of Federal Regulations Parts 1910.133 & 1926.102.

7.2.4 Fall-Protection Harness and Lanyard

Work performed at heights in excess of six feet above the floor level requires fall protection. Fall protection can be provided through the use of guardrails, safety nets, or personal fall arrest systems. The personal fall arrest system consists of an anchorage, body harness, and connectors. The retractable lanyard is recommended as it allows much more freedom of movement once you are anchored to the structure. The body harness with tongue buckle leg straps is also recommended because they are much easier and quicker to put on and take off. Like the arc flash protection gear, your fall protection PPE should be kept in a dedicated bag for protection and easy identification. Additional safety information can be obtained by reviewing OSHA Fall Protection Standard, Title 29 Code of Federal Regulations, Part 1926.502(d).

7.2.5 Knee Pads

Knee pads are recommended if you have to kneel, crouch, crawl, or scoot under or through areas of the construction site. The older you are, the more you will agree that they are necessary field equipment. There are no regulations on knee pads. They only need to be comfortable, durable, and available.

7.2.6 Foot Protection

Steel-toe footwear complying with ANSI Z41 or Z41.1 is required on most active construction sites. Review the safety requirements for your projects. More information can be obtained by reviewing the OSHA Standard for Foot Protection, Title 29 Code of Federal Regulations Parts 1910.136 & 1926.96. On most post-construction job sites, footwear is not a critical issue. Follow your company's safety guidelines, project contract documents, and your best judgement in choosing a comfortable pair of work shoes.

7.2.7 Hearing Protection

Close proximity to operating HVAC equipment and construction machinery exposes us to high decibel levels which can have a long-term impact on hearing. Hearing protection should be used any time the noise becomes uncomfortable or when you are going to be around noisy activities for extended periods. Foam in-ear hearing protection is preferred over the over-ear hearing protection because of the size, weight, and they can be stored in multiple locations for easy access. Over-ear protection is difficult to wear when a hardhat is worn. Depending on the anticipated decibel levels, both may be required. More information can be obtained by reviewing the OSHA Standard for Hearing Protection, Title 29 Code of Federal Regulations Parts 1910.95 & 1926.101.

7.2.8 Arc Flash Protection

Arc flashes are always a potential danger when working around energized high-voltage equipment. Often, the testing and calibration of electrical monitoring devices such as current sensing relays, enable relays, safety interlock relays, current transmitters and power meters require access to live electrical circuits within disconnect switches, combination motor starters, junction boxes, wire troughs, disconnect switch panels, motor control center buckets, and VFD cabinets. Inside these enclosures are live conductors with voltages that approach 500 VAC. Most three-phase motors used in HVAC applications are rated for 208 VAC or 460 VAC. To install these devices, the electrical power can be de-energized and locked out. However, current and/or voltage measurements and setpoint adjustment of current sensing relays are required while the circuits are live and in operation. In these situations, we must dawn the appropriate PPE.

Each piece of equipment operating in excess of 50 volts and not de-energized must be evaluated for arc flash and shock protection. If you have to open energized high-power (>50 VAC) electrical panels, proper PPE (arc-rated clothing) is required to reduce the risk of injury. There are four Risk/Hazard Categories for selecting the appropriate level of PPE. One is the lowest and four is the highest level of protection. Each level corresponds to an incident energy level or range (calories per square centimeter).

PPE Category	Incident Energy (Cal/cm^2)
1	4
2	8
3	25
4	40

Table 60 - PPE Categories (NFPA 70E Handbook – 2021 Edition)

To determine the appropriate PPE level of protection requires the review of the arc flash hazard labels installed on the electrical enclosure. These labels provide a summary of the arc flash hazard analysis results which includes the arc flash hazard rating. This determines the minimum Risk/Hazard category that your PPE must provide. If these labels are not provided, then you must assume the highest risk/hazard category and use the appropriate PPE. To be on the safe side, de-energize the electrical panel or enclosure before performing any work inside it. Refer to NFPA Standard for Electrical Workplace Safety, 70E, for additional information on arc flash safety.

7.2.9 Gloves

We encounter many sharp edges and surfaces in the field, particularly with ductwork. Protecting our hands is extremely important. Lightweight synthetic gloves provide protection, yet provide tactile feedback and allow writing without removing them. Leather gloves give better physical protection, but significantly reduce manual dexterity. If you have to work in cold environments, fingerless gloves come in handy. They offer warmth and allow you to use your fingers to write, type, and operate test instruments. Every person has to determine their preferences and choose the appropriate gloves. More information can be obtained by reviewing the OSHA Standard for Hand Protection, Title 29 Code of Federal Regulations Parts 1910.138.

7.2.10 Lock-Out/Tag-Out

Lock-Out/Tag-Out (LOTO) procedures protect people from hazardous energy releases while they perform service activities. If you have to perform testing and troubleshooting in an electrical enclosure and it is safer to do it while it is de-energized, you will use Lock-Out/Tag-Out procedures. Upon de-energizing power, it should be locked-out and tagged-out to ensure that it is not inadvertently energized by someone else while you are performing your work. This is done by installing a hasp on the disconnect switch lever to prevent activation, installing a lock on the hasp, and providing a LOTO tag. It is a good idea to leave your phone number on the LOTO tag so that you can be contacted if you are not in the immediate area. When the work is completed, the LOTO lock, hasp, and tag are removed and the equipment reenergized. LOTO kits can be purchased that have several types of LOTO devices, locks, and tags. More information can be obtained by reviewing the OSHA Standard for the Control of Hazardous Energy (Lockout/Tagout), Title 29 Code of Federal Regulations, Part 1910.147. Section 1926.417(a), (b), and (c) ("Lockout and tagging of circuits").

7.2.11 Respirator

Occasionally, we are exposed to dust, fibers, and other respiratory hazards in the environment and air systems that we work with. Inspection and testing of the outdoor and return dampers while inside the air-handling unit mixed-air plenum, drilling holes in supply ducts, touching filters, adjusting supply air devices, and opening access doors in supply air ducts are examples of activities that expose us to air-born particulates. Lifting acoustic ceiling tiles and touching supply air Diffusers, Registers, and Grills (DRGs) can also dislodge accumulated dust and debris. To protect ourselves, dust masks and respirators are available. Half-mask elastomeric respirators with particulate filter cartridges are preferred to simple dusk masks (Photograph 88). They provide a much better seal against your face which maximizes the protection and minimizes the risk of particulates bypassing the filter media. This is especially important when working on existing air distribution systems that have lots of accumulated dust and debris. Without a respirator, particulate matter will be inhaled. OSHA requires a Respirator Medical Evaluation Questionnaire, medical evaluation, and fit testing if respirators are used. These steps are required to verify that an employee is medically able to use a respirator. More information can be obtained by reviewing the OSHA Standard for Respiratory Protection, Title 29 Code of Federal Regulations, Parts 1910.134 and 1926.103

7.3 Essential Field Tools

7.3.1 Ground Fault Current Interrupter (GFCI)

Ground Fault Current Interrupters are fast-acting circuit breakers that de-energize the power when current imbalances in the circuit are detected (Photograph 90). It monitors the current going to the electrical device and compares it to the current returning from the same device. If the difference in current exceeds 5 milliamps, the GFCI interrupts the electrical power. GFCIs are required for all devices plugged into temporary power sources. Extension cords should be plugged into a portable GFCI to monitor the current in the extension cord and all connected loads. GFCIs for construction use are generally large devices, but if only a laptop requires protection, then the Power First 15 Amp single outlet GFCI works well. It is compact, effective, and fits easily in a backpack. Additional safety information can be obtained in Title 29 Code of Federal Regulations, Parts 1910.304 & 1926.404.

Photo 89 - USB-Powered Air Pump

Photo 90 - Single Outlet Ground Fault Current Interrupter

Photo 91 - Electrical Receptacle Tester

7.3.2 Lighting

Good lighting is essential to implement field survey, testing, and photographic documentation. It is good to have several types of lighting available. If an electrical outlet is available and you will be working in the same area for an extended period, a 120 VAC LED work light works very well because it provides lots of light without the use of your hands to hold or position it. A recently acquired battery-operated LED work light has proven very convenient because it alleviates the need for an electrical cord and 120 VAC outlets (Photograph 93). If you are mobile and are constantly searching for the next sensor, actuator, or controller, then a Maglite® flashlight (uses two D-cell batteries) is useful because it can illuminate large areas at long distances. The Olight Swivel is a rechargeable light with an articulating magnetic base which is very useful in close quarters where you need to work with both hands (Photograph 94). In addition, it's small enough to store in your backpack, tool bag, or safety vest. Once the work location is determined, smaller handheld flash lights, work lights, or headlamps are used. It is a good idea to keep extra batteries, charging cable, and/or a charger handy.

Photo 92 - Maglite® Flashlight and LED Head Lamp

Photo 93 - Rechargeable LED Work Light

Photo 94 - Rechargeable Olight Swivel Work Light with Magnetic Base

7.3.3 Electrical Receptacle Tester

Testing and calibrating the BAS during construction will require that you connect your electrical devices to permanent and temporary sources of 120 VAC power. If you care at all about the replacement costs of the instruments (laptops, test instruments/meters, phone charger, lights, etc.) or the inconvenience that their loss or damage would cause, then a receptacle tester (Photograph 91) should be included in your tool bag or box. It is used to test the wiring of 120 VAC electrical receptacles to verify that they are correctly wired before plugging in your devices. It is good practice to be critical of all temporary and permanent 120 VAC power supplies on construction sites. Receptacle testers easily and quickly identify the most common wiring and connection errors. Most receptacle testers provide LEDs that indicate six possible conditions: Correct, Open Neutral, Open Ground, Open Hot, Hot/Ground Reversed, and Hot/Neutral Reversed (also called reverse polarity).

7.3.4 Electrical Extension Cords

Electric extension cords are often required in the field to connect laptops, chargers, lights, etc. to power sources that may not be near the immediate work site. Because of their temporary nature and the increased potential for physical damage, the use of GFCIs is recommended by OSHA. Only grounded extension cords should be used on construction sites. Do not exceed the manufacturer's amperage limit of the extension cord. If an extension cord has curls or waves, it very likely has been overheated and should be replaced. Extension cords should be inspected before each use for damage. If damage is found, they should be removed from service. Additional safety information can be obtained in Title 29 Code of Federal Regulations, Parts 1910.334 & 1926.405.

7.3.5 Allen Wrench Set

An Allen wrench (also called Hex Key) set is handy when you come across panels or other enclosures that are secured with socket cap screws. It is a good idea to have a compact folding hex key set and a set of individual Allen wrenches in your tool set. The handle of the folding hex key set serves as a good gripping surface to apply extra torque. A hex shank socket driver and a hex socket set or should be in your cordless drill case to make light work of hex head screws.

7.3.6 Torx Bit Set

More and more, screws with a Torx head are used in equipment such as Variable Frequency Drives (VFD). Their design resists cam out better than Phillips or slot head screws. T25 Torx screws are often used on the covers of VFDs. A T25 Torx bit and a cordless impact driver or drill make easy and quick removal of VFD covers.

7.3.7 Nut Driver Bit Set

A nut driver bit set is very useful when the installation of self-tapping sheet metal screws is required. The 1/4 inch hex shanks fit quick-change chucks making them compatible with any drill or driver which can save a lot of time when compared to manual installation and removal. It is typically a good idea to keep this power nut driver bit set in your cordless drill case. It is also a good idea to have both English and Metric sizes available to ensure the best fit for the fasteners.

7.3.8 Pressure/Temperature Ports

Pressure/Temperature (P/T) ports allow direct access to the fluid in the hydronic system for pressure and temperature measurements without disturbing the system or losing fluid. Because hydronic systems are typically under pressure, testing and calibration of hydronic sensors (temperature sensors, temperature switches, differential pressure transmitters, and differential pressure switches) are inherently more difficult and time consuming. The piping element that makes the most significant impact on the testing and calibration time of hydronic sensors is the Pressure/Temperature (P/T) port.

Photo 95 - P/T Ports Used for Temperature Differential Measurement

Photo 96 - P/T Ports Used for Pressure Differential Measurement

Photo 97 - Close up of P/T Port On Condenser-Water Piping

They are also referred to as Pete's Plugs® which is a product manufactured by Peterson Equipment Company, Inc. When a P/T port has been installed adjacent to hydronic pressure and temperature monitoring devices, they can be calibrated in a matter of minutes instead of hours. If you are involved in the design phase of a project, these are worth fighting for. The cost of P/T ports and their installation is well worth the time-saving benefits they provide for the initial and future testing, troubleshooting, and calibration of hydronic temperature and differential pressure input devices. However, only those who perform the testing and calibration work can fully appreciate a well-placed P/T port.

At the center of the P/T port is a neoprene or nordel core through which the temperature pressure probe passes. The core material maintains a physical barrier between the pressurized hydronic system and ambient air conditions outside the hydronic system. When the test probe is removed, the penetration in the core closes by compression. The lower the hydronic system pressure, the longer the resealing time. The P/T port cap also has a gasket for additional sealing should the P/T port weep. Without a P/T port, the time required to calibrate the input devices that monitor hydronic systems will be significantly increased because other more time-consuming methods must be employed.

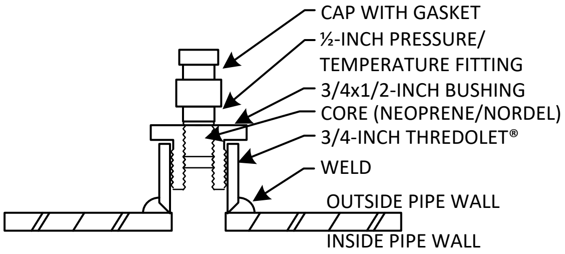

Figure 115 - Typical Pressure/Temperature Port Detail

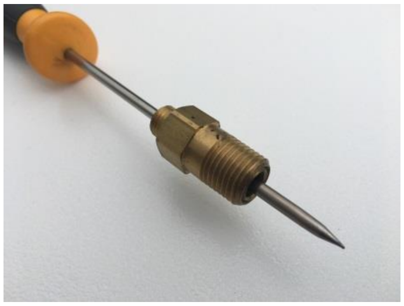

Photo 98 - Piercing Probe Through the Core of a Pressure/Temperature Port

As a general rule, P/T ports should be installed next to any hydronic temperature sensor and all piping system taps where piping/tubing connects to differential pressure switches and transmitters. This allows their readings to be tested and compared to reference readings without disassembly or the addition of piping fittings. Many specifications require that P/T ports be installed. However, the installing Pipefitter typically does not have the project specifications. They typically have the mechanical drawings and details, but will not install them if they are not clearly indicated on the mechanical details. To be sure that the P/T ports are installed, they must be shown on the mechanical drawings, details, schematics, project specifications, and symbol legend.

It is not uncommon to test and calibrate hydronic sensor/transmitters of systems that are not yet complete and operational. Testing and calibrating immersion temperature sensors under no-flow conditions when P/T ports are not available is not recommended. Therefore, removal of the temperature sensors from their thermowell and placement in a water bath is required to test and calibrate them. When this option is not feasible or safe (because of access and/or height), measuring the temperature of draining fluid corresponding to the temperature sensor under test may be required. These options are much more time-consuming than simply penetrating a P/T port with a piercing probe of a calibrated temperature meter.

Photo 99 - Removal of Immersion Temp. Sensor from Thermowell

Photo 100 - Immersion Temp. Sensor Placed in an Ice Water Bath

Photo 101 - Measurement of Chiller Condenser Water Temps.

7.3.9 Thermal Trap

A thermal trap is simply a length of pipe designed to prevent the sensor/transmitter from exceeding its high and low ambient temperature and humidity limitations. If the length of the sensing lines is too short, the hydronic differential pressure transmitter or switch could potentially be heated or cooled by conduction to the temperature of the flowing liquid. Providing the additional tubing/piping length and vertical directional change allows the convective and radiant thermal losses and gains to overcome the heat of conduction. This facilitates the cooling of hot pipes and heating of cold pipes to maintain the connected sensor/transmitter within its manufacturer-specified temperature and humidity limits. Thermal traps preclude the condensation of moisture on and inside the sensor housing. The thermal trap also works when the sensor transmitter is connected to piping systems at elevated temperatures. The minimum length of the thermal trap should be 24-36 Inches depending on the size of the sensing lines and the temperature difference between the hydronic system and space.

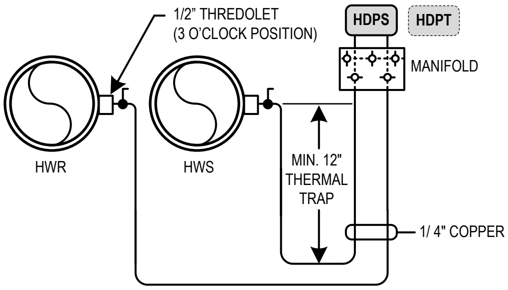

Figure 116 - Typical Thermal Trap Construction Example

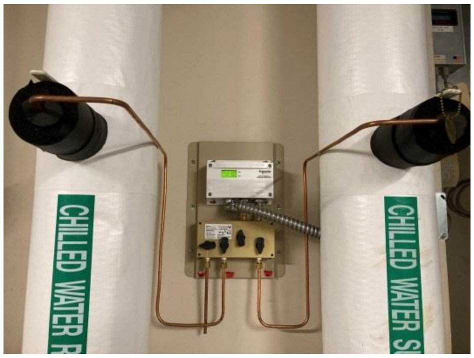

Photo 102 - Actual Thermal Trap Example

The connections to the sampled system should have isolation valves to facilitate field modifications of the pressure-sensing lines. If the sensing lines are not equipped with isolation valves, a system shutdown may be necessary to implement any required service after the initial construction. The threadolet fittings in the horizontal mains should be made between the 8 to 10 o'clock positions and the 2 to 4 o'clock positions of the pipe. They should not be installed at the 6 o'clock position (bottom) of the pipe cross section as the sensing lines could fill up with debris or the 12 o'clock position (top) as they could fill with air.

7.3.10 Magjumper™

The Magjumper™ is a temporary jumper wire that is equipped with magnetic contacts that make electrical connections on low-voltage (<50 Volts) circuits. Its magnetic ends allow you to temporarily "jump" or electrically connect the terminals monitored by the BAS. It is typically used on binary input devices like Air Differential Pressure Switches (ADPS), Hydronic Differential Pressure Switches (HDPS), Low-Temperature Detectors, or Current Sensing Relays (CSR). Placing the Magjumper™ ends across the open contacts will electrically simulate the alternate state. The Magjumper™ does not actually test the binary input device, but it does provide a quick way to identify the inputs, verify the point data (connectivity, logic, alarms, etc.), and verify the data point bindings with the BAS graphics.

Photo 103 - Magjumper™

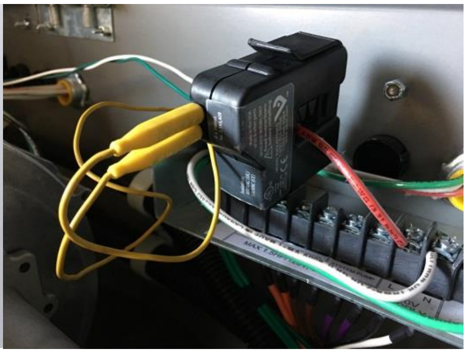

Photo 104 - Magjumper™ on a Current Sensing Relay Contacts

Photo 105 - Wire Pigtail For Hands-Free Wiring Connections

7.3.11 Hot Air Blower

A hot air blower may be used to heat the air surrounding wall-mounted space temperature sensors. The same can be performed with a space heater. It is useful when performing point-to-point checkout of VAV terminal units equipped with space temperature and discharge air temperature sensors. It is not uncommon for these temperature sensors to be switched. The hot air blower can be used to heat the space temperature sensor while monitoring the temperature readings (point data and BAS graphics) through the BAS. If the space temperature reading increases, it is logical to deduce that the temperature sensors have been properly landed on the BAS controller terminal board. If the discharge air temperature reading increases, then the sensor wires need to be switched at the BAS controller analog input terminals. Be sure to maintain a distance of at least 12 inches between the blower and the temperature sensor to avoid melting the cover or damaging the temperature sensor.

7.3.12 Slotted Precision Screwdriver

When working inside control panels, a slotted precision or "controls" screwdriver is essential. It is often necessary to disconnect sensor wiring for point-to-point verification, troubleshooting, and signal generator use. Normal-sized screwdrivers are too large for this task. The Klein 612-4 1/8 inch terminal block screwdriver has become the preferred controls screwdriver because of its long shank and rubber grip.

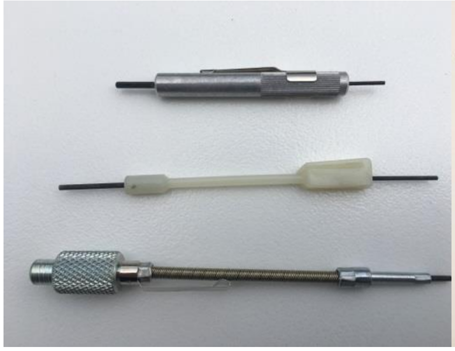

Photo 106 - Small Allen Wrenches for Sensor Covers and Pneumatics

Photo 107 - Klein Terminal Board Screwdriver and Wire Stripper

Photo 108 - Precision Slotted Screwdrivers

7.3.13 Wrench Set

A set of wrenches (ratcheting or non-ratcheting) make light work of most threaded fasteners. They may be used to install, adjust, or remove actuators, pneumatic fittings, adjust linkages, etc. It is a good idea to have both English and Metric sizes available to ensure the best fit. When working with electric actuators, 8 millimeter and 10 millimeter sockets are often required to tighten/loosen the jaws. The use of a Crescent® wrench and especially pliers to tighten/loosen nuts and bolts is not advised because the corners of nuts and bolt heads are easily rounded since torque is applied to only two of the six corners. The box ends of the wrenches, flare nut wrenches, and sockets contact all six corners of the nut or bolt head drastically decreasing the chance of damaging the corners.

Photo 109 - Electric Hot Air Blower

Photo 110 - Nut Driver Bit Set

Photo 111 - Inspection Mirror, Magnetic Retriever, 6-In-1 Screwdriver

7.3.14 Flare Nut Wrench Set

Flare nut wrenches are required to tighten and loosen piping and compression connections to avoid damaging the brass, copper, and steel fittings. The use of Crescent® wrenches, channel locks, and pliers is not recommended on pipe fittings because they contact only two corners when torque is applied which typically results in the rounding of the corners. Flare nut wrenches contact all six corners simultaneously and minimize the risk of damage. When connecting test instruments to hydronic pressure switches and pressure transmitters, flare nut wrenches are ideal because they prevent damage to the fitting connections. It is a good idea to have extra flare nut wrenches in the 1/2 inch and 9/16 inch sizes because they tend to be required more often than other sizes when tightening and loosening compression connections.

7.3.15 Socket Wrench Set

A socket wrench set and a ratchet are very useful tools to have available when bolt heads and nuts need to be turned. Deep well sockets are very nice to have when the bolt shafts extend well beyond the nut threads. When working with electric actuators, 8 millimeter and 10 millimeter deep-well sockets are often required. It is also a good idea to have both English and Metric sizes available to ensure the best fit for the fasteners. A 1/4 inch hex drive to 1/4 inch (or 3/8 inch) square adapter is also recommended to allow the use of a drill or driver to quickly turn the sockets.

Photo 112 - Pipe Wrench for 1" Damper Shaft

Photo 113 - Socket to Tighten/Loosen Actuator Jaws

Photo 114 - Pipe Wrench for 1/2" Damper Shaft

7.3.16 Utility Knife

A utility knife or pocket knife is another general tool that is always good to have available when something needs to be cut, trimmed, scraped, opened, or otherwise modified. A utility knife that can be retracted or folded so that it can be safely transported is recommended. It is also a good idea to keep a roll of duct tape, white all-service jacketing tape, and aluminum insulation jacket foil tape for the repair of duct and pipe insulation, if required.

7.3.17 Pipe Wrench

A pipe wrench allows you to turn damper and valve shafts, piping fittings, as well as the pipe itself. A 10 or 14 inch pipe wrench will suffice as most pipes, shafts, and fittings are under an inch and large turning forces are not required. A light-weight aluminum pipe wrench is typically preferred for use and transport. The pipe wrench is used to grip the damper or valve shaft, rotate it to the correct position (fully open or fully closed), and hold it there while securing the actuator jaws to it.

7.3.18 Wire Strippers

Wire strippers are used to cut wires as well as strip the plastic sheath from the individual wires in preparation for placement in a terminal strip or wire nut. When existing wires are modified, the ends are often too frayed and deformed to allow reinsertion into the terminal block or wire nut. A short section of wire is often trimmed and the sheath stripped to create a neat wire end for final termination. Wire strippers that can be locked in the closed position are preferred for safety as well as to minimize the space they take up when not in use.

7.3.19 Pliers

Pliers are a great general tool for a variety of miscellaneous tasks where gripping, pulling, twisting, and cutting of various parts are required. They should not be used to apply high torque levels because they only contact two of the six corners of the nut or bolt head and will damage them. A pair of needle-nose pliers is also very handy when inserting wires and resistors into controller, sensor, or actuator terminal blocks. The point of needle-nose pliers can also be used to expand the ends of polyethylene tubing before making connections with pneumatic fittings. They are especially useful for placing and removing wires in congested control panels.

7.3.20 Flexible Measuring Tape

Flexible measuring tapes are used when it is difficult to measure the duct or pipe size. Measuring the circumference and dividing this value by π (3.141593) is an easy way to determine the outer diameter. If the duct or pipe is insulated, determine the outer circumference with the flexible measuring tape and calculate the outer diameter ($D=C/\pi$). Using a nail, wire, or knife, determine the insulation thickness and subtract twice this value from the outer diameter to determine the diameter of the pipe or duct.

7.3.21 MagBench

The MagBench is a mobile magnetic workbench that can support a laptop, tablet and field tools. Its strong neodymium magnets can easily support the weight of a laptop as well as a variety of field tools. Apply the MagBench to the side of any ferrous panel or enclosure and lower the bench. Your laptop or tablet will be safely and securely supported. It is highly recommended that you apply rubber bumper pads on the MagBench surface to prevent your laptop or tablet from sliding off.

Photo 115 - Fluke Networks Pro3000 Tone Generator and Probe

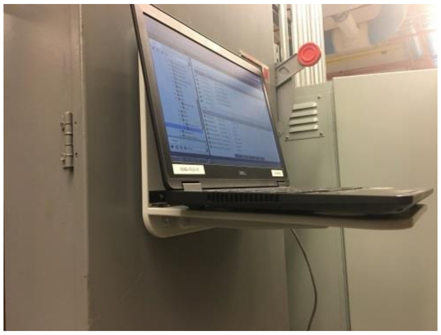

Photo 116 - MagBench Supporting a Laptop

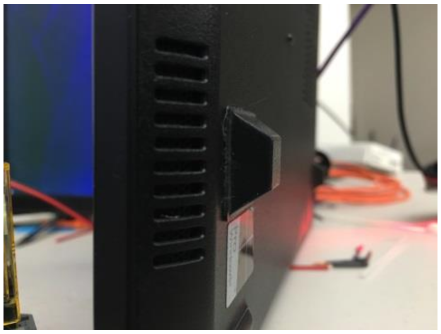

Photo 117 - Rubber Feet to Maintain Laptop Airflow

If you are on a rooftop, be sure not to locate the MagBench on any door of an air-handling unit or electrical enclosure which may be moved by people or the wind. A tarp and magnetic hangers are very useful for creating a quick canopy when it is raining or shade for yourself and your laptop when it is sunny. Creating shade can greatly improve the visibility of the computer screen and reduce heating of the laptop when working under direct sunlight. Lighter colored and opaque tarp and canvas materials are recommended to lower solar heat absorption and reradiation when working below them.

Photo 118 - Squeeze Bulb

Photo 119 - Magnetic Hangers for Tarp Support

Photo 120 - Temporary Cover for Controls Laptop

7.3.22 Tone Generator and Probe

Unfortunately, we are often faced with unidentified or mislabeled wires in a local control panel, wire bundle, trough, or device. The Fluke Networks Pro3000 tone generator and probe are used to identify questionable wires (Photograph 115). A tone generator is connected to the accessible end of the electrical conductor(s) and a signal is broadcast on it. The other end of the wire is identified by passing the probe over the wires until it detects the signal from the tone generator and generates an audible and visual signal. The newly identified wire can then be labeled or its label corrected. This tool saves a lot of time when faced with making sense of unidentified or mislabeled wires. Without it, following wires end-to-end and continuity tests are typically conducted to identify unknown wires which can be ridiculously time consuming.

Photo 121 - Label Maker

Photo 122 - RJ45 Ethernet Crimper

Photo 123 - Ethernet Cable Tester

7.3.23 Adjustable Wrench

An adjustable wrench, also called a Crescent® wrench, is a type of wrench that is often useful when making piping and mechanical fastener connections. Crescent® is a wrench manufacturer and its name has become synonymous with this type of wrench. They provide a means to twist the heads of bolts, nuts, and other threaded components. They are not good for large torques as they can easily round the corners of the bolts and nuts. Higher levels of torque are safely applied with socket, box-end wrenches, and flare nut wrenches.

7.3.24 Inspection Mirror

An inspection mirror is recommended because the equipment is not always installed for best visibility. There are many situations where we need assistance to see under, over, or behind another object and an inspection mirror provides this capability. Often nameplate data is blocked by other equipment, duct, piping, or conduits and we need a way to see what is not readily visible. Cell phone cameras can also be used to view and take photographs of nameplates that have been installed in positions and locations that do not permit easy access for inspection.

7.3.25 Label Maker

All wires, tubing, sensors, sensor transmitters, power supplies, BAS controllers, actuators, relays, space temperature sensor, space static pressure pickups, etc. should be labeled. This label indicates their purpose, designation, system to which it belongs, or BAS controller input/output to which it is connected. Labels are a very good indicator of the quality of the BAS installation. When the installing contractor has labeled the components, wires, and tubing of the BAS installation, there is a much higher likelihood that these devices were properly installed, connected, and configured. Labeling minimizes the work required for all involved in the operation, warranty, service, maintenance, and troubleshooting activities that will follow the initial installation. As innocuous as labels may seem initially seem, they actually have a significant impact on the time that will be spent resolving temperature control issues, troubleshooting the system, and tracing wires and tubing to verify their connectivity over the system's lifetime. Every task related to the BAS takes longer when its wires, tubing, and devices are not labeled.

There are many label makers available. Typically, the simpler, smaller devices are better in the field. The Brady M210 is an extremely flexible labeler that can print in multiple orientations on a variety of tapes (Photograph 121). With an optional 120 VAC transformer you can charge the rechargeable battery and print when the regular batteries are fully discharged. To minimize the frequency of label tape replacement, it is a good idea to buy label tape refills with a larger capacity. Most label tapes are 3/8 inch, 1/2 inch, or 3/4 inch wide and the printer generates black text in various sizes. A case or shell to protect the label maker when it is not in use is recommended. In addition, it provides a great place to store spare label cartridges, transformer, and batteries. It is a good idea to keep a small pair of scissors handy if the label tape requires trimming to fit the available space.

Photo 124 - Label Tape Wrapped around Control Wires

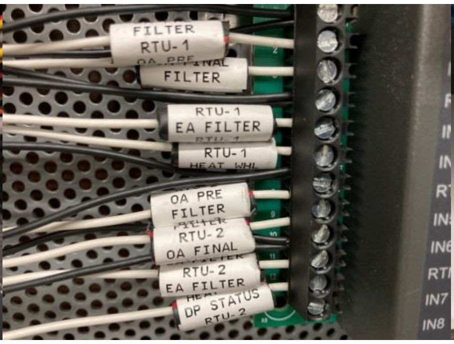

Photo 125 - Label Tape Wrapped Around Pneumatic Tubing

Photo 126 - Label Tape Wrapped Around Wire Sheath

Controls Contractors have devised many different ways of labeling the wires and tubes. The simplest form of wire labeling is performed by writing the signal (source or destination) on the sheath of the wire with a permanent marker. Label tape with adhesive backing may be wrapped around the wire sheath to identify the wire's source or destination (Photograph 124). Another method utilizes a short length of 1/4 inch polyethylene pneumatic tubing on which the label tape is applied and the two or three wires pass through the labeled tubing (Photograph 125). This method has the most professional look and the labels stay in place. When controls are installed and the wires are landed on the controllers, there is no shortage of scrap wire. The wires are removed from the protective sheathing and it is cut to length to fit the label tape. The wires then pass through the labeled wire sheath (Photograph 126). An additional application of clear tape may be required in areas subject to elevated temperatures to prevent the label tape from falling off.

The labels are not for the person or persons that just installed the controllers, devices, the wiring. They are for the various people that will visit this system to survey, test, and troubleshoot the control wiring in the years to come. It allows them to quickly learn the system and its configuration. JACE panels should be labeled with the primary and secondary IP (Internet Protocol) addresses and subnets to aid in establishing the network connections necessary to access the system. Labeling is a sign of quality and that the Controls Contractor has verified the connectivity of installation. BAS controller input devices should be labeled to indicate the monitored parameter and the intended binary or analog input. This applies to equipment-mounted, duct-mounted, pipe-mounted, as well as the devices mounted in the occupied/monitored space. For example, space sensors (temperature, humidity, carbon dioxide, space static, occupancy override switches, etc.) should be labeled to indicate the associated system, zone, or terminal unit. Output devices should also be labeled to indicate controlled equipment/system and the source of the signal (BO-2 or AO-1). As the number of BAS points (inputs and outputs) increases, the importance of labeling likewise increases. In the life span of a typical BAS, labeling can have a significant effect on the operational costs.

Photo 127 - Label Tape with IP Address and Subnet of JACE

Photo 128 - Label Tape on Space Temperature Sensor

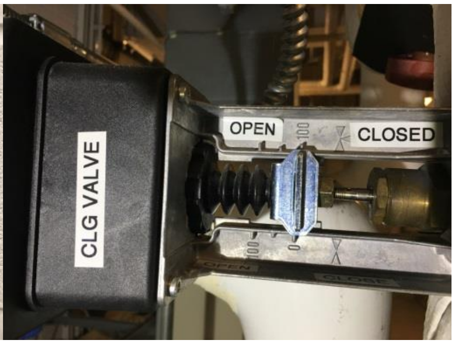

Photo 129 - Label Tape Marking Control Valve and its Positions

7.3.26 Measuring Tape

A measuring tape at least 12 feet in length is recommended. It is used for a variety of tasks requiring measurement of short distances. Measuring tapes are used for verifying clearances to combustibles, duct sizes, room dimensions, and to verify minimum lengths of duct and piping upstream and downstream of air and water flow measuring devices. The measuring tape is also used when airflows are determined by the duct traverse method. To perform a duct traverse, the measuring tape is used to mark the locations where the duct penetrations will be drilled. It is also used to mark the depths at which Pitot tubes and air foil probes will be inserted into the duct. The main disadvantage of measuring tapes is that they are typically constructed of ferrous metal and once they get wet, they begin to corrode. If room dimensions and/or ceiling heights measurement are required, a laser distance meter is highly recommended to save time.

7.3.27 Laser Distance Meter

Laser distance meters function by measuring the time that it takes a pulse of light to travel to the target surface and back to the source. Knowing the speed of laser light, the distance is calculated by multiplying the time it takes the laser to make the round trip by the speed of the laser light. This value is then divided by two because the laser light makes the trip twice. The laser distance meter is used to measure clearances, room dimensions, and ceiling heights. The Bosch GLM165-40 laser distance tool is economically priced and performs well for typical building dimension measurements. It is an immense time-saver when compared to the use of conventional measuring tapes.

7.3.28 Cordless Drill/Nut Driver

A cordless drill/driver are highly recommended tools because it is often necessary to install and remove screws, nuts, and bolts. They may also be used to drill holes in the ducts or air-handling unit enclosures to facilitate field measurements, static pressure profiles, and perform sensor/transmitter calibrations. Socket adapters, power nut driver bit set, Torx, Allen, and drill bit sets are also recommended accessories to have on hand. It is also good idea to maintain a supply of 3/8 inch duct plugs and several 3/8 inch diameter drill bits on hand if duct static pressure or duct traverse measurements are required. If temperature readings in a duct are taken with a bead probe temperature sensor, self-tapping screws can be used to make the hole and seal it after the measurements are made. Small holes can also be sealed with foil tape.

7.3.29 Ladders

A minimum six-feet tall, fiberglass, A-frame ladder is recommended as standard equipment because we cannot always count on a free ladder being available for use on a job site. BAS system components are often installed high enough that we cannot reach them from the ground, so a ladder is often necessary. Providing your own ladder is preferable because it is available when you need it, its condition is known, and you will not impede the work of someone else by borrowing their ladder. Ladders rated for 300 pounds are very sturdy and do not wobble. The downside is that they are heavier and require a bit more effort to carry and maneuver. Depending on the height you have to attain and the project requirements, other ladder types and sizes may be required. Do not use the top rung of any ladder as this is forbidden by OSHA. If using an extension ladder, it must extend at least three feet above the point of support and the top and bottom of the ladder should be secured to a point of anchorage. If your vehicle has a ladder rack, be sure to have the ladder stop accessories that prevent the ladder from sliding off. Additional safety information can be obtained in Title 29 Code of Federal Regulations, Part 1926.1053.

7.3.30 Ethernet Crimping Tool

An Ethernet crimper tool is required on most jobs to install Ethernet connectors on the ends of the Ethernet cables. Many Ethernet crimping tools are available. The simpler tools work best and offer the fewest opportunities to commit errors. The Ideal 30-495 FT-45 is an Ethernet crimping tool that is specifically designed for RJ45 connectors (CAT5e and CAT6). It is a compact, simple, and economical Ethernet crimping tool. Once the stripper/crimper tool has been selected, the type of RJ45 connector to install on the ends of the Ethernet cable is the next big decision to make. Pass-through connectors are often preferred because they preclude the need to strip the wire ends and the wires pass through the network connector end to allow the review of the wire sequencing one last time before they are trimmed and crimped. Be sure to verify that the connector is compatible with the type of wire used. As the use of Ethernet-connected controllers becomes more commonplace, the value of this tool will only increase.

Photo 130 - Dewalt Cordless Drill

Photo 131 - Milwaukee Cordless Impact Driver

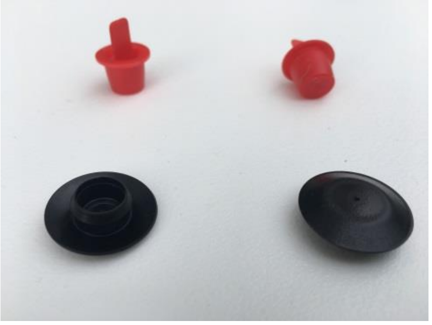

Photo 132 - Typical Duct Plug Types

7.4 Transport and Storage

7.4.1 Equipment Cart

Controls work often requires the transport of numerous tools, instruments, project documentation, bags, etc. An equipment cart makes it easy to transport all of the necessities around the worksite. Your equipment cart may have several upgrades to facilitate fieldwork which include a ladder rack, locking casters, rubber/foam wheels, and an electrical power strip. Its value increases if you are working on a large site where you have to move from place to place frequently or there are large distances between work areas. The equipment cart is especially useful when the use of a laptop is required. An audio/visual cart with upgraded 4 inch diameter casters elevates the top shelf making it an ideal height for laptop use which minimizes back and eye strain.

7.4.2 Table and Chair

Comfort has a significant impact on the quantity and quality of work when testing and calibrating BAS components in the field. A folding table and folding chair provide optimal comfort for working on a laptop, reviewing documents, and taking notes. There comes a time in everyone's career when sitting on a bucket and supporting your laptop on filter boxes will no longer suffice. The availability of a table and chair is often dependent on the type of vehicle that you drive. It is much easier to carry tables and chairs when you are equipped with a vehicle with sufficient space.

Photo 133 - Equipment Cart

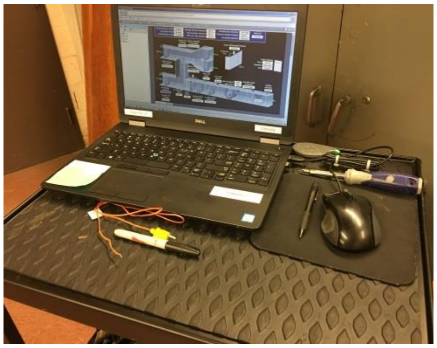

Photo 134 - Top Tier of Equipment Cart for Controls Laptop

Photo 135 - Table and Chair for Field Use of Controls Laptop

7.4.3 Work Vehicle

A work vehicle (van or truck) allows the transport of larger items and more items than can be carried in a car. Examples of these larger items include ladders, equipment carts, instruments, job boxes, tables, chairs, etc. A person works more accurately and effectively when properly equipped for the job. Minivans with ladder racks are a great option because they are big enough to hold all that is needed in the field yet small enough to fit in most parking garages. Having a work van or truck removes the limitations on how much you can transport to a job site thus allowing you to work more effectively and create the conditions that maximize work productivity and comfort.

7.4.4 Job Site Box

If the project is large enough, it may warrant the use of a job site box. Within the job site box, all of your tools, equipment, documentation, and instruments can be securely stored onsite overnight. It eliminates the need to transport the required resources to and from the job site every day which is advantageous at high-security facilities. If you have instruments, laptops, tablets, or other electronics that need to be charged, many job boxes have a penetration on the side or bottom to allow an electrical extension cord to pass.

Photo 136 - Job Site Storage Box

Photo 137 - Work Vehicle

Photo 138 - Veto Pro Tech Pac LT Tool/Instrument Bag

7.4.5 Tool Bag/Box

Control work requires a variety of tools, instruments, and equipment. Most people carry a small tool pack or backpack with the essential tools and keep the rest in their vehicle or office. The tools and instruments that are most commonly carried include: multimeter, 6-in-1 screwdriver, wire strippers, snipe note pliers, adjustable wrench, electrical tape, LED flashlight, and precision screwdriver. With these tools, you can accomplish 80-90% of the typical controls survey, testing, and troubleshooting tasks. Depending on what is planned, a large canvas tool bag can be filled with the miscellaneous instruments, tools, and documentation required for the day.

7.5 Instruments

7.5.1 Digital Camera

Digital cameras aids in the documentation of testing and calibration results, commissioning issues, nameplate data, as well as construction progress. If issues or deficiencies are identified, a photograph or video is a convenient way to document, time stamp, and share this information. Today mobile phones can take high-quality photos and videos that equal or surpass most point-and-shoot digital cameras. Another advantage with mobile phone cameras is that they are always available as we typically have our phones nearby. One disadvantage of phone cameras is that most do not function well in low-light conditions. Supplemental lighting is often required to produce clear, focused photographs in low-light conditions.

7.5.2 Continuity Tester

Testing of binary input devices and tracing wires may require continuity tests. Most multimeters provide this capability, but their volume is typically too low to be heard in a noisy environment. The Extech CT-20 continuity tester is very useful because it provides both visual and audible indications of continuity that are distinguishable from equipment operating noise and is visible in brightly lit spaces. This unit emits a loud tone and illuminates a light when continuity between the two alligator clamps is established.

7.5.3 Network Cable Tester

A network cable tester is recommended where Ethernet cables are installed. These units are used to verify that the eight wires were properly sequenced in the Ethernet connector before they were crimped and put into service. Most cable testers have the ability to test several types of voice and data cables. The Klein VDV526-100 is an economical RJ45 cable tester that has proven to be simple to use and reliable. Most testers have LEDs that indicate the result of the cable test. A remote module connects the appropriate pairs of wire and the tester verifies connectivity at the other end of the Ethernet cable to confirm that they were properly installed in the connectors. If the tester identifies a problem, it will indicate the issue with a code or LED indication. Review the wire sequencing at both ends, install another connecter, and retest.

7.5.4 Digital Multimeter

A digital true Root Mean Square (RMS) multimeter is used to measure several parameters including voltage [Alternating Current (VAC) and Direct Current (VDC)], amperage, resistance, and continuity. It provides a means to test and troubleshoot control and power wiring. The Fluke model 179 multimeter is a good, reliable multimeter for field work. The Klein Tools® MM400 is also a very good, economical alternative. It is a good idea to have alligator clips and several wire pigtails to create hands-free test connections. In addition, it is recommended that the magnetic hanger kit be used to allow the multimeter to be hung on the side of any ferrous panel which also helps to keep your hands free.

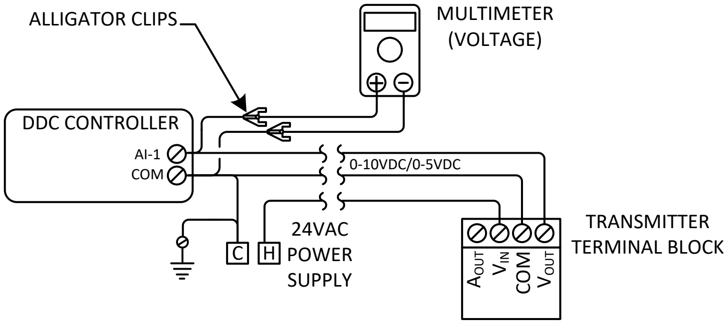

Figure 117 - Voltage Monitoring with Digital Multimeter

Amperage readings will often be required when testing loop-powered sensor transmitters that provide a current output. The digital multimeter must be part of the electrical circuit to get a current reading. This will require that at least one short wire be installed at either the BAS controller or at the transmitter terminal block to allow a hands-free connection with the multimeter alligator clips. Review your multimeter instructions to ensure that the wire probes are properly placed for current measurements. When you are finished with current measurements, be sure to change the multimeter setting back to voltage readings before touching voltage terminals with the test leads to avoid blowing the internal fuse. It is a good idea to have a backup multimeter or multimeter fuses in case this occurs.

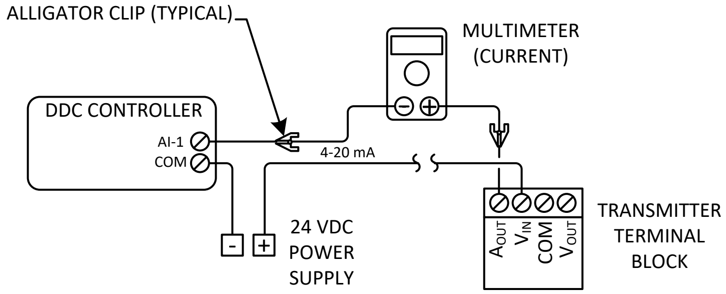

Figure 118 - Amperage Measurement in a Loop-Powered Circuit with a Digital Multimeter

7.5.5 Signal Generator

A voltage/milliamp calibrator is used to simulate analog input signals (humidity, carbon dioxide, differential pressure, etc.) and output signals (capacity, speed, actuator positions, etc.) for BAS testing. It is typically called a “signal generator.” Occasionally, you may not have access to the program, but you have access to the graphics. Voltage and analog signals can be simulated to verify how the BAS controller interprets the signal. Simulating a 10 VDC (or 20 mA) signal will cause the value displayed on the graphic to change. Changing this signal to 5 VDC (or 12 mA) will cause another change in displayed value. If there is any doubt of the analog input parameters or the operation is critical, the signal generator provides an additional means to test and verify the analog input configuration and control logic operation. The Fluke model 715 is simple, easy to use, and can simulate amperage as well as voltage input signals. The Victor 71B is also a very good, economical alternative. The signal generator can make stepped signal increases of 25% or finer steps, if desired. Signal generators give us the flexibility to simulate control signals before, during, or after the completion of the BAS installation.

Photo 139 - Digital Multimeter (Fluke 179)

Photo 140 - Volt/Amp Calibrator (Fluke 715)

Photo 141 - Process Clamp Meter (Fluke 773)

Before disconnecting any BAS controller terminals to connect the signal generator, be sure that you understand the configuration of the analog input, the transmitter characteristics, and the output device reaction. Make a sketch or take photographs of the wiring to ensure that the circuit where the signal generator is connected is understood and documented. Disconnect the sensor transmitter wiring from the BAS controller. In its place, connect a wire pigtail to the BAS controller terminals and use the signal generator’s alligator clips to connect to the ends of the wire pigtail. Follow the wiring directions of your signal generator because the connection requirements for simulating voltage and current signals are typically different. Ramp the simulated voltage or current signal up and down to verify that the BAS controller properly interprets the analog input signal and provides the correct reading. Simulate the suspected voltage or current range and verify what the BAS controller reports.

7.5.5.1 Analog Input Signal Simulation

The signal generator may be used for testing the programmed logic of a BAS controller by simulating changes in the process variable and observing the reaction. For example, if we wanted to simulate changes in differential pressure in a chilled water system and observe the system response (pump speed adjustment), the signal generator would be connected to the analog input for the differential pressure transmitter. Suppose the differential pressure transmitter had a 0-50 PSIG input range and a 2-10 VDC output range. This would mean that the BAS would interpret a 2 VDC as 0 PSIG and 10 VDC as 50 PSIG. All other points can easily be simulated with the signal generator. As the simulated pressure reading is ramped above and below the setpoint, the speed of the pump VFD will adjust accordingly.

Percent of Scale	Simulated Signal (VDC)	Differential Pressure (PSIG)	Pump Speed (Hertz)
0%	2	0	60
25%	4	12.5	45
50%	6	25	30
75%	8	37.5	25
100%	10	50	15

Table 61 - Simulated Analog Input Steps – Voltage Signal

The positive signal generator lead is connected to the positive terminal of the BAS controller's analog input and the negative signal generator lead is connected to the negative terminal of the analog input using alligator clamps. A wire pigtail is typically used to provide hands-free wiring connections. If the analog input device (typical of differential pressure transmitters) is remotely located, the signal generator should be connected to the circuit at the device end. This allows the wiring and their connections to be part of the test.

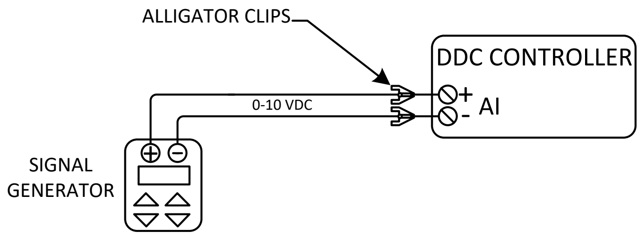

Figure 119 - Signal Generator Schematic (Simulating BAS Voltage Signal)

7.5.5.2 Analog Input Signal Simulation - Loop-powered Transmitters

Using the signal generator requires knowledge of the "loop-powered" circuit. The sensor transmitter outputs an amperage signal between 4 mA and 20mA that is proportional to the sensor range. The signal generator simply replaces the sensor transmitter in the loop-powered circuit and allows manual control of the current flow through it. This ability allows the manual adjustment of the analog input signal using the existing 24 VDC power supply as the current source.

Percent of Scale	Milliamps	Static Pressure (Inches W.C.)
0%	4.0	0.0
25%	8.0	2.5
50%	12.0	5.0
75%	16.0	7.5
100%	20.0	10.0

Table 62 - Simulated Analog Input Steps – Current Signal

For example, if you have 0-10 inches W.C. static pressure transmitter with a 4-20 mA output signal, the signal generator current can be stepped at 25% increments to verify that the analog input has been correctly configured in the BAS controller. At each mA signal step, the corresponding static pressure readings should be observed for the corresponding analog input data point. At the same time, the sequences of operation related to this static pressure reading can also be tested.

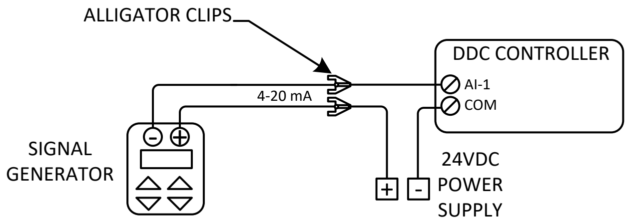

Figure 120 - Signal Generator Schematic (Simulating a Current Transmitter) Check

7.5.5.3 Analog Output Signal Simulation – Equipment Capacity/Setpoint Control

The signal generator can also be used to simulate analog output signals from a BAS controller that controls the setpoint or output capacity of packaged equipment such as variable frequency drives, boilers, chillers, humidifiers, SCR electric coils, etc. Typically, 0-10 VDC or 2-10 VDC analog output signals are used. Review the equipment submittals to verify whether the equipment is configured for capacity or setpoint control. It is not uncommon to find that equipment is configured for remote setpoint control when the design requirements call for remote capacity control or vice versa.

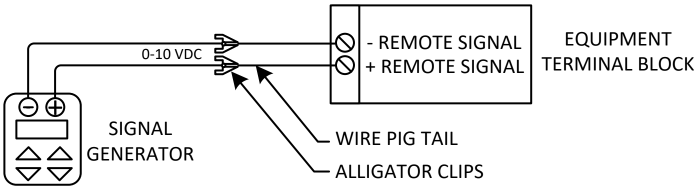

Figure 121 - Signal Generator Schematic (Simulating BAS Voltage Signal)

In many cases, the analog input signal type and range may be configurable from a keypad, jumpers, terminal assignments, selector switch, dip switches, or user interface screen. For example, chillers typically have a setpoint reset based on an external voltage signal. If the chiller has a 5°F reset from 45°F based on an external signal range of 0-10 VDC, then the chiller's setpoint may reset as indicated in the following table. You should consult the equipment submittal to verify whether the setpoint reset is absolute or relative to the manual discharge setpoint as this affect how the setpoint is calculated.

Percent of Scale	Simulated Signal (VDC)	Chiller Setpoint (°F)
0%	0	45
25%	2.5	46.25
50%	5.0	47.5
75%	7.5	48.75
100%	10.0	50.0

Table 63 - Simulated Analog Output Steps – Voltage Signal

7.5.5.4 Analog Output Signal Simulation – Actuator Control

The signal generator can be used to simulate analog outputs from a BAS controller to control valve and damper actuators. Typically, 0-10 VDC or 2-10 VDC analog output signals are provided to the input terminals of electric actuators. Verify the analog signal requirements before performing control signal simulations. Electrical actuators typically have selector switches that are used to set the analog control signal range. The signal generator allows the actuator to be ramped to various positions to test its operation and range without the BAS.

Percent of Scale	Simulated Signal (VDC)	Actuator % Open
0%	0	0
25%	4.0	25.0
50%	6.0	50.0
75%	8.0	75.0
100%	10.0	100.0

Table 64 - Simulated Analog Output Steps – Voltage Signal

Connecting the signal generator to the actuator requires a review of the current wiring configuration. Before connecting, de-energize the 24 VAC actuator power supply and reenergize it when the signal generator is connected. Actuators are typically powered by 24 VAC transformers, but they may also be powered by 120 VAC circuits. Verify the actual voltage of the terminals you plan to disconnect before proceeding.

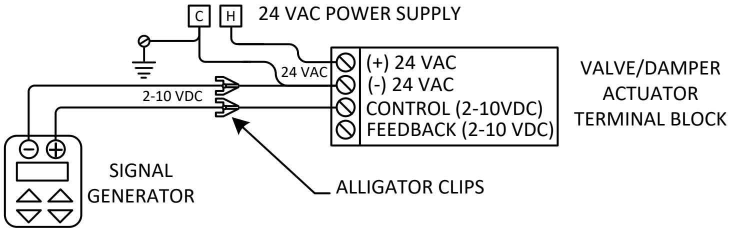

Figure 122 - Signal Generator Controlling a Valve/Damper Actuator with a Voltage Signal

The connections to the power supply must be maintained because the signal generator provides only the control signal – not the power to drive it. Connect one end of a wire pigtail to the 24 VAC common and control signal input terminals of the actuator. The signal generator will be connected to the other end of the wire pigtail with the alligator clips for a hands-free connection. Using the buttons on the signal generator, the actuator control signal can be ramped up and down, so that its operation and range can be verified.

7.5.6 Process Clamp Meter

The Fluke model 773 is a milliamp process clamp meter used for testing and calibrating sensor transmitters and output devices. It has all of the capabilities of the Fluke 715, plus it has a current transducer that can be placed around the electrical conductor to measure the current flow without breaking the wiring connections. In addition, it can source the current signal and simultaneously measure the current flow.

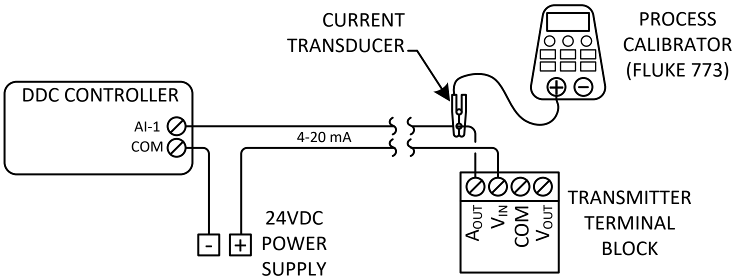

Figure 123 - Loop-Powered Amperage Measurement with a Process Calibrator

7.5.7 Ultrasonic Flow Meter

A calibrated Ultrasonic Flow Meter (UFM) can make verification of hydronic flows easy and it does so with a high degree of accuracy. UFMs use ultrasonic sound waves to measure the velocity and flow rate of flowing liquids and they can also determine the direction of flow. UFMs do not require the installation of the sensors or fittings in the piping system. They are completely non-invasive and only require that the piping insulation be temporarily removed to facilitate access to the pipe surface. UFMs can be used to verify flow meter, pump, coil, and equipment flow rates and can also be used to determine the fully open and closed positions for control valves with no mechanical stops or markings to indicate their position. The Fuji Portaflow flowmeter can be utilized with an FLD-22 transducer for small pipe (6” and smaller) or a FSGB41Y1 transducer for larger pipe diameters. It is easy to configure, set up, and acquire flow measurements quickly. Locate the flow transducer as you would a flow meter or choose the optimum location if no “ideal” location is available.

Photo 142 - Insulation Removed and Pipe Surface Prepared

Photo 143 - Ultrasonic Sensor /Transmitter on Pipe Surface

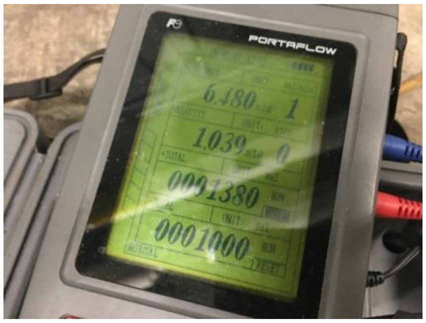

Photo 144 - Ultrasonic Flow Meter Reading

Ultrasonic flow meters operate on either the Transmit Time or Doppler-Shift principle. Ultrasonic flow meters in HVAC applications are typically based on the Transit Time principle where the flow meter measures the travel time of the ultrasonic waves with and against the fluid flow. A sensor/transducer assembly consisting of two pairs of sensor/transducers is placed on the pipe surface. The space of the sensor/transducer is calculated by the flow meter upon entry of the fluid and pipe parameters. Couplant is applied to the sensor/transducer face to allow the ultrasonic wave to bridge the air gap between it and the pipe surface and penetrate the pipe wall into the fluid. The upstream transducer emits an ultrasonic wave with the direction of flow and the downstream sensor measures the time it takes to receive the signal. Simultaneously the downstream transducer emits an ultrasonic wave against the direction of flow and the upstream sensor measures the time it takes to receive that signal. At zero flow there is no difference in the transit times. As the fluid flow rate increases, the time difference required to receive the upstream and downstream ultrasonic waves increases. The difference in transit times, fluid type, speed of sound in water, and speed of sound in the pipe material are used to determine the fluid velocity and ultimately the flow rate of the fluid.

For increased accuracy, the use of an ultrasonic thickness gauge is recommended. The Panametrics model 26MG ultrasonic thickness gauge is used to determine the actual wall thickness of the installed pipe. Upon removing the insulation and jacketing, a pipe stamp or marking may reveal the pipe specifications. If the steel pipe schedule or wall thickness is unknown, then the pipe is typically assumed to be Schedule 40 in most HVAC installations. However, it can be a mistake to make this assumption. Inputting the correct material, pipe diameter, wall thickness, and fluid properties is very important to the accuracy of the UFM readings. Once the surface of the pipe is exposed, the pipe material will be evident (steel, copper, PVC, etc.). What is not evident from the outside of the pipe is its wall thickness. Ultrasonic thickness gauges remove this unknown from the list of variables. Knowing the fluid type is another important fact to consider. The velocity of sound in fluids can vary substantially according to the fluid properties.

UFMs are susceptible to pipe coatings and corrosion on the outer surface of the pipe that block transmission of the ultrasonic waves into and out of the pipe, so preparation of the pipe surface is very important. All pipe coatings and corrosion should be completely removed down to the bare metal surface with a wire wheel or metal file. To minimize the area which requires surface preparation, enter the fluid and pipe parameters into the ultrasonic flow meter so that it calculates the required sensor/transducer spacing. Mark the pipe with two points at the calculated longitudinal spacing and clean and prepare areas of 2-4 inches diameter circles centered on these marks. The 6 o'clock and 12 o'clock positions in horizontal pipe should never be used because there could be internal debris accumulations and under-deposit corrosion at the bottom of the pipe and gas bubbles at the top of the pipe which can block the transmission of the ultrasonic waves in the fluid. In addition, avoid the longitudinal welds of pipe because these areas tend to have variations in wall thickness and material composition. Unfortunately, acquiring a flow reading with an ultrasonic flow meter is not guaranteed. It's all or nothing with these meters. UFM settings can be adjusted when difficulty is encountered during a flow measurement. We only have control of the conditions outside the pipe. The conditions of the internal pipe surface, suspended solids in the fluid, and entrained gases can preclude the successful measurement of fluid velocity and flow with an UFM. Other methods of flow verification may ultimately be required if a valid UFM reading cannot be acquired. Moving to a different location and trying again is typically the only option.

7.5.8 Ultrasonic Diagnostic Tool

Ultrasonic Diagnostic Tools (UDTs) detect and amplify the ultrasonic sound waves that are inaudible to the human ear and convert them to an audible frequency range. Ultrasonic waves are generated by mechanical frictional forces in bearings and shafts, fluid leaks and cavitation, and electric discharges. All three sources of ultrasonic sound waves can be found in any HVAC system. The UDT is commonly used to identify leaks in compressed air, steam, vacuum, and refrigerant systems. Bearings produce a distinct noise pattern when they are worn and the UDT can be used to detect and monitor these patterns so that the bearings can be scheduled for replacement before complete failure. The UDT can also detect ultrasonic noise in hydronic systems where cavitation occurs in pumps and valves. It is a useful tool when the verification that a control valve is fully closed is required. UDTs have air and contact probes to enhance the detection of ultrasonic waves in fluid, mechanical systems, and electrical systems. The Marksman MDE-1000 UDT is manufactured by the Spectronics Corporation and it comes with an ultrasonic emitter that generates ultrasonic sound waves. By placing the emitter on one side of a barrier and scanning for ultrasonic waves on the opposite side, openings in the barrier (windows, doors, ducts, walls, roof, flexible connections, duct connections, etc.) can be detected and evaluated. The ability to identify air gaps makes it useful for building enclosure testing, duct leakage testing, and duct sealing.

7.5.9 Clamp Meter

The clamp meter provides direct measurement of amperage (AC & DC), voltage (AC & DC), resistance, continuity, and more. This is a very useful instrument for testing and calibration of current switches and current transmitters. The Fluke model 376 is a true RMS (Root Mean Square) clamp meter for high-power voltage and current measurements. It is equipped with a low-pass filter that allows current measurement between a Variable Frequency Drive (VFD) and the motor that it is driving. Without the low-pass filter, the current reading will bounce all over the place rendering the acquisition of an accurate current measurement impossible. Inrush current measurements are also possible with the Fluke 376. Another useful feature of this clamp meter is its ability to detect the frequency (in Hertz) that the motor is currently operating when installed between the VFD and motor. The Klein Tools® CL380 is also a very good, economical alternative.

Photo 145 - Digital Clamp Meter (Fluke 376)

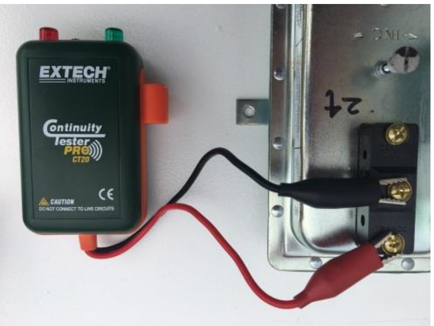

Photo 146 - Continuity Tester (Extech CT-20)

Photo 147 - Pipe Clamp Temperature Probe (Fluke 80PK-8)

Clamp meters come in two main types: True RMS and Average-Responding. Average-Responding clamp meters are ideal for pure sinusoidal waveforms but are not suited to nonlinear, non-sinusoidal, and distorted waveforms that are typical on the load side of variable frequency drives. Therefore, this type of clamp meter should only be used on the line side of VFDs. The true RMS clamp meter can be used anywhere in the electrical circuit. The Average-Responding clamp meters are the lower cost option between the two. True RMS clamp meters typically have prominent labeling indicating they are the true RMS type.

7.5.10 Thermometer

A calibrated thermometer is required for temperature measurements. The Fluke model 52 II thermometer is equipped with dual inputs to allow simultaneous measurement of two thermocouples probes. This provides the ability to test the inlet and outlet temperatures of chillers, boilers, heat exchangers, water-source heat pumps, solar thermal panels, etc. simultaneously.

Photo 148 - Thermocouple Thermometer (Fluke 52-II)

Photo 149 - Bead Probe (Fluke 80PK-1)

Photo 150 - Infrared Thermometer (62Max+)

Recommended accessories include the magnetic meter hanger, a surface probe, pipe clamp probe, piercing (immersion) probe, and bead probes. A surface temperature probe (Fluke 80PK-3A) is used to take surface temperature readings (Photograph 155). For pipe surface temperature measurements, the Fluke 80PK-8 pipe clamp temperature probes stay in place with their spring-loaded clamps (Photographs 147 & 154). These are especially useful when testing differentials at Water Source Heat Pumps (WSHP) units, fan coil units, terminal unit reheat coils, and unit ventilators. Ideally, a P/T port has been installed and the piercing probe (Fluke 80PK-25) penetrates the core of the P/T port to allow direct measurement of the fluid temperature (Photographs 153 & 156).

The piercing probe can also be used to penetrate flexible connections to acquire air temperature readings at air-handling unit fans (Photograph 152). This method of discharge air temperature measurement does not require any drilling of holes in the duct or duct plugs. The piercing probe is held in place by friction between the probe and flexible material. It is recommended that existing holes in the flexible connection be used to acquire temperature readings so as to minimize damage. At flexible connections, the air velocity is typically high which reduces the acclimatization time. These reference temperature readings are then compared to the BAS air temperature readings.

Photo 151 - Bead Probe in Supply Air Diffuser

Photo 152 - Piercing Probe at Air-Handling Unit Flexible Connection

Photo 153 - Piecing Probe at P/T Port (Condenser Water)

If 3/8 inch holes were drilled in the air-handling unit enclosure or ducts, be sure to place appropriately-sized duct plugs in the penetrations when your testing is complete. If the air is moving, the piercing probe is also good for air temperature measurements. When the air is not moving, the bead probe (Fluke 80PK-1) is typically used because the low mass of the sensor tip allows it to acclimatize to the ambient conditions much more rapidly than a temperature sensor encased in a metal jacket.

Photo 154 - Pipe Clamp Temperature Probe (Fluke 80PK-8)

Photo 155 - Surface Probe (Fluke 80PK-3A)

Photo 156 - Piercing Probe (Fluke 80 PK-25)

7.5.11 Infrared Thermometer

An infrared thermometer is useful for taking initial exploratory or troubleshooting temperature measurements to determine the operating status of equipment. In ducted systems, it is used at diffusers, registers, and grills to confirm the delivery of heated or cooled supply air. In piping systems, it may be used to verify that hot water or steam pipes and/or piping components are hot and that chilled water piping and/or piping components are cold. This is a commonly used field test instrument among building Owners and Operators all over the world. Infrared thermometers sample the observed surface area when the trigger is depressed and provide an instantaneous reading of the SURFACE temperature (not air temperature) by measuring the infrared energy on the surfaces sampled by the sensor. This is a very important fact to keep in mind when using this instrument. Several factors can impact the acquired surface temperature readings, so it is important to know the capabilities and limits of infrared thermometers.

1. The emissivity setting directly impacts the surface temperature reading. Adjustment and calibration is necessary to get accurate surface temperature readings.
2. The laser pointer only indicates the center of the sampled area. It has nothing to do with the temperature measurement. Some models indicate both the center and the radius.
3. Temperature readings on exterior walls are influenced by the outside air temperature and the radiant energy absorbed by the sun. They are generally higher than the room air temperature in the cooling season and lower than the room air temperature in the heating season.
4. Temperature readings on interior partition walls provide a better indication of room temperature than exterior walls.
5. Surface temperature readings may be affected by adjacent hot or cold objects which may be reflected.
6. The size of the sampled area increases with increasing distance from the measurement point.
7. Lower mass objects within a room provide a better indication of the current air temperature than higher mass

objects.

8. Higher mass objects within a room will provide an averaged space temperature indication because it takes a longer time for the room air to impact its temperature.
9. If the surface temperatures of the higher mass objects differ from the surface temperature of the lower mass objects, then the room temperature has changed or is changing.
10. Air currents flowing over sampled objects and surfaces will impact the surface temperature readings.

The Fluke model 62 Max+ is very compact and has a fully adjustable emissivity setting. Emissivity is the ratio of the emissive power of the sampled surface compared to the emissive power of a perfectly black body at the same temperature which is very similar to the concept of percent Relative Humidity. The emissivity, ε setting directly impacts the resultant temperature reading. Using an emissivity of 0.95 generally works well. However, the emissivity corresponding to the material being sampled and its surface finish should be used for increased accuracy. Emissivity tables are available for a variety of materials and it is a good idea to keep them close to the infrared thermometer. If the emissivity is unknown or the material type is unknown, a temperature meter with a surface temperature probe can be used to measure the surface temperature. Once this is known, the emissivity of the infrared thermometer can be adjusted until it provides the same surface temperature reading. The infrared thermometer is now calibrated to this surface type and finish. However, it would not be a good idea to assume that the emissivity that was just determined will work everywhere else. The calibration process should only be used on a surface that has a repeatable or consistent finish because of its manufacturing process (i.e. temperature sensor cover). Masking tapes used for painting can be used to cover the surface of the test material and create a consistent surface finish. Tapes with a clear, shiny finish are not recommended.

Every infrared thermometer has a Distance to Spot (D:S) ratio and it is a good idea to understand this concept because this greatly affects the resultant temperature readings and the corresponding course of action. Most infrared thermometers come in either 12:1 or 10:1 D:S ratios. The infrared sensor is behind a lens and its view is much like the light beam from a flashlight. As the distance between the infrared thermometer and the sampled area increases, so does the diameter of the sampled area. A D:S ratio of 12:1 means that the diameter of the sampled area is 1 inch at a distance of 12 inches. At a distance of 5 feet the diameter of the sampled area is 5 inches. With this in mind, it is a good idea to be aware of the distance to the point of measurement. To measure the surface temperature of the cover of a wall-mounted temperature sensor (typically 3.5 inches wide), the infrared thermometer should be located at a distance of no more than 42 inches. At distances greater than 42 inches, the diameter of the sampling area will be larger than the temperature sensor cover width whose temperature is being measured and may provide erroneous readings.

Infrared thermometers typically are equipped with a laser beam. The first thing to keep in mind is that the temperature measurement does not take place at this projected dot. This projected beam is used to mark the approximate center of the circular area sampled by the infrared sensor. The distance to the sampled area and the D:S ratio determines the size of the sampled area. The problem with infrared thermometers is that there are no markings to indicate the circular area being sampled. The Fluke 62 Max+ addresses this concern by providing a second laser beam that provides a visual indication of the radius of the sampled area. Ideally, the spot or sampled diameter should be smaller than the smallest dimension of the object or surface being sampled. This is not always possible so we must be aware of the impacts that increased distances will cause. Objects, both in front of and behind, may affect the infrared temperature reading. The following table illustrates the impact of distance on the diameter of the sampling area used by the infrared thermometer.

	D:S Ratio	
	12:1	10:1
Distance (Feet)	Spot Size Diameter (Inches)	Spot Size Diameter (Inches)
1	1	1.2
3	3	3.6
6	6	7.2
10	10	12
15	15	18
20	20	24
25	25	30

Table 65 - Distance to Spot Comparison

The temperature reading provided by the infrared thermometer displays either the average, minimum, or maximum value acquired in the sampled area. The appropriate setting depends on what you are trying to accomplish and the field conditions at the time of testing. When the trigger is pulled, the infrared thermometer begins to sample the surface and displays its measured temperature values. If it is set to Average, it will provide an average of the sensor readings acquired over the sampled area. If it is set to Maximum, it will provide the maximum temperature reading acquired over the sampled area. If it is set to Minimum, it will provide the minimum temperature reading acquired over the sampled area. This shows the importance of using the correct setting when using the infrared temperature meter.

The use of infrared thermometers for temperature sensor calibration is not recommended because air temperature and surface temperature readings can be quite different. Changes in surface temperature of solid materials can lag far behind changes in air temperature and the difference increases with increasing thermal mass of the walls, ceilings, and floors of the structure. In short, there are too many variables to account for which precludes the acquisition of accurate reference air temperature readings with an infrared temperature meter. Its use is acceptable for a qualitative analysis, but not for a quantitative analysis.

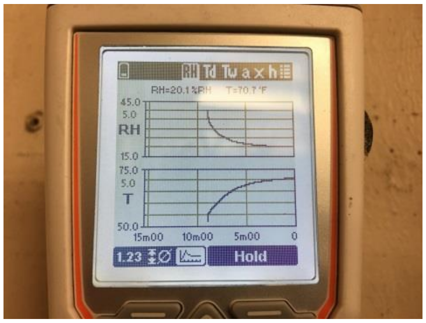
Photo 157 - Humidity Meter (Vaisala HM40) Graphing Function


Photo 158 - Humidity Meter at Space Humidity Transmitter


Photo 159 - Bead Probe at Space Temperature Sensor

7.5.12 Humidity Calibration Salts

Calibrated humidity salts are also used to test and calibrate humidity transmitters and hand-held meters. When salt is mixed with distilled water in a closed container, the humidity level (%RH) of the air above the saturated solution reaches equilibrium at the rated relative humidity of the salt. Various salt compounds reach equilibrium at specific humidity levels. It is recommended that salts with at least two substantially different humidity levels be utilized for this testing method. The container should have a minimum of air inside. The greater the volume of air inside the container, the longer it will take to reach equilibrium. Expose the humidity sensor under test for the time recommended by the manufacturer of the calibration kit. After this period, the instrument humidity reading should match the humidity rating of the salt. If it does not, then the humidity transmitter should be calibrated and retested. This method of testing is only recommended for the reference instrument before or during the humidity transmitter calibration process. In situ testing of humidity transmitters with this method is not practical because they have to be placed in a closed container for a period of time (4-24 hours). If the transmitter is already installed on the wall or duct, then its removal is not typically desired.

7.5.13 Temperature/Humidity Meter

A calibrated instrument for taking humidity readings will be required to test and calibrate humidity transmitters. Humidity transmitters are required for the monitoring of outside air, space, and return air humidity levels. Dehumidification cycles are typically activated when humidity levels exceed a maximum threshold. Humidification cycles are enabled when humidity levels drop to a minimum threshold.

The Vaisala HM40 humidity meter provides a graphical trend of the temperature and humidity readings which provides an indication of acclimatization progress. When the trend lines become horizontal, this indicates that the temperature and humidity sensors have fully acclimatized to the space conditions (Photograph 157). In addition, it can record up to 40 readings for later review. This meter is useful when both space temperature and humidity readings are required. Once temperature and humidity are known, all of the other psychrometric properties (enthalpy, specific humidity, wet-bulb temperature, dew point temperature) of air can be calculated.

7.5.14 Variable Resistor

The variable resistor has a knob and is used to simulate changes in temperature sensor resistance. With a 100K Ohm, 10-turn variable resistor it is possible to simulate temperature changes in most BAS controllers. As a starting point, set the resistance of the variable resistor using a multimeter to the base resistance (20k Ohm, 10k Ohm, 1k Ohm, etc.) of the installed temperature sensors. When the space temperature sensor is removed and replaced with the variable resistor, BAS controller configured for thermistor input should indicate 77.0°F or very close to it. RTDs will typically indicate 32.0°F. From this point, the temperature reading of the BAS may be changed by turning the knob which adjusts the applied resistance. With variable resistors, the control logic may be tested with simulated temperatures instead of changing setpoints.

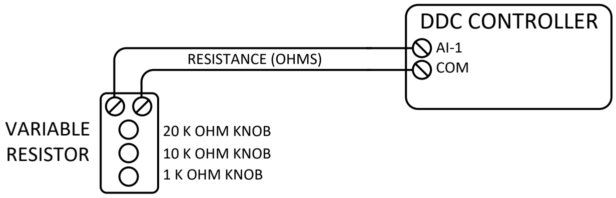

Figure 124 - Variable Resistor Connection to BAS

7.5.15 Resistance Decade Box

A Resistance Decade Box is an instrument that accurately and precisely simulates various preset levels of electrical resistance. This is useful for simulating the base resistance of thermistors and Resistance Temperature Detectors (RTDs). Suppose you have a temperature sensor with a base resistance of 10K Ohms that you suspect is not reporting correctly. You can temporarily disconnect the 10K thermistor and connect the resistance decade box in its place. The 10,000 Ohms switch is enabled. If BAS controller is properly configured, wired, and bound to the graphics, it will indicate a temperature equal to the reference temperature. The reference temperature for most thermistors is 77.0°F and the reference temperature for most RTDs is 32.0°F.

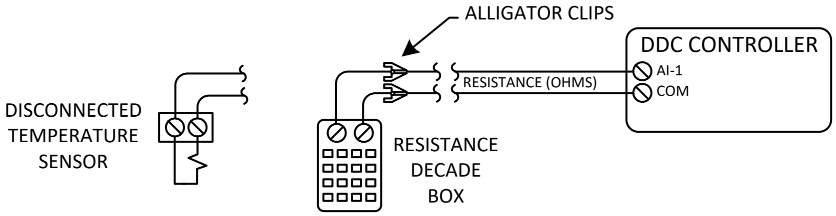

Figure 125 - Temporary Resistance Decade Box Wiring

The resistance decade box is also a quick and effective way for Control Technicians to "pre-calibrate" thermistor and RTD temperature sensor readings. If the BAS-indicated temperature reading is more or less than the reference temperature with the base resistance applied to the temperature sensor terminals, enter an offset value to pre-calibrate the temperature reading. If the offset required to calibrate the temperature reading exceeds the sensor accuracy specifications, then review the wiring and all connections. This test method does not test the accuracy of the installed temperature sensor, but it verifies that the analog input properly interprets the resistance and accounts for the resistance variations caused by the wire and its connections between the temperature sensor and BAS controller. The resistance decade box may also be connected to the space temperature sensor wiring to simulate a high or low space temperature to enable full cooling or full heating modes of operation of terminal unit controllers.

Photo 160 - Resistance Decade Box Buttons

Photo 161 - Variable Resistor

Photo 162 - Resistance Decade Box for Simulating High/Low Temps.

7.5.16 Low-Pressure Calibration Pump

Testing and calibrating of low-pressure devices such as Air Differential Pressure Switches (ADPS) and Air Differential Pressure Transmitters (ADPT) require a low-pressure source. The Dwyer® A-396A calibration pump allows the application of test pressures in a gradual and controlled fashion. It includes a hand-actuated piston for large increases in pressure, a screw-driven piston for fine pressure adjustments, and a bleed valve to release pressure. The calibration pump is used in conjunction with a calibrated pressure gauge or manometer to test and calibrate static pressure transmitters and switches. Squeeze bulbs are often used by Control Technicians, but the applied pressure can change abruptly at the very low test pressures (under 10 inches W.C.). Some people use their mouth to produce the required test pressures.

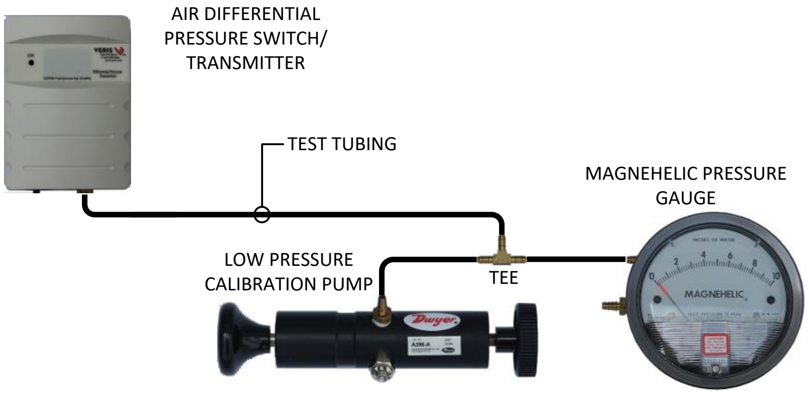

Figure 126 - Test Apparatus for ADPSs & ADPTs

7.5.17 Low-Pressure Calibration Pump Assembly

Many Air Differential Pressure Transmitters (ADPTs) have a porous pressure-sensing membrane or diaphragm that precludes the use of low-pressure, hand-actuated calibration pumps and squeeze bulbs because the applied test pressure dissipates. Testing this type of differential pressure sensor requires a dynamic pressure source that constantly replenishes the air that passes through the ADPT membrane. A USB-powered air pump, valve to control the bleed rate, tees, and some hose are all that is needed to create a very portable low-pressure test apparatus that can be stored in a backpack. It produces more than 20 Inches Water Column of pressure which is plenty for most low-pressure air switches and transmitters.

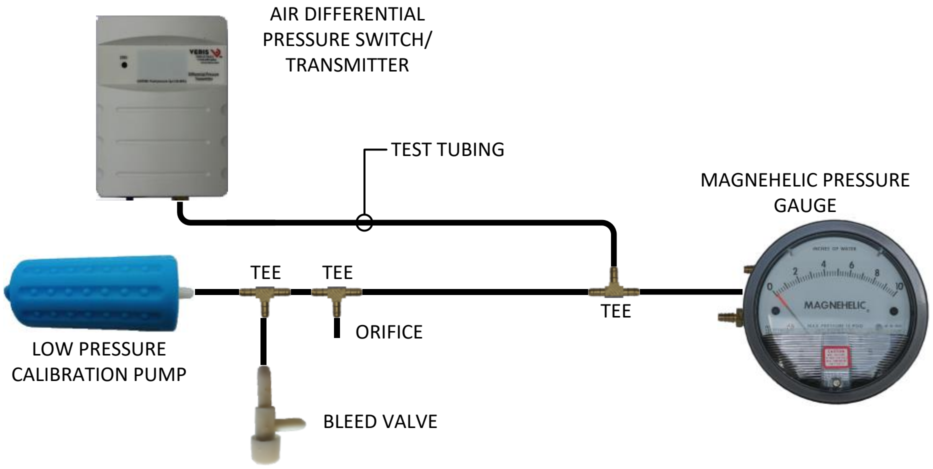

Figure 127 - Test Apparatus for ADPSs & ADPTs

This air pump is typically used for aquariums and can generate pressures high enough to damage ADPTs, so be sure to add an orifice with a small diameter tube (1/32 Inch to 1/16 Inch) or hole drilled into a pneumatic cap. It acts as a pressure regulator in the event that the bleed valve is fully closed and allows finer control of the applied air pressure. The red tube that comes with WD-40 or other lubricants works well for this purpose. This tube can be pinched to limit the maximum applied test pressure to approximately 10-15 Inches W.C. Other small air pumps for inflating mattresses were tested, but they were noisy and produced a pulsating pressure that was very difficult to control. This aquarium pump produces pressure with very low noise and very little pulsation which makes it ideal for calibration of air differential pressure switches and transmitters.

7.5.18 Evergreen Telemetry WristReporter™ and Wireless Devices

Evergreen Telemetry has developed a line of wireless field instruments that can be utilized in controls, commissioning, and testing, adjusting, and balancing projects. Their wireless products represent the most significant leap forward in field testing technology in recent years. The unique separation of data display and the measurement modules simplifies its use, increases safety, and allows for a significant size reduction in both components. The WristReporter™ connects to a series of measurement modules wirelessly and can display live data from up to ten devices simultaneously. All of the wireless modules that communicate with the WristReporter™ are very light and compact compared to their full-sized counterparts because they don't include a dedicated display. This provides a higher level of flexibility than other comparable products on the market. The following table summarizes the wireless modules and accessories that I own and commonly use in the field. Evergreen Telemetry has many more to choose from and they are constantly improving their products based on user feedback.

Device	Description
WR-401 WristReporter™	Displays data and stores the readings
CH-15D Airflow Hood	Capture and measure airflow from ceiling/wall DRGs
CH-8D Airflow Hood	Capture and measure airflow from smaller ceiling/wall DRGs
RM-T-1 Temperature Module	Measures and transmits temperatures
PR-T-5 Temperature Probe	Temperature probe (connects to PR-T-5 Module)
S-PVF-1 Air Pressure Module	Measures and transmits air pressures
Velocity Grip™ Handle	Custom grip to hold pitot tube/air foil probes and WristReporter™
S-DP-250PSI Hydronic Pressure Module	Measures and transmits hydronic differential pressures

Table 66 - Evergreen Telemetry Instruments Used by Author

7.5.19 Low-Pressure Digital Manometer

The Evergreen Telemetry air pressure modules (S-PVF-1) are very useful when static pressure (duct and space), differential pressure, and duct traverse readings are necessary. Duct traverses can be performed without dealing with the hoses that are typically necessary with other low-pressure manometers because the pressure module is attached directly to the pitot-tube or air foil probe by very short lengths of tubing as shown in Photograph 164. This module is often used for calibration of Air Differential Pressure Switches (ADPSs) and Air Differential Pressure Transmitters (ADPTs). The pressure modules have a magnetic back which allows them to stick on the side of ferrous air-handling unit enclosures and ducts freeing up your hands (Photograph 161). Evergreen Telemetry also manufactures its own lightweight, see-through flow hoods which make it easier to maneuver through tight spaces and verify correct placement over the air device (Photograph 162). The pressure module can also be used on Shortridge hoods which can significantly lighten this hood's weight. Battery life is always a concern and the rechargeable batteries in the WristReporter™ and all modules can easily last 12-18 hours depending on usage.

Photo 163 - WristReporter™ Data Display

Photo 164 - Pressure Module for Duct Static Pressure Readings

Photo 165 - Pressure Module on an Evergreen Telemetry Hood

7.5.20 Airflow Capture Hood

Airflow capture hoods (Photograph 162) are instruments that are typically used to measure supply, return, and exhaust airflows at Diffusers, Registers, and Grills (DRGs). They are also used to test airflows through fume hoods and outdoor air intakes. Most TAB Contractors use primarily Evergreen Telemetry, Shortridge Instruments, or Alnor airflow capture hoods. These instruments consist of a frame, a skirt, airflow pickup, air differential pressure transmitter, and circuitry with a user interface. Airflow capture hoods typically have the ability to sum the airflow readings and store multiple sets of readings for later recall.

Controls Contractors often replace terminal unit controllers for existing terminal units as they fail or as controls systems are upgraded. However, the airflow indications are not always calibrated during these projects. Calibration of the airflow readings ensures that the proper amount of primary air is delivered and heated by the reheat coil (if equipped). Poor airflow calibration has negative energy and comfort implications especially for terminal units equipped with reheat capacity. The K factor appropriate for the terminal unit inlet diameter is typically entered into the BAS controller configuration. This allows it to calculate the airflow based on the differential pressure measured at the airflow pickup connections. When too much air is delivered by the terminal unit, the cooling and reheat loads are unnecessarily increased. In addition, the supply fan unnecessarily operates at higher speeds. When too little air is delivered, the terminal unit has both poor cooling and heating performance resulting in a lack of space temperature control.

Controls Contractors are often called to diagnose temperature control issues with pressure-independent terminal units and the first step is to verify that the airflow indication is correct. Controls Contractors with calibrated airflow capture hoods could calibrate terminal unit airflow readings which increases their value and maximizes the energy efficiency of the system. Alternatively, a TAB Contractor can be subcontracted to provide the same service.

7.5.21 Hydronic Manometer

The Evergreen Telemetry water pressure module S-DP-250PSI is a fraction of the size of a typical hydronic manometer and provides a live reading rather than a reading only when the store button is pressed. Follow the manufacturer's instructions to start-up and zero the hydronic manometer. Many of the hydronic systems that we test are filthy. If we used this water to fill our lines and purge them of air this will eventually clog the hydronic manometer. Before connecting to any system, the high- and low-pressure lines and the meter should be filled with clean potable water. A hose-end adapter with a Schrader connection is used to allow a connection to a mop sink or hose bibb. Once the meter is zeroed, purged of air, filled with clean water, and hose isolation valves are closed, the hydronic meter is prepared for field-testing.

Photo 166 - Hydronic Differential Pressure Module

Photo 167 - Velocity Grip™ for Air Foil and Pitot Tube Probes

Photo 168 - Temperature Module for Space Temperature Calibration

Connect the hoses to the balancing valve or Schrader connections to be tested and open the isolation valves on the hoses to begin sampling the hydronic differential pressure. Record the readings, close the isolation valves on the high-pressure and low-pressure hoses, and remove them from the sampling points. This process is repeated for each test location. When the measurements are completed, it is recommended you purge the lines and meter with clean water. These steps help to keep the hydronic manometers clean and clog-free for years.

7.5.22 Wireless Air Temperature Module

Evergreen Telemetry air temperature modules RM-T-1 are available to take air temperature measurements for coil performance testing and sensor calibration. The temperature modules are especially useful for taking temperature measurements in locations that are difficult to access (inside of a duct or air-handling unit). The temperature module can be placed inside an air-handling unit and the readings are transmitted wirelessly to the WristReporter™ outside the unit. Ceiling air temperatures in rooms with very high ceilings can be attained by securing the air temperature module to the end of the telescoping pole or drones. Temperature modules can be located next to BAS temperature sensors and used to calibrate several temperature sensors at the same time. Several units can be placed inside air-handling units to verify temperatures without drilling holes or using several separate temperature meters or moving a single temperature several times.

7.5.23 Low-Pressure Magnehelic® Test Gauges

Digital manometers such as the Evergreen Telemetry S-PVF-1 (and WristReporter™) or Shortridge ADM manometers are typically used for duct and space pressurization readings. Analog gauges may also be used for the same purposes, but their range must match the application to provide accurate readings. This device should either be calibrated or compared against a calibrated device to verify its accuracy. They are used to provide a reference pressure when testing low-pressure ADPSs and ADPTs. The main advantage that Magnehelic® gauges have over digital instruments is that they require no batteries. Magnehelic® air pressure gauges in the 0-0.5 Inch W.C. or 0-0.25 Inch W.C. ranges are recommended for space pressure readings. A 0-5 Inch W.C. Magnehelic® gauge may be used for testing and calibration of duct ADPTs or high static safety switches (ADPS). Prior to use, be sure to zero the Magnehelic® gauge while it is in the same orientation in which it will be used. The zero changes from its vertical to horizontal positions. To avoid damaging Magnehelic® gauges, start with a 0-10 Inch W.C. gauge to determine the required pressure range of the Magnehelic® gauge. Protective cases are recommended to protect these units when not in use.

7.5.24 Static Pressure Profiles

When an air-handling unit is initially tested and balanced to design conditions, it is typically postured for full cooling and minimum outdoor airflow. This state provides a standard condition upon which future performance readings may be compared. Static Pressure Profiles (SPP) are a common technique or "tool" performed on air-handling units and duct systems to verify the pressure drops and rises along the air's path of travel. This provides baseline performance data for initial installation and can also be used as a diagnostic tool to locate restrictions or bypassing air in the air distribution system. It is also an effective way to assess the performance of air-handling units and its components.

Photo 169 - Forgotten Supply Airflow Straightener

Photo 170 - Debris-Laden Preheat Coil

Photo 171 - Forgotten Return Air Construction Filter

Photograph 166 shows a honeycomb airflow straightener which was installed ahead of the airflow measuring station approximately ten feet from the air-handling unit supply fan discharge. The flexible connection of the supply fan was blown out because of the excessively high discharge air pressure. The SPP readings indicated a discharge static pressure of 5.5 inches W.C. at the air-handling unit discharge, but it was only 0.5 inches W.C. at a distance of 50 feet from the mechanical room which indicated a significant restriction. The supply fan VFD speed operated at 60 Hertz all of the time and all downstream Variable-Air-Volume (VAV) terminal units were starved for supply air. As a result, the building occupants in these zones were miserable year-round. This airflow measuring station and airflow straightener was previously used by the original pneumatic control system. It had been retired in place and forgotten by the building operating staff when the DDC system (current BAS) was installed. This issue had been plaguing them for more than ten years according to the current plant operating staff. Removal of the airflow straightener significantly reduced the supply fan VFD operating speed, noise, and discharge static pressure (at the unit) and increased airflow. In addition, the downstream zones finally received enough supply air to maintain their spaces at their respective setpoints.

Photograph 167 shows the upstream side of a preheat coil in an office air-handling unit that was identified from the static pressure profile readings that indicated very low pressure differential across the filter bank and a high pressure differential (>1 inch W.C.) across the preheat coil. The filter rack inserts that take up the space between the end of the filter and the air-handling unit access doors were missing. As a result, the airflow bypassed the filter bank and the preheat coil became the air filter. Because the air filters always looked clean, the operating staff never changed them. Debris accumulations are also common in heat exchangers and the coils of recirculating energy/heat recovery units that are not equipped with return/exhaust air filter racks.

Photograph 168 shows a return air construction filter that had been installed on the plenum return/exhaust duct. Unfortunately, it was not removed and had been in place since the original construction. It was heavily laden with fine dust and debris when it was discovered during a retro-commissioning project 6 years later. The SPP readings indicated an abnormally low return duct static pressure at the energy recovery air-handling unit which indicated a possible restriction. Upon removal of the filter fabric, the energy recovery ventilator exhaust fan speed immediately lowered, the exhaust airflow rate increased, and the energy exchange between the supply air and exhaust air streams significantly increased, and the heating and cooling loads reduced.

Symptom	Possible Causes
Reverse Outdoor Airflow	Return air fan moving more air than the supply fan
Very Negative Mixed-Air Plenum Pressure	Restrictive return duct design, partially/fully-closed fire/smoke dampers, clogged return airflow straightener, forgotten temporary plenum return filter fabric, incorrect damper positions, failed/impaired return fan, air flow measuring station calibration
Positive Mixed-Air Plenum Pressure	Return air fan moving more air than the supply fan (air flow measuring station calibration)
Low Filter Pressure Drop	Missing filters, missing filter rack inserts, incorrect filter rating, collapsed filters
High Filter Pressure Drop	Dirty filters, Incorrect filter rating
Low Coil Pressure Drop	Coil bypass
High Coil Pressure Drop	Debris accumulation in coil
Low Supply Fan Total Pressure	Flexible connection failure, debris accumulation on fan blades, belt slippage, loose belts, fan turning backwards, incorrect fan speed
High Supply Fan Total Pressure	Incorrect fan speed, incorrect fan, incorrect sheaves
Low Discharge Static Pressures	Flexible connection failure, debris accumulation on fan blades, belt slippage, loose belts, fan turning backwards, incorrect fan speed, incorrect VFD maximum speed, closed isolation dampers
High Discharge Static Pressures	Partially/fully-closed fire/smoke dampers, clogged supply airflow straightener, restrictive supply duct design

Table 67 - Static Pressure Profile Symptoms and Causes

7.5.25 Hose Adapter (ADPS and ADPT Testing)

Testing of ADPSs and ADPTs requires a connection to a pressure source and reference gauge. This is typically accomplished by placing the test tubing on the barbed fitting of the pressure switch or transmitter. However, most ADPSs come with compression fittings, so a hose adapter will be required. The hose adapter consists of a ferrule, compression nut, insert, and short length (2-4 inches) of ¼ inch polyethylene (or copper) tubing. With the hose adapter installed on the compression fitting, test hose can then be directly connected. Working with pneumatic tubing typically requires pneumatic fittings such as couplings, tees, and caps. It is a good idea to keep a stash of them handy to facilitate field testing and calibration work. Tees and caps are also required when test tees have not been installed in the pneumatic tubing that connects the velocity pickup to the BAS terminal unit controller. It is not uncommon to find missing or dry-rotted caps on the test tees of existing pressure-independent terminal units.

Photo 172 - Compression Fittings for Pneumatic Test Connections

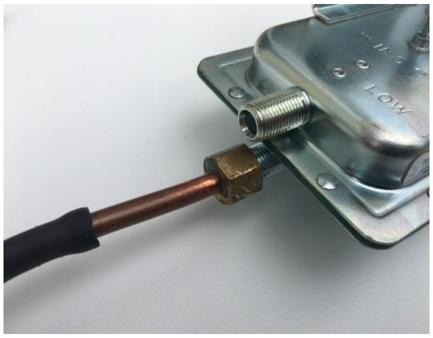

Photo 173 - Test Connection with ADPS

Photo 174 - Pneumatic Fittings (Couplings, Tees, and Caps)

7.5.26 Compressed Air Test Apparatus

Compressed air can also be used to test and calibrate air and hydronic switches and transmitters. The test apparatus consists of a compressed air tank, test tubing, two pressure regulators, and a test gauge. Test pressures using compressed air are typically limited to 125 PSIG. The first pressure regulator reduces the compressed air pressure to the maximum required for the testing and calibration. Typically, only 15 PSIG is required for stroking most pneumatic control actuators. Higher pressures may be required when testing HDPSs and HDPTs. The second pressure regulator at the end of the test hose is used to vary the test pressure applied to the device under test. This configuration provides pressure control at the device being tested and limits the volume of compressed air lost to only the volume beyond the second pressure reducing valve. This is also an excellent method to determine the pressures associated with the fully-open and fully-closed pneumatic actuator positions before setting the control signal range of the Electric to Pneumatic Transducer (EPT). This will be covered in more depth in Chapter 40: Modulating Pneumatic Actuators.

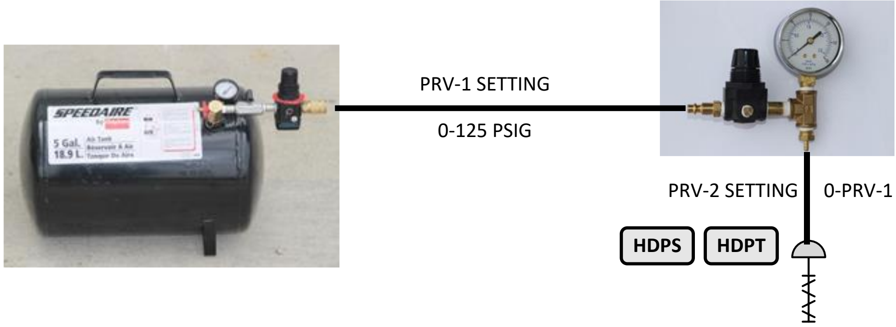

Figure 128 - Compressed Air Test Apparatus

7.5.27 High-Pressure Calibration Pump

Hydronic Differential Pressure Transmitters (HDPT) and Hydronic Differential Pressure Switches (HDPS) require higher pressures to perform testing and calibration checks. The Ralston AGPV calibration pump includes a hand-actuated pump, precision bleed valve, and integral test gauge connection. This calibration pump provides an easy way to calibrate and verify the operation of HDPTs and HDPSs.

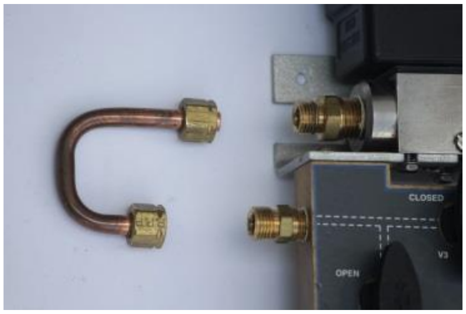

Photo 175 - Remove Piping from High and Low-Pressure Ports

Photo 176 - Attach Hose Adapter to High Pressure Port

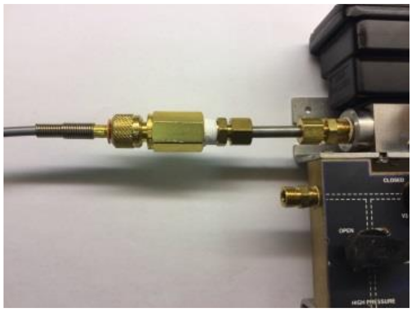

Photo 177 - Calibration Pump Connected to HDPS

A calibrated analog or digital test gauge rated for the maximum expected test pressures should be used. If using a Bourdon-tube test gauge, its pressure rating should be approximately twice the expected test pressures to avoid test gauge damage and improve measurement accuracy. Be sure to have Teflon tape or other acceptable means of sealing the threads of the fittings. A digital test gauge is recommended to avoid this issue and preclude the changing of test gauges.

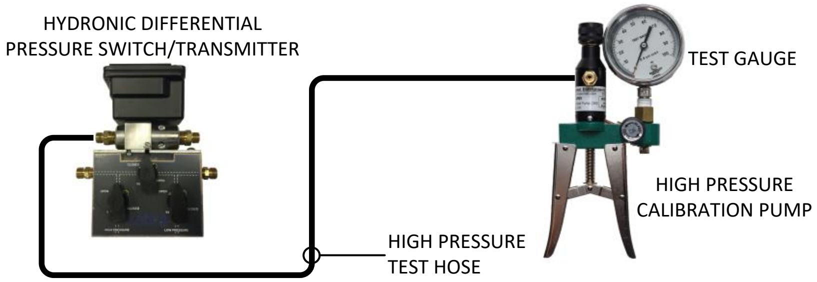

Figure 129 - Water Differential Pressure Switch/Transmitter Test Apparatus Configuration

7.5.28 Hose-End Drain Adapter

Drain valves with hose-end drain connections are typically provided to allow the fluid to be drained from hydronic systems or its components. They can also be found on pump casings, suction diffusers, strainer discharge valves, and equipment to be drained by using a hose. Hose-end drain adapters are useful for testing and calibration of immersion temperature and pressure sensors when properly located pressure/temperature ports have not been provided. Piping connections to air-handling unit hydronic coils, pumps, chillers, and boilers typically have vertical headers or riser pipes where the final piping connections are made. These risers or headers are typically equipped with drain valves (with hose-end connections) at the bottom and vent valves at the top.

One of two hose-end drain adapters will be used depending on whether temperature or pressure readings are required. Before connecting any reference instruments to drain valves at these locations, they should be cleaned with a short duration jet of system fluid to clear it of settled debris that could clog your test instruments. A five to ten feet length of 3/4 inch water hose is connected to the hose-end drain connection and the isolation valve quickly opened and closed to clear any debris that has collected in the bottom of the riser. Remove this hose and install the test hose-end drain adapter.

Photo 178 - Test Hose with Hose-End Drain Adapters

Photo 179 - Temperature Testing of Fluid with Piercing Probe

Photo 180 - Hose-End Adapter with Schrader Adapter

If a hydronic pressure reading is required, a hose-end drain adapter with a 1/4 inch Schrader fitting and a bushing may be used (Photograph 177). It facilitates a hydraulic connection between the hydronic system and the hydronic manometer to measure the pressure when the drain isolation valve is opened. When fluid temperature measurements are required, a hose-end drain adapter with a small diameter hose is used to drain a small amount of system fluid. The temperature of this fluid is measured with a temperature meter and temperature probe (Photographs 101, 156, 175, and 176) as the fluid discharges into a bucket or other approved location. Allow time for the temperature of the discharging fluid to stabilize before recording the final readings.

7.5.29 Carbon Dioxide Calibration Gas

Checking the calibration of carbon dioxide transmitters can also be accomplished with the use of carbon dioxide calibration gas provided the carbon dioxide transmitter is equipped with a test gas port. Calibrated gas is accurate to ~2% of reading depending on the source and quality of the gas. Therefore, field calibrating with calibration gas is generally more accurate than calibrating with a hand-held carbon dioxide meter which has an accuracy range of 2%-5% depending on the meter. The calibration gas can be obtained in several concentrations. The important thing to remember when ordering is that the balance gas volume should be air instead of Nitrogen to more closely simulate ambient air.

Photo 181 - Hand-Held Carbon Dioxide Meter

Photo 182 - Carbon Dioxide Calibration Gas

Photo 183 - Carbon Dioxide Gas Connected to CO2 Transmitter

For best results, use two concentrations of carbon dioxide. A concentration of 400 PPM simulates the typical ambient outdoor air carbon dioxide level and 1,000 PPM to 1,200 PPM represents the typical DCV setpoint. Calibration gas is ideal when you are testing and calibrating carbon dioxide transmitters with a calibration gas port such as the Veris CDE and CDLS models. If the transmitter does not have a gas test port for field calibration, then a handheld carbon dioxide meter will be required.

7.5.30 Carbon Dioxide Meter

It is now commonplace to see Demand-Controlled Ventilation based on carbon dioxide concentration as part of air-handling unit sequences of operation. This is a control strategy where the ventilation airflow rate is modulated in response to ventilation requirements as indicated by carbon dioxide readings. Calibrating the carbon dioxide transmitter requires that its readings be compared to calibrated instrument readings. The EInstruments model AQ Comfort meter uses Non-Dispersive Infrared (NDIR) technology to quantify the concentration of carbon dioxide in the air to 2% of reading accuracy. It also has an internal sampling pump to quickly and directly sample the ambient air without having to wave the meter around or actuate a squeeze bulb.

When the carbon dioxide transmitters are wall-mounted within the space or outside, a reference reading with a calibrated carbon dioxide meter can be taken within inches of the carbon dioxide transmitter to verify its accuracy. Because we discharge high levels of carbon dioxide with each breath, it is very important to hold your breath as you set and recover the carbon dioxide meter while it is energized. It is typically best to place the carbon dioxide meter near the carbon dioxide transmitter and remove yourself from the area so as not to affect the readings of either device.

When carbon dioxide measurements are required to verify the accuracy of duct-mounted carbon dioxide transmitters, a modified strategy is required. Carbon dioxide transmitters are typically installed on the outside of the duct or air-handling unit and sample the air within the return duct. To verify the accuracy of the carbon dioxide reading, the calibrated carbon dioxide meter must sample the air stream under the same conditions. Access to the return air is accomplished by three typical methods: duct access door, drilling a hole in the duct, or entering the air-handling unit or duct. Because return ducts are typically negatively pressurized, mechanical equipment room air is pulled into the return duct when an access door is opened. The carbon dioxide meter must be inserted, placed upstream of the access door, and the access door fully closed. The carbon dioxide meter is then retrieved after two to five minutes depending on the meter and airflow rate. It is best to read the carbon dioxide meter reading just as the access door is opened because as the meter gets closer the access door opening for removal, the incoming equipment room airflow will affect the reading.

If you have a carbon dioxide meter with an internal aspirating pump and a short length of hose, a hole drilled in the return duct is a convenient way to acquire a carbon dioxide reading with minimal difficulty. Mechanical equipment room air will be drawn into the new sampling hole which affects the reference meter and carbon dioxide transmitter reading. To prevent this from occurring, a piece of tape is used to seal the annulus between the hose and the hole drilled in the duct. When the measurement is complete, you then have to seal this opening with a duct plug or tape. If the return air duct or air-handling units are large enough to climb into, an accurate reference reading can be acquired for comparison to the carbon dioxide transmitter reading.

7.6 High Technology

7.6.1 Mobile Power Supply

The availability of electrical power can be a significant issue on projects where electrical power is not readily available. Without electricity, laptops, phones, and test instruments cannot be recharged. A deep-cycle marine battery and a true-sine wave inverter make it possible to provide a mobile source of safe, clean 120 VAC electrical power. Depending on the connected load and the size of the battery, this power supply can last several days without charging. A marine battery box with a charge indicator and 12 VDC power sockets is recommended. With this mobile power supply, you will not have to search for a 120 VAC outlet at every stop or carry extension cords. Deep cycle batteries are heavy, so an equipment cart or hand truck is recommended. When recharging is required, use a charger that is compatible with deep cycle batteries and locate them in a well-ventilated area.

7.6.2 Additional Monitor

A second monitor can significantly increase the productivity of all laptop functions (document review, point-to-point checkouts, calibration, programming, BAS graphic bindings, and functional performance testing, etc.). It allows you to see multiple screens simultaneously as shown in (Photograph 189). In addition to the productivity increase, it reduces eye strain, minimizes the zooming and panning, and also increases the accuracy of your work by minimizing the opening and closing of windows to switch between programs. The second monitor also provides a convenient way for a second person to observe the control laptop without having to sit shoulder to shoulder.

7.6.3 Wireless Routers

Wireless routers provide mobility for the people that are field testing and commissioning the BAS. With a properly configured wireless router, the laptop can be anywhere within range of the router and communicate with the BAS as if it were wired. Typically, the control laptop is bound by a six feet long Ethernet cable that is plugged into the JACE either directly or through a network switch. Another technician is typically stationed at the input or output device to relay their observations or manipulate the devices. The wireless router effectively reduces the manpower needs of the Controls Contractor from two to one for most field testing and calibration tasks and reduces the potential for errors. With a 100 feet long CAT5 Ethernet cable and a wireless router, most HVAC equipment controls (air-handling units and its supply air terminal units) can be accessed with the controls laptop in hand. It allows a Control Technician to be at the devices being tested or overridden, minimizing the need for a second person and the need for radios or phones to communicate between them. Tablet PCs or cellular phones can also connect to the wireless router to further extend the field testing capabilities of the Control Technician, Commissioning Agent, or Owner. This capability is very useful when field testing is required in hard-to-reach areas of the job site or while on a ladder.

Photo 184 - Field Wi-Fi Router

Photo 185 - Remote Desktop Connection with a Tablet PC

actual_airflow	2701 cfm {ok}
ma_temp_sensor	89.4 °F {ok}
oa_dewpoint_sensor	38.5 °F {ok}
static_press_input	0.805 in/wc {ok}
ra_filter_press_input	0.140 in/wc {ok}
oa_filter_press_input	0.280 in/wc {ok}

Photo 186 - Remote Desktop Connection to Laptop with Phone

7.6.4 Remote Desktop Applications

Remote desktop applications allow one computer to control another through a common network. Once the remote desktop connection is made, the remote computer controls the local computer as if you were physically on the local computer. When performing a point-to-point check out of the BAS inputs and outputs, observation of the control point data is required while the input/output is overridden, disconnected, or otherwise manipulated (Photograph 185 & 186). This helps us to not only identify each input and output, but also to test and calibrate them. Tablets and phones can remotely control the laptop computer which is loaded with the required software to calibrate sensors, validate valve and damper control, and to field test the programmed logic.

Two remote desktop applications will be discussed. RDP is a free application that can be installed on most computers and tablets. This program is typically used when it is not possible to get cellular service on the phone or tablet. With the control laptop and the phone/tablet connected to the wireless router, it is possible to establish a remote desktop connection from the phone/table to the control laptop. Manual configuration of the program settings is required, so this method requires some knowledge of networking. Both computers must be on the same network and subnet to make remote connections. The IP (Internet Protocol) addresses of both computers/devices must be known. In addition, the username and password of the computer to be accessed must be known to access it remotely.

When a remote desktop connection is made over the internet, Remote PC or similar program may be used. Functionally, it is the same as RDP. However, it vastly simplifies the network connection configuration process because it does it for you. It only requires that the RemotePC software be installed on both devices (PCs, laptops, tablets, and phones). No knowledge of IP addresses, user names, or passwords on either end is required. You can leave a computer equipped with internet access and the required controls software at the job site that is physically connected to the BAS and remotely access it through another device with RemotePC. This allows a person to access the BAS remotely or offsite. It also allows a Control Technician to remotely access the control system through a phone or tablet PC while onsite during point-to-point checkout, troubleshooting, calibration, or functional performance testing. This ability comes in very handy because it can turn several tasks that typically require two people into single-person tasks.

7.6.5 Tablet Personal Computers (PCs)

Quickly referring to project documentation like drawings, specifications, submittals, etc. is where tablet PC or simply "tablets" shine. You can easily navigate, zoom, and pan across contract drawings. You can also quickly flip through the pages of electronic documents (specifications, operations & maintenance manuals, submittals, TAB report, etc.). A tablet PC is a valuable tool that effectively reduces the amount of hardcopy documentation that you have to carry in the field. A ruggedized case is recommended to withstand field conditions (dust, drops, bumps, etc.). Project files accumulate quickly, so it is recommended that you buy a tablet with at least 64 Gigabytes of storage to ensure sufficient memory. The next decision is whether you select a Wi-Fi-only or one that uses cellular service for data communication. It is very convenient to access the internet, files on cloud storage sites, and research issues in the field without having to find Wi-Fi access or carry a wireless access point. Using remote desktop applications, tablet PCs can take job site mobility to an even higher level. It is such an advantage to leave the control laptop at the control panel and take the tablet with you to perform the input/output testing and calibration work. It takes a while to adjust to the touchpad, but you will not be sorry once you get the hang of it.

Photo 187 - QR Code for ATC Submittal on Local Control Panel

Photo 188 - Black Box Network Switch

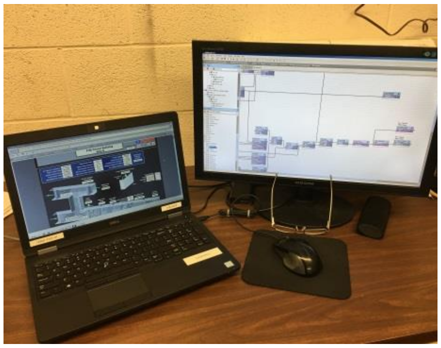

Photo 189 - Laptop with Additional Monitor

7.6.6 Network Switch

Local control panels do not always provide a network switch for extra network connections to the JACE. A network switch is a device that adds network connectivity for additional devices and computers. If you don't have to work beyond a few feet of the local control panel, this is an ideal device to use. The compact model LGB304A Gigabit Ethernet switch made by Black Box has four RJ45 ports (Photograph 188). It is powered by a USB power source which can be supplied by your laptop. This is a very handy feature when there are no additional 120 VAC outlets. This device allows multiple people to connect and work on the BAS at the same time. While one person is looking at the control logic, another can be reviewing the BAS graphics. It is good idea to keep an inline RJ45 coupler (Photograph 127) in your tool bag for when it is necessary to connect two RJ45 cables with male ends. The switch allows the Engineer or Commissioning Agent to connect to the JACE to see the BAS graphics through their own laptop. This allows them to review and test the graphics screens, change setpoints, and review trends on their own and make all the screenshots they want to document the results of their testing.

7.6.7 Cloud Data Storage

Cloud data storage is an innovative tool that allows us to store project documentation remotely in the "cloud." There are many providers of this service. Box.com and Dropbox are examples of popular cloud storage websites. Server farms located throughout the world are used to provide digital storage space for a fee. Through a common web browser or application, you can have access to all of your project documentation. This reduces the amount of project documentation that you have to carry to the job site. You can also upload field data on the same cloud storage account from the field for safe-keeping and sharing. Project folders and directories can be constructed to organize your cloud documents. You can also use the cloud to share files that are too large to be emailed. Keep in mind that the cloud is only available while internet access is available. Files that are used on a daily basis should be downloaded to our device or laptop while you are connected to wifi in your home or office. This will avoid having to download the files while in the field over slow networks or at secure facilities where cloud access is not permitted.

7.6.8 QR Codes

Many Control Contractors are beginning to utilize QR codes to provide a way to make their ATC submittals available to their service staff, Engineers, Building Owners, Operator, Service Technicians, etc. A copy of the ATC submittal is typically left on site at the end of construction. However, that is one of the first documents to disappear. Control Contractors are now leaving a laminated QR code on or in their local control panels which links to the ATC submittal (typically in PDF format) that is stored on a cloud storage service (Box, Dropbox, etc.). Anyone with a cellular phone camera or tablet with an internet connection can scan the QR code and instantly access the linked ATC submittal. The same can also be done with the mechanical plans, TAB reports, etc. Therefore, there is no need to print multiple paper copies and everyone that scans the QR code gets a fresh copy of the linked documents. A QR code is similar to a bar code for products. It is a graphical method of representing digital data which may be web links, images, PDFs, email, vcard, wifi passwords, etc. During the pandemic, its use flourished in the mainstream as QR codes were used to provide a hands-free method of providing restaurant menus. It is only natural for businesses to adopt technologies that benefit and promote their services and the industry.

7.6.9 Linear Interpolation Application

Linear interpolation is required when testing and calibrating analog input and output devices. We don't realize it, but we are constantly linearly interpolating in our head. If two dollars will buy 10 pieces of gum, then one dollar will buy 5 pieces of the same gum. Likewise, if we have a 0-50 PSIG transmitter that provides a 0-10 VDC output signal that is sensing a system pressure of 25 PSIG, then the output voltage should be 5 VDC. This calculation is easily performed, but what if the pressure reading is 39.4 PSIG. Then the corresponding voltage signal is not so easily calculated. This is where phone applications, websites, and spreadsheets with linear interpolation come in handy. The interpolation tool at www.tabcalcs.com is often used to perform sensor transmitter calibration work.

7.7 Review

1. Test pressures for pneumatic devices when using the compressed air apparatus are typically limited to ________ PSIG.
2. Work performed at a height in excess of ______________ feet requires fall protection.
3. If arc flash hazard labels are not installed on electrical enclosures, we must assume the highest risk/hazard category and use level ________ PPE.
4. PPE is not required if the electrical enclosure is __________________.
5. OSHA recommends the use of ______________________________ to monitor the current flows of extension cords their connected loads because of their temporary nature and increased potential for damage.
6. A ______________________ is used to create hands-free connections between the electrical meters and the terminal boards.
7. True or False: The multimeter must be inline or part of the loop-powered circuit to measure the current flow. Answer: ________
8. True or False: A low-pass filter allows a clamp meter to acquire current measurements through the conductors between the VFD and the driven motor. Answer: ________

7.8 References

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3. https://www.osha.gov/sites/default/files/2019-03/electricalhazards.pdf
4. https://www.osha.gov/sites/default/files/training-library_electrical.pdf
5. https://evergreentelemetry.com/
6. http://www.shortridge.com
7. http://www.alnor-usa.com/#
8. https://www.fluke.com/
9. https://www.kleintools.com

Section 2: Binary Input (BI) Devices

Chapter 8 - Low-Temperature Detectors (BI)

8.1 Description

A Low-Temperature Detector (LTD) is a temperature-actuated device whose switched status contacts actuate on a drop in temperature below its setpoint. It is also referred to as a Freezestat (FZ) and Low-Limit Controller and is typically used in air-handling units to detect the absence or failure of heating capacity when installed downstream of a heating coil. The Honeywell L482A1004 is a commonly used LTD that has a 20 feet long capillary tube, manual reset button, and two sets of status contacts – one set of contacts is normally closed and the other set is normally open. LTDs use a capillary tube to detect low temperatures in an airstream in an HVAC system. The vapor/liquid contained within the capillary tube expands and contracts with the temperature of the air flowing over it. This expansion works against the bellows and spring. When its temperature setpoint is reached, the electrical contacts actuate to their alarm state until the capillary tube is warmed and the manual reset button (if equipped) is reset.

The manufacturer's installation recommendations should be strictly adhered to or it will not function properly. Each manufacturer has installation instructions specific to their product, so the installation requirements vary and should not be considered the same for all. The LTD capillary tube should not be kinked as this will negatively affect its operation by changing the volume of liquid/vapor acting on the bellows and spring. Cutting the capillary tube will render the LTD useless because the liquid/vapor is no longer contained and its status contacts will never actuate. The manufacturer-recommended accessories should be utilized to install and secure the capillary tubing. It is not enough that the capillary tube is inside the duct. It must be properly mounted to sample the entire cross-section of the coil or duct. Grommets are recommended where the capillary tube passes through penetrations in air-handling units or ducts. Many Controls Contractors utilize ¼ inch polyethylene tubing (Photograph 191) instead of grommets to provide LTD tubing protection at sheet metal penetrations. Mounting clips are used for mounting the capillary tube across the cross section of the duct or coil. They also ensure that the bends in the LTD capillary tubing are not less than the minimum bend radius recommended by the manufacturer.

Photo 190 - LTD Installation Inside of AHU

Photo 191 - LTD Installation Outside of AHU

Photo 192 - LTD Mounting Clip Example

The location of the LTD is a very important point to consider. The best place to locate the LTD is downstream of the hydronic heating coil (typically the preheat coil) where it detects the absence of heat or the inability of the heating coil to provide adequate heating capacity. The LTD may also be mounted at the upstream side of the downstream cooling coil. If the HVAC system is functioning properly, the air temperature leaving the heating coil should never get low enough to actuate the LTD. However, there are several potential situations that could result in insufficient heating coil capacity. These include, but are not limited to, the following:

1. Failure of the hot water coil control valve or its actuator.
2. Failure of the heating plant (pump failure) to supply hot water.
3. Failure of the heating plant (boiler failure) to supply hot water of an adequate temperature.
4. Inadequate flow of hot water through the heating coil (VFD control issue, clogging (partial or total) of the strainer, valve closure, opening of a bypass valve, etc.).
5. Loss of power to the heating coil's hot water control valve with non-spring return actuator.
6. Loss of valve control signal (software or hardware).
7. Overriding of the coil's hot water control valve to a position that provides insufficient heat.
8. Control programming issues typically related to the control of the outdoor air damper.

9. Control valve action is reversed or opposite of what it should be
10. Air in the hot coil.

If the air-handling unit is installed on a rooftop or other unconditioned space and directly exposed to the weather, then the location of the base of the LTD becomes an important point to consider. The base of the LTD is typically installed outside the unit and the capillary tube is mounted inside the unit across the coil/duct cross section. However, when the air-handling unit is installed in an unconditioned space, this leaves the base of the LTD exposed to the outdoor air conditions. In this case, the entire LTD should be installed inside the unit enclosure in the airstream to prevent nuisance activations. In addition, the LTD should be located adjacent to an access door for easy access for testing, service, and resetting.

Beware of LTDs installed or planned for installation upstream of the preheating coils. Review the design and controls submittals to verify the project requirements. Warn the Engineer and Owner that this situation typically generates nuisance trips at low outdoor air temperatures. In this position, the LTD is monitoring the mixed-air temperature which could potentially drop below the LTD setpoint and cause it to actuate. Once actuated, the equipment de-energizes and, if equipped with a manual reset LTD, someone must travel to the site to reset it before it will restart. This typically becomes a huge inconvenience. If there is no preheat coil in the air-handling, you may consider the following steps:

1. Locate the LTD downstream of the filter banks instead of the upstream side. The filters will help to mix the air and reduce the amount of stratification that may be occurring.
2. Consider the use of an automatic reset LTD and its implications.
3. Lower the LTD setpoint to a point that minimizes the potential for nuisance trips, but still provides freeze protection.

LTDs typically have an adjustable setpoint that corresponds to the lowest temperature allowed before its status contacts actuate. If the temperature at any segment of the capillary tube drops below setpoint, the LTD's electrical contacts will actuate. The detection length for LTDs varies with different manufacturers, but is typically 8-12 inches. When an LTD trips, most sequences of operations require that a series of events occur. These may include any combination of the following: air-handling supply fan de-energizes, outdoor-air and relief-air dampers close, return air damper opens, coil freeze protection pump energizes (if applicable), the hot water control valve opens fully to provide maximum heating to the coil, email notification, and an LTD alarm is generated in the BAS. The goal of these sequences of operations is to prevent freezing of the heating coil and the resulting water, pipe, electrical, and coil damage.

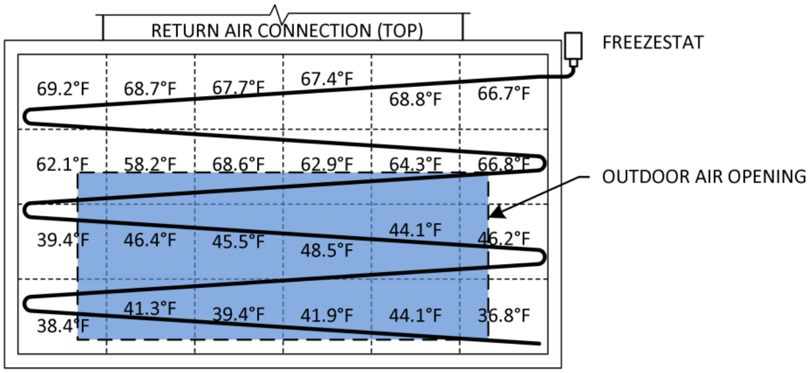


Figure 130 - Cross Sectional View of an LTD Installation and Temperature Distribution

LTDs come with automatic reset and manual reset options. It is a good idea to review the specifications and sequences of operation to determine which type is required for each project. It is not uncommon to discover that the wrong type has been installed. If actuated, manual-reset LTDs require that they be reset before the protected equipment will energize. This ensures that a person has to physically visit the equipment to verify that no damage has occurred and that it is safe to reenergize the equipment. Automatic reset LTDs will automatically reset when the low-temperature condition no longer exists, but if the cause is not identified and corrected, it will continually trip and reset which may cause mechanical and electrical damage to the air-handling unit.

Many controls specifications call for a minimum LTD length of capillary tubing per square foot of coil or duct cross-sectional area. It is fairly typical to see one foot of length for every square foot of protected coil/duct area prescribed. This means that an eight feet wide by five feet high heating coil should be equipped with a minimum 40 feet long LTD. This length can be attained with either a single LTD or multiple LTDs. If multiple LTDs are used, their status contacts are typically wired in series in the air-handling unit's safety circuit (motor starter or VFD) so that if either of the LTD status contacts opens, the air-handling unit will be de-energized. Check your project's requirements to verify the minimum acceptable level of coil or duct coverage.

(Equation 85) $$A_{Coil} = \mathrm{W(Ft)} * \mathrm{H(Ft)} = \mathrm{X}\,Ft^2$$

(Equation 86) $$L_{LTD} = A_{Coil} * \frac{Ft}{Ft^2} = (8\mathrm{Ft} * 5\mathrm{Ft}) * \frac{1\,Ft}{Ft^2} = 40\,Ft^2$$

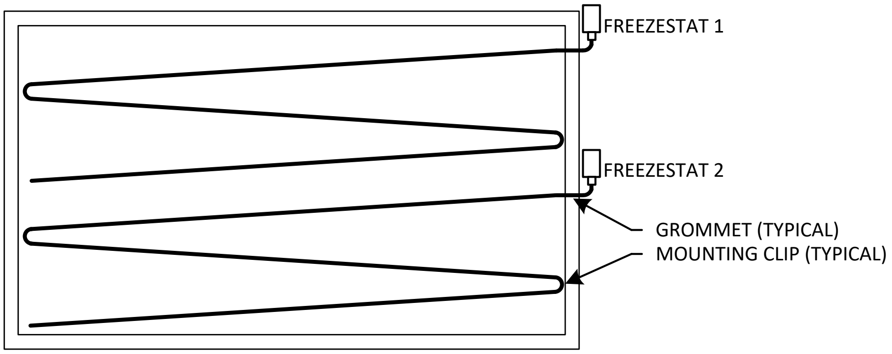


Figure 131 - Cross Sectional View of Multiple Freezestat Installation

8.2 Applications

1. **Hydronic Coil Freeze Protection**. The most common use of LTDs in HVAC applications is protecting the heating and/or cooling coils in air-handling units from freezing. Water expands as it freezes which can easily damage the piping and the tubes within the heating and cooling coils. Ruptured coils can cause extensive water damage, equipment downtime, lost productivity, and significant repair, clean-up, and restoration costs. In climates subject to freezing conditions, air-handling units are typically equipped with preheating coils which provide the principal source of heating. LTDs typically have a setpoint range that is adjustable from 15°F to 60°F depending on the manufacturer. LTDs are typically adjusted to a setpoint that is a few degrees (36°F to 40°F) above the freezing temperature of water 32°F .

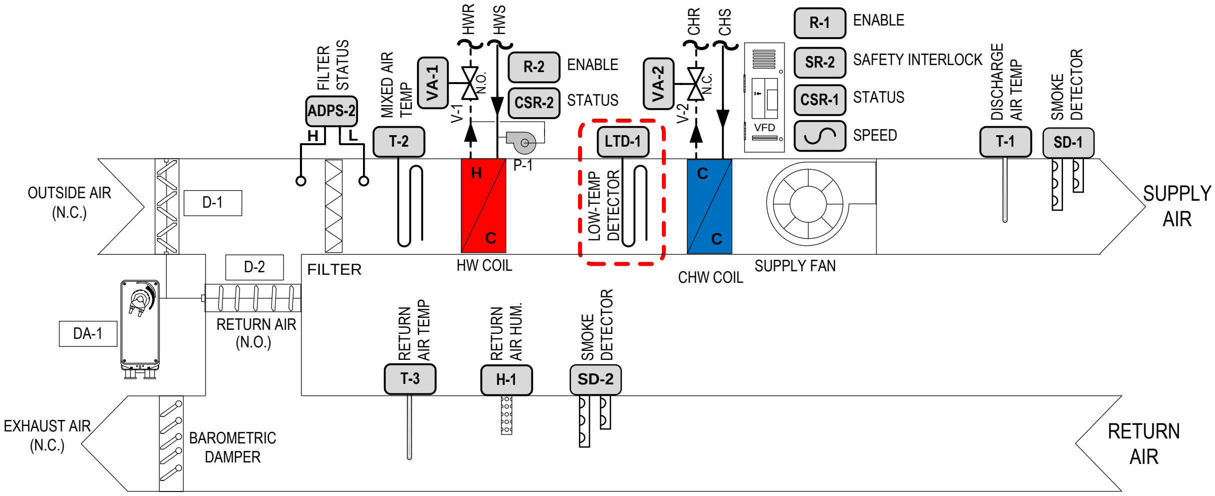


Figure 132 - Schematic of Typical Heating & Ventilating Unit with Low-Temperature Detector

8.3 Typical Control Wiring

The control wiring strategy used in each installation will vary depending on a number of factors. Based on the assumption that the air-handling unit will be disabled upon activation and the status of the low-temperature detector will be monitored by the BAS, the LTD will be part of either the traditional or solid-state fan safety alarm circuit. Refer to Chapter 6: Wiring Practices for Safety Devices for a more detailed description of these fan safety alarm circuits. The fourth rung of the PS-1 ladder diagram (Figure 133) indicates that the two LTD status contacts are wired in series to control the coil of its safety isolation relay SR-2. Should either of the LTDs actuate, the master safety relay (SR-3) and the power to the supply fan and damper/valve safety interlock relays (SR-4,5) will be disabled.

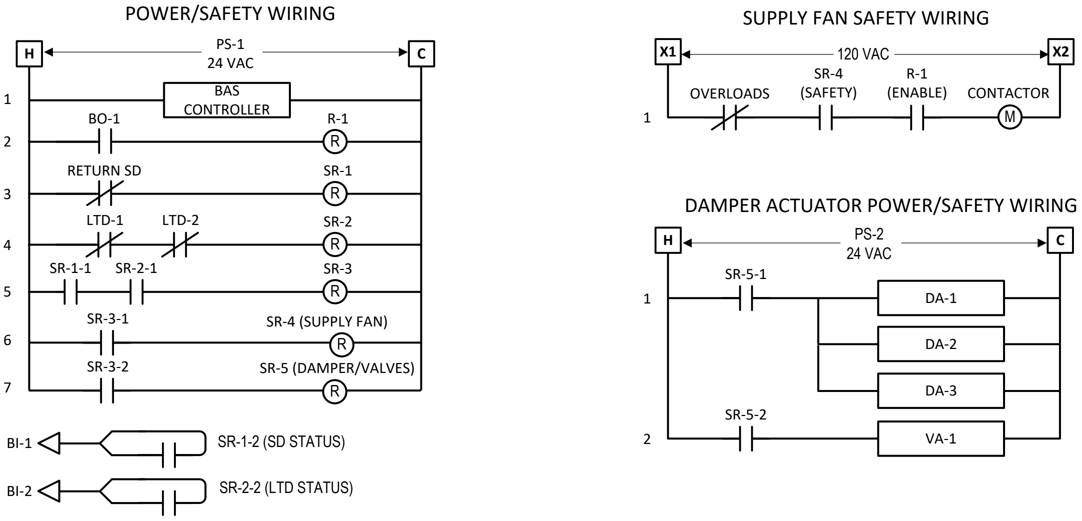


Figure 133 - Example Low-Temperature Detector Wiring Example

8.4 Binary Input Testing and Verification

Testing and verification of LTDs may pose an electrical hazard because of the potential exposure to high-voltage (120 VAC and higher) electrical conductors. De-energize the electrical power whenever possible. Use the appropriate personal protective equipment to ensure your safety and those around you when access to live electrical enclosures is required. The general test procedures for LTDs include the following:

1. Verify that the LTD has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The manufacturer, mounting, orientation, operating range, number of output contacts, normal position of the available contacts, and type of reset (manual or automatic), capillary tube length, and setpoint range are some of the features that should be verified. The minimum required level of protection or coverage should also be verified because multiple low-temperature detectors may be required.
2. Verify that the LTD has been installed at the correct or optimum location. Low-temperature detectors should be installed downstream of the preheat coil to detect the absence of adequate heat capacity to prevent freezing of the hydronic coil. If there is no preheat coil, then it should be located downstream of the filter bank to take advantage of the mixing that the filters provide. The base of the LTD should be located at a point where it is easily accessible by the operating staff when resetting is required. Units installed well inside the air-handling unit access doors (beyond arm's reach) should be avoided. If the LTD is installed in an air-handling unit that is located in an unconditioned environment, its base should also be installed inside the air-handling unit to avoid nuisance trips.
3. Verify that the LTD has been installed per the manufacturer's installation requirements. Pay special attention to the mounting requirements of the capillary tube. If it is not properly installed, it can render the LTD useless or its setpoint inaccurate. The LTD capillary tube should be protected with a grommet or ¼ inch pneumatic tubing where it passes from the outside of the air-handling unit or duct to the inside of the unit or duct.
4. Verify that the BAS controller's binary input has been properly configured to match the specifications of the LTD contacts. This typically consists of verifying whether the binary input device contacts are normally-closed or normally-opened. For example, if the normally-closed contacts are monitored, continuity signifies the normal state and the opening of the contacts signifies the alarm state.
5. Verify that the LTD has been correctly wired. It may have multiple sets of normally-open and normally-closed contacts which must be properly landed and coordinated to provide the desired control logic. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify and document how the LTD status contacts are interlocked with fans, damper actuators, and valve actuators. LTDs are typically connected to a fan safety alarm circuit which disables the associated air-handling unit and generates a BAS alarm. They may also be directly wired depending on the wiring strategy used.
7. Verify that the LTD is connected to the correct binary input of the BAS controller. Assuming that the normally-closed status contacts of the LTD are monitored by the BAS, one of the wires connected to the alarm contacts of the LTD (not at the controller) can be disconnected to simulate the alarms status. Prior to implementing this test method,

be sure that you understand the wiring, verify the voltage of this circuit, and understand the effect that its disconnection will have on the motor starter or VFD safety circuit and the BAS. You may occasionally find LTDs that are part of the 120 VAC motor starter control circuit. LTDs equipped with a manual reset button may be similarly tested by pressing and holding its reset button. However, this button must be held for the entire time that the alarm status is simulated. These methods may be used to conduct preliminary tests to document the collateral sequences of operation, but they do not actually test the LTD operation.

8. At the same time that the electrical contacts of the LTD are opened and closed, verify and document that the data point bound to the BAS graphics also changes. Binary inputs that are used as safety devices typically display a color change (typically red) to clearly and prominently indicate its status.
9. Verify that the LTD generates an alarm in the alarm console upon activation.
10. Verify that the LTD and its wires at the BAS controller and fan safety alarm circuit have been labeled.
11. Verify that the facets of the LTD data point are correctly displayed for each state. The facets for LTDs are typically displayed as “Normal/Alarm.”
12. If status or alarm delays are used, they should be verified and documented. LTD alarms signals typically have no delays.
13. Verify that the LTD functions by using one or more of the following test methods.
    A. A length of the LTD can be exposed to an ice bath to lower the temperature of the capillary tube to the trip point. This test method typically requires that a section of the capillary tube be removed from its coil/duct mounts so that 12-24 inches of its length can be submerged in the ice bath. It is typically easiest to perform this test with the end of the LTD sensing element. Extra care must be taken to avoid damage of the capillary tube by kinking it or bending it too much as this can adversely affect its functions. Alternatively, rags may be used to envelope the capillary tube (without removal) and hold ice cubes in close contact to the capillary tube surface. This test method can be messy and time consuming.

    B. Freeze sprays and similar compressed gases (nitrogen and carbon dioxide) can be used to cool a short section (6-12 inches) of the capillary tube. Freeze sprays can quickly reach very low temperatures (-160°F) and are much less messy than ice baths. For best results and minimal freeze spray use, an enclosure or tube can be used to envelope a length of capillary tube and contain the freeze spray within the annulus. This maximizes exposure of the capillary tube to the freeze spray and minimizes the amount of freeze spray required to actuate the LTD. The use of freeze spray is often preferred to ice because it is easier, faster, and does not require modification or disassembly of the capillary tube mounts.

    C. If ambient conditions permit, the outdoor air itself can be used to actuate the LTD. This is an effective method of testing and verifying actuation of LTDs. If the air-handling unit temperature sensors (mixed-air, heating coil temperature, supply air, outdoor air, etc.) have been tested and calibrated, they may also be used to monitor the air temperatures during this test. This test method is not recommended if the outdoor air temperature is below 36ºF. If the outdoor air temperature is above 36ºF and below the maximum LTD setpoint, the outdoor air and relief air dampers can be modulated open while the return damper is modulated towards the closed position. If the outdoor air damper reaches 100% open and the LTD has not actuated, the setpoint of the LTD is gradually raised from its current setpoint (Typically 36ºF to 38ºF) toward the current outdoor air temperature. It is recommended that you wait 10 to 30 seconds between adjustments.

    Following these tests, reset the low-temperature detector (if manual reset type is used), secure the capillary tube, and restore the original LTD setpoint.

14. Upon resetting the LTD (if required), verify that all system components restart as expected and resume normal operation. Occasionally, resetting a virtual reset button on the BAS graphics may also be required in order to restart the system.
15. Once the LTD has been proven to function and display properly, verify and document any collateral sequences of operation that initiate as a result of its activation. When the LTD actuates and the system is shutdown, one or more of the following may be executed: an alarm is generated, notifications issued (emails, text messages, etc.), coil circulation pump energizes, outdoor air dampers close, and hot water control valve fully opens.
16. Verify that a trend or alarm has been configured and enabled for this data point using the change of state criteria. The LTD will not alarm during the course of a typical day, so manual actuation will be required to verify and document that the LTD status trend functions.

17. Document the results of all testing. Screenshots of the LTD point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor and indicate the status of the LTD.

8.5 Review

1. True or False: After actuation, automatic reset freezestats automatically energizes the equipment when the temperature sensed by the capillary tube falls below its setpoint. Answer: ________
2. True or False: Freezestats produce a modulating analog signal proportional to the temperature. Answer: ________
3. True or False: When freezestats are used in air-handling units, they typically de-energize the supply fan (and return fan) and close the outdoor air damper when they trip. Answer: ________
4. Where should low-temperature detectors be installed to detect the lack of or failure of the coil's heating capacity? Answer: ________
   A. Upstream of the preheating coil
   B. Downstream of the preheating coil
   C. Downstream of the supply fan
   D. In the mixed-air plenum
5. True or False: Subjecting 1.5 inches of the freezestat element to an ice bath is enough to trip a freezestat. Answer: ________
6. A 12 feet by 8 feet heating coil requires that 1 foot per square feet of coil area coverage. What is the minimum length of freezestat element required? Answer: ________

Chapter 9 - Smoke Detectors (BI)

9.1 Description

Smoke Detectors (SD) are used in HVAC systems to disable air-handling units when smoke is detected in the connected duct systems. There are two main smoke detection technologies – ionization and photoelectric type. Ionization smoke detectors have two chambers that use a radioactive isotope to ionize the air. One chamber is the reference chamber which is sealed and the sampling chamber is exposed to the airstream. The electrically charged ions allow current flow in each chamber. When particles of combustion pass through the open chamber, the ions attach to them thus reducing the current flow. The smoke detector circuitry detects the difference in current flow between the chambers. When the difference exceeds a maximum threshold, it indicates an alarm condition by changing the position of its status contacts.


Photo 193 - Smoke Detector #1


Photo 194 - Smoke Detector #2

Photo 195 - Smoke Detector #3

Photoelectric smoke detectors contain a light source and a photoelectric receiver. There are two types of photoelectric smoke detectors – Photoelectric Light Obscuration and Photoelectric Light Scattering. Smoke particles can block light or scatter light. Photoelectric light obscuration detectors function by detecting a blockage or reduction in light levels caused by the presence of smoke particles between the light emitter and light sensitive detector. Most photoelectric smoke detectors are the light scattering type. This type of smoke detector detects smoke particles by detecting the scattering of light rays. When the obscuration or scattering exceeds a maximum threshold, they indicate an alarm condition which results in the activation of its status contacts.

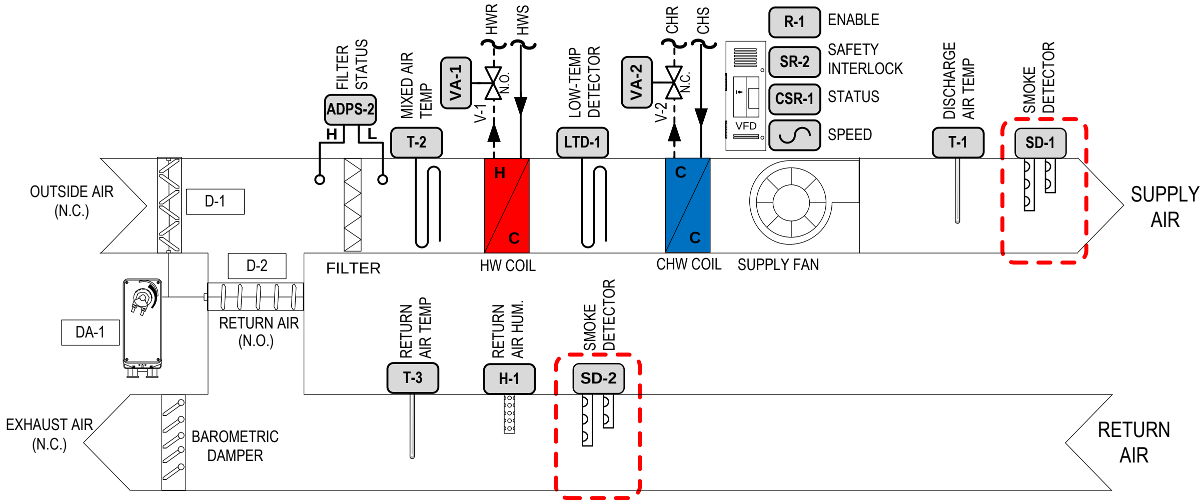


Figure 134 - Air Handling Unit with Smoke Detectors

Sampling tubes are connected to the back of the smoke detector and are used to create the differential pressure necessary to generate airflow through the smoke detector enclosure and over the smoke detector. This pressure differential is necessary because the smoke detector is mounted to the outside of the duct that it is sampling. The sampling and exhaust tubes are connected to the back of the smoke detector body and are inserted through holes drilled in the duct wall. The sampling tube has sampling ports (holes) that are oriented so that they face into the oncoming airflow. After the sampled air has entered the sampling tube and flowed across the smoke detector sensor, it returns to the duct through the exhaust tube. Most smoke detectors have a range of pressure differentials in which the measured differential pressure must fall to ensure the adequate flow of air through the smoke detector.

The presence of a Fire Alarm Control System (FACS) typically determines how the smoke detector signal is received by the BAS. When the smoke detector status contacts are connected directly to the BAS or indirectly through an interlocking isolation relay or fan safety alarm circuit, the air-handling unit is disabled when the products of combustion are detected. Smoke detectors typically have multiple sets of status contacts which allow hard-wired interlocking with the motor starter or VFD safety circuit and status monitoring by the BAS. If the smoke detector has only one set of status contacts, a multi-pole isolation relay or a fan safety alarm circuit (RIBMNLB) may be used to deliver the alarm signal to multiple destinations (BAS, motor starter control circuit, VFD safety circuit). The normal-closed status contacts are typically interlocked with the supply fan motor starter or VFD circuit to provide the immediate hard-wired shutdown upon activation. The BAS typically monitors a second set of status contacts. The control logic is typically programmed to allow air-handling unit operation only while its safety devices are in their normal status. However, the real shutdown signal is hard-wired and provides protection whether or not the programmed software interlock exists.

Photo 196 - Fire Alarm Relay Module for Air-Handling Unit Shutdown

Photo 197 - Fire Alarm Relay Module next to VFD

Photo 198 - Typical Fire Alarm Relay Module Contacts (Without Cover)

If the building has a FACS, the end result (equipment shutdown) is the same, but the path is slightly different. The FACS is typically a separate UL-listed (Underwriters Laboratory) control system dedicated to the protection of property and life as it relates to fire and smoke emergencies. It receives sensory data from its many manual (pull stations and break glass stations) and automatic initiating devices (heat detector, smoke detector, flame detector, tamper switches, water flow detectors, etc.). Depending on the location and monitored data, it activates the appropriate notification appliances and communication protocols. A FACS relay module is typically located adjacent to the air-handling unit or its motor starter or VFD that require shutdown upon detection of an alarm condition. This addressable fire alarm relay module typically provides two sets of switched electrical contacts that actuate upon command by the FACS. One set is used to implement the hard-wired equipment shutdown of specific equipment (typically air-handling units). The other set of contacts is monitored by the BAS. The FACS and controls submittals should be reviewed to determine how the air distribution system is to be de-energized when the products of combustion are detected. Once confirmed, the appropriate strategy can be utilized for its testing and verification.

9.2 Applications

1. **Smoke Detection**. The National Fire Protection Association (NFPA) produces fire and electrical codes and standards dedicated to the safety of property and building occupants. According to NFPA 90A- Standard for the Installation of Air-Conditioning and Ventilating Systems, smoke detectors and automatic shutdown of air-handling units are required in air distributions systems with a design capacity greater than 2,000 CFM. Additionally, smoke detectors are required at each floor level where return air risers serve two or more floor levels. NFPA 72 – National Fire Alarm and Signaling Code® and NFPA 101 – Life Safety Code® will provide the necessary information about fire alarm systems. Upon detecting the products of combustion, the air distribution shall shut down to mitigate the spread of fire and smoke. Smoke detection is generally not required for air duct systems with a design capacity less than 2,000 CFM.

9.3 Typical Control Wiring

The control wiring strategy employed for the smoke detector will depend on whether a FACS is installed at the facility. If a FACS is installed in the building, the smoke detectors are connected to the Fire Alarm Control Panel (FACP). The relay module is controlled by the FACS and the status of its alarm contacts are used to implement the hard-wired equipment shutdowns and their status is monitored by the BAS (directly or indirectly through the fan safety alarm circuits).

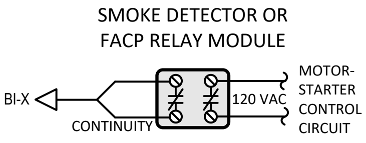


Figure 135 - SD/FACS Relay Module Example #1

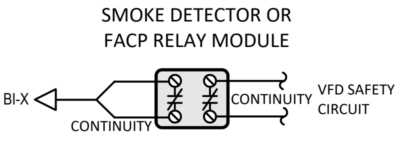


Figure 136 - SD/FACS Relay Module Example #2

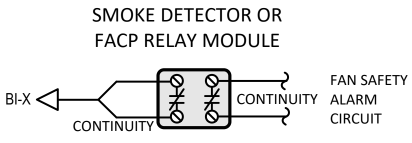


Figure 137 - SD/FACS Relay Module Example #3

If there is no FACS, then the smoke detector status contacts are hard-wire interlocked with the supply fan motor starter or VFD safety circuit. Another set of smoke detector contacts are monitored by the BAS either directly or indirectly through a fan safety alarm circuit. Upon activation of the smoke detector alarm contacts, the supply fan will be disabled. The following example shows the safety wiring for a FACS relay module (rungs 3-7). Refer to Chapter 6: Wiring Practices for Safety Devices for additional wiring examples.

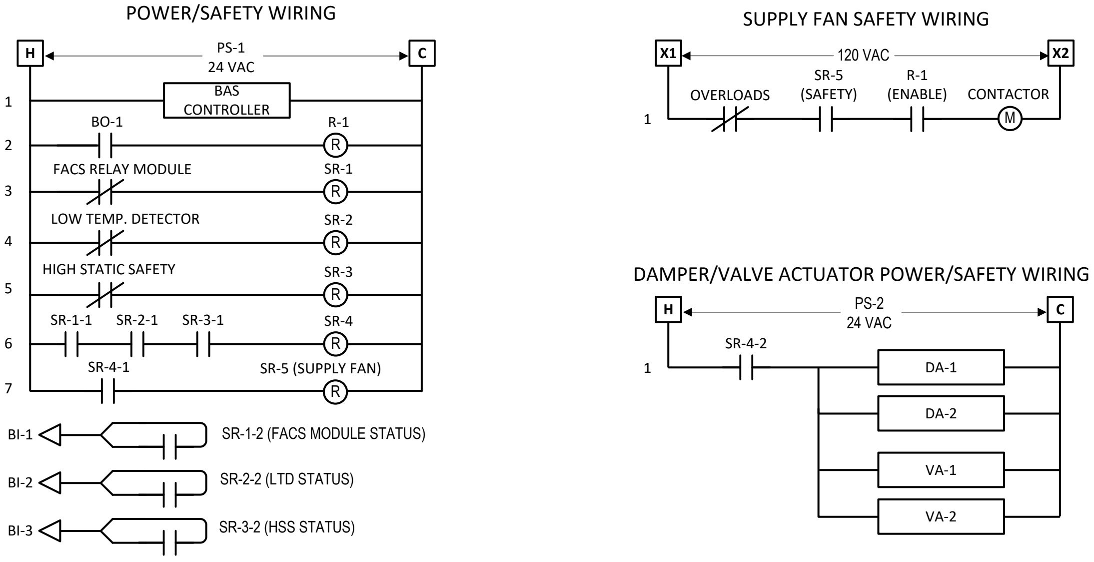


Figure 138 - Air-Handling Unit Ladder Logic Example

9.4 Binary Input Testing and Verification

Testing and verification of SDs/FACP s may pose an electrical hazard because of the potential exposure to high-voltage (120 VAC and higher) electrical conductors. De-energize the electrical power whenever possible. Use the appropriate personal protective equipment to ensure your safety and those around you when access to live electrical enclosures is required. The general test procedures for SDs/FACP relay modules include the following:

1. Verify that the SD/FACP relay module has the capabilities and accessories required by the project contract documents (design drawings and specifications), FACP submittal, and controls submittal. The manufacturer, mounting, orientation, operating range, number of output contacts, smoke detector sensor type, and normal position of the available contacts are some of the features that should be verified.
2. Verify that the SD/FACP relay module has been installed at the correct or optimum location(s). Many jurisdictions may require that smoke detectors be installed on the supply as well in the return air duct.
3. Verify that the SD/FACP relay module has been installed correctly in accordance with the manufacturer's installation recommendations. Verify that the sampling tube have been properly installed and supported. Measure the differential pressure across the sampling tubes while operating under normal conditions to verify adequate airflow over the smoke detector sensor.
4. Verify that the BAS controller's binary input has been properly configured to match the specifications of the SD/FACP relay module status contacts. This typically consists of verifying whether the SD/FACP relay module status contacts are normally-closed or normally-opened. For example, if the normally-closed contacts are monitored,

continuity signifies the normal state and the opening of the status contacts signifies the alarm state.

5. Verify that the SD/FACP relay module has been correctly wired. It may have multiple sets of normally-open and normally-closed contacts which must be properly landed and coordinated to provide the desired control logic. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify and document how the SD/FACP relay module is interlocked with fans, damper, and valve actuators, if applicable. Safety devices are typically wired to disable the associated air-handling unit fans, close outdoor air dampers, and generate an alarm when smoke is detected. Update the control logic ladder diagram that is typically included with the controls submittal.
7. Verify that the SD/FACP relay module is connected to the correct BAS controller binary input. Initiate the SD/FACP relay module signal by either causing the smoke detector to actuate (key or test magnet) or by breaking the electrical circuit at the smoke detector (not at the controller). When the electrical connection is broken, the status of the SD/FACP relay module point should also change.
8. At the same time the SD/FACP relay module electrical contacts are actuated, verify and document that the data point bound to the BAS graphics also changes. SD/FACP relay modules that are used as safety devices typically display a color change (typically red) to clearly and prominently indicate its status.
9. Verify that the activation of the SD/FACP relay module alarm contacts generates an alarm in the alarm console.
10. Verify that the SD/FACP relay module and its wires at the controller end have been labeled. The wiring from the BAS controller may be wired to the SD/FACP relay module contacts or to an intermediate relay contact or fan safety alarm circuit so labeling is an important part of conveying the purpose and defining to which system it is connected.
11. Verify that the facets of the SD/FACP relay module data point are correctly displayed for each state. SD/FACP relay modules typically display "Normal/Alarm" facets.
12. If alarm delays are used, they should be verified and documented. SD/FACP relay module alarms typically have no delay.
13. Verify that the smoke detector functions. Smoke detectors activate when they detect smoke particulates in the air, so there is nothing to measure. The test procedure involves exposing the smoke detector sensor to smoke and verifying that it actuates and shuts down the interlocked system.
    A. Canned test smoke can be sprayed into the SD sensor to verify its operation. If the SD has a smoke test port, it will be plugged. Test smoke can be sprayed into this opening to test the SD operation. Alternatively, the cover of the SD may be removed to expose the SD sensor. Test smoke can be sprayed directly toward the SD sensor. Some people cover the SD sensor with a paper or plastic cup and spray test smoke into the cup through a small hole. This provides a means to concentrate test smoke in the sensor and minimize the amount of test smoke required.

Photo 199 - Smoke Detector Test Smoke

Photo 200 - Smoke Detector Test Magnet

Photo 201 - Remote Smoke Detector Test Stations

    B. The entirety of the fire alarm system is inspected and tested by the Authority Having Jurisdiction (AHJ) which is typically the state or local Fire Marshall. It is often advantageous to wait until this occurs and observe their testing of the fire alarm system while the smoke detectors and the resulting air-handling unit shutdowns are tested. They typically perform the smoke detector tests with canned test smoke. Observing the AHJ testing reduces the duplication of work, ensures that the fire alarm system is complete, and eliminates the risk of the fire department responding to an inadvertent emergency call.
    C. Many SDs come with a test magnet which when placed in the designated location on the smoke detector will

cause a simulated activation of the smoke detector. Once tripped, the smoke detector status contacts actuate and an alarm status LED is illuminated.

D. Fire Alarm Systems may have SDs with remote keyed test stations that may be used to simulate activation of the SD. These test stations typically have LEDs that indicate the normal and alarm states of the SD.

14. Upon resetting the SD/FACP relay module (if required), verify that all system components restart as expected and resumes normal operation. Occasionally, resetting a virtual reset button on the BAS graphics may also be required in order to restart the system.
15. Once the SD/FACP relay module has been proven to function and display properly, this would also be a good time to verify and document any collateral sequences of operation that initiate as a result of its activation. When the SD activates and the system is shutdown, one or more of the following may be executed: an alarm is generated, notifications issued (emails, text messages, etc.), and outdoor air dampers close.
16. Verify that a trend or alarm has been configured and enabled for this data point using the change of state criteria. The SD/FACP relay module will not alarm during the course of a normal day, so manual actuation will be required to verify and document that the SD/FACP relay module status trend functions. This trend will allow the BAS operator to determine when any SD activation occurs.
17. Document the results of all testing. Screenshots of the binary input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the SD.

9.5 Review

1. True or False: Ionization smoke detectors use radioactive asymptote to ionize the air. Answer: ________
2. True or False: The difference in current flow is the basis of the detection in ionization smoke detectors.

   Answer: ________
3. True or False: Photoelectric smoke detectors are typically the ____________________type.
4. True or False: The difference in light levels is the basis of detection in photoelectric smoke detectors.

   Answer: ________
5. Smoke detectors are typically connected to the ______________________ prior to its ultimate connection with the supply fan VFD or motor starter.
6. If the smoke detector is connected to the FACP, a ______________________ will be provided so that the air-handling unit supply fan VFD or motor starter is disabled.
7. NFPA 90A requires that all air-handling units above ___________ CFM be equipped with smoke detectors.
8. Smoke detectors can be tested by the following methods: Answer: ________
   A. Test Smoke
   B. Magnet
   C. Remote Smoke Detector Test Station
   D. All of the above

9.6 References

1. National Fire Protection Association. 2021. NFPA 90A – Standard for the Installation of Air-Conditioning and Ventilating Systems.
2. National Fire Protection Association. 2019. NFPA 72 – National Fire Alarm and Signaling Code. ®
3. National Fire Protection Association. 2019. NFPA 101 – Life Safety Code.®
4. National Joint Apprenticeship & Training Committee for the Electrical Industry and American Technical Publishers, Inc. 2008. Building Automation: Control Devices and Applications.

Chapter 10 - HVAC Emergency Shutdown Switches (BI)

10.1 Description

The Emergency Shutdown Switch (ESS) is used by emergency response personnel and building staff to de-energize the HVAC system in the event of a fire or smoke emergency. It is also referred to as an Emergency Stop (Estop), Emergency Shutdown (ESD) switch, or an Emergency Power Off (EPO) switch. The ESS is typically located at or near the main entrance to the building. Because there is typically only one Estop in a building, this shut down signal is distributed to the air-handling units through either hardware or software means.

Photo 202 - Keyed HVAC Shutdown Switch

Photo 203 - Push Button Emergency Shutdown Switch

Photo 204 - Push Button Emergency Shutdown Switch

The ESS may take many forms depending on the application, preference, and contract requirements. It may be a typical electrical toggle switch just like those used as light switches or they may be a push button installed in a panel cover or single gang box on the wall. HVAC shutdown buttons used in commercial environments typically come with a protective cover to prevent accidental activation with bright colors and labeling. In school applications, an audible alarm is generated when the cover is lifted from its normal position. This feature is useful for discouraging children from activating the actual shutdown button.

Inside this switch is at least one set of electrical contacts which may be either Normally Open (N.O.) or Normally Closed (N.C.). When it is manually actuated, the emergency switch contacts take the opposite position. The normally-open contacts close and the normally-closed contacts open. Life safety alarm devices are typically monitored with the normally-closed contacts so that if these wires are cut during a subsequent construction project, the Owner/Operator would be immediately notified because a break in this circuit would initiate an Estop alarm. This circuit must remain continuous to prevent activation of the equipment shutdown sequence. When more than one unit requires shutdown, isolation relay contacts are used to provide additional alarm signals.

This emergency shutdown switch should not be confused with the central plant shutdown switch required by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 15 which disables the central plant equipment (boilers, domestic water heaters, and chillers) in the event a refrigerant leak is detected by a refrigerant monitoring system. It also should not be confused with the shutdown switch required by the American Society of Mechanical Engineers (ASME) Safety Code for Controls and Safety Devices (CSD) for Automatic Fuel Fired Boilers or CSD-1 for short. CSD-1 requires that the boilers be shut down upon activation of a manually-operated remote shutdown switch or circuit breaker located at the interior door(s) to the boiler room that may be used as an exit and just inside the exterior doors to the boiler room.

10.2 Applications

1. **Emergency HVAC Shut-down.** The National Fire Protection Association (NFPA) Standard 90A indicates that a manual means of de-energizing all air moving equipment must be provided to shut down the HVAC system in the event of a life safety emergency. This is typically accomplished through the use of an emergency shutdown switch. When activated, all connected equipment should immediately shut down. The shutdown switch contacts may be hard-wired directly to the motor starter safety circuit or fan VFD safety contacts or indirectly through a fan safety alarm circuit. Alternatively, they may be connected directly to the BAS and it transmits the shutdown command to all HVAC equipment.

10.3 Typical Control Wiring

The control wiring strategy used in each installation will vary depending on a number of factors. Based on the assumption that the air-handling unit will be disabled upon activation and the status of the Estop command will be monitored by the BAS, the Estop will be part of the fan safety alarm circuit. Refer to the Chapter 6: Wiring Practices for Safety Devices for a detailed description of fan safety alarm circuits.

The following diagram shows a hard-wired example of the Estop interlock wiring used to disable multiple air-handling units simultaneously. In this example, each air-handling unit is provided with a set of interlocking relay contacts which are typically connected to the air-handling unit fan safety alarm circuits. The Estop interlocking relays can either be centrally located in a panel or distributed throughout the building to deliver the signal to the air-handling units. These circuits are easiest to test when they are installed in a common enclosure, but it requires more wiring. The common side of the low-voltage (24 VAC) power supply connects to one side of the interlocking relay coil contacts in a daisy chain fashion. The hot side of the 24 VAC power typically connects to one side of the Estop switch terminal and from the other Estop terminal the wiring proceeds to the other side of the interlocking relay coils in a daisy-chain fashion. When the power supply is energized, the coils of the interlocking relays are energized causing the normally-open switched contacts of all interlock relays to close. The fan safety alarm circuit of each air-handling unit monitors the state of its contacts which are closed as long as power is available and the Estop switch is in its normal state (closed). When the Estop is activated or power is lost to the Estop interlocking relay circuit, the switched contacts of the interlocking relays open, disabling the air-handling units.

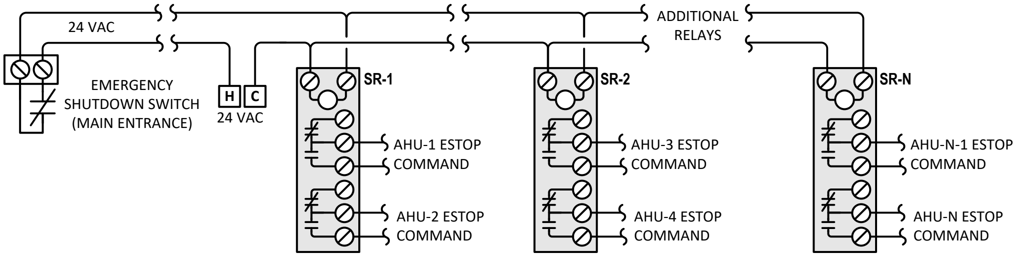


Figure 139 - Emergency Shutdown Switch Wiring

Some projects allow the use of "communicated" or "networked" Estop shutdown commands. This means that the Estop button is directly connected to a free binary input at the closest BAS controller. This controller is constantly monitoring the status of the normally-closed Estop contacts. When the Estop button is depressed, the BAS interprets the opening of the normally-closed circuit as an indication that an alarm condition exists and then transmits a mass shut-down command to all equipment whose shutdown is required. This emergency shutdown sequence is typically required to complete in a certain amount of time. This method of equipment shutdown should only be implemented on small air-handling equipment such as fan coil units and unit ventilators that are numerous, distributed throughout a building, and condition a single room. Emergency stop commands to the central air-handling unit equipment should be communicated through hard-wired connections only. The BAS controller to which the Estop button is connected could lose power, the communication bus may be down or impaired, or the network controller that relays the shutdown message could be down or otherwise impaired. There are too many things that could go wrong. If networked Estop shutdowns are specified, it would be prudent to implement regularly scheduled testing to verify that all included air-handling units are shut down within the specified time period.

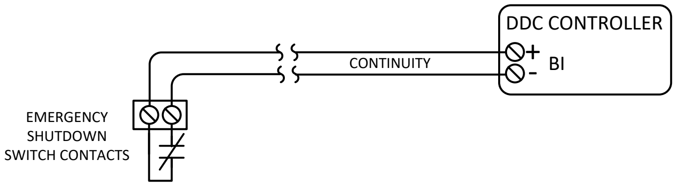


Figure 140 - Typical Estop Wiring for Networked Shutdown Command

10.4 Binary Input Testing and Verification

Testing and verification of emergency shutdown switches may pose an electrical hazard because of the potential exposure to high-voltage (120 VAC and higher) electrical conductors. De-energize the electrical power whenever possible. Use the appropriate personal protective equipment to ensure your safety and those around you when access to live electrical enclosures is required. The general test procedures for emergency shutdown switches include the following:

1. Verify that the emergency shutdown device has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The manufacturer, mounting, audible warnings, orientation, number of output contacts, normal position of the contacts, color, cover, wiring, and type of reset method are some of the features that should be verified.
2. Verify that the emergency shutdown device has been installed at the correct or optimum location. It is usually installed at the entrance of the building close to the fire alarm annunciator panel.
3. Verify that the emergency shutdown device has been installed correctly in accordance with the manufacturer's installation recommendations.
4. Prepare a list of all equipment that will be de-energized as a result of the emergency shutdown switch activation.
5. Verify that the BAS controller's binary input has been properly configured to match the specifications of the emergency shutdown device contacts. This typically consists of verifying whether the emergency shutdown device contacts are normally-closed or normally-opened. Typically, the normally-closed contacts are used for safety devices. For example, if the normally-closed contacts are monitored, continuity signifies the normal state and the opening of the contacts signifies the alarm state.
6. Verify that the emergency shutdown device has been correctly wired. The device may have multiple sets of normally-open and normally-closed contacts which must be properly landed and coordinated to provide the desired control logic. Drawings or sketches are typically best for documenting the wiring strategies used.
7. Verify that the emergency shutdown device is connected to the correct BAS controller binary input. Depending on the wiring strategy, this device may either be directly wired to the BAS controller or indirectly through the FASC. Initiate the emergency shutdown device and verify that the status of the binary input point in the BAS controller also changes. Also verify that all equipment associated with this device is disabled and that each unit generates the appropriate alarm.
8. At the same time that the emergency shutdown switch is activated, verify and document that the data point(s) bound to the BAS graphics also changes. The emergency shutdown device will typically display a color change to clearly and prominently indicate its status.
9. Verify that the activation of the emergency shutdown device generates an alarm in the alarm console. Depending on the wiring and programming strategies employed, the equipment that is shutdown may also generate their own alarms.
10. Verify and document how the emergency shutdown device is interlocked with relays, fan alarm safety circuits, fans, damper, and valve actuators, if applicable. Emergency shutdown devices are typically wired to disable the associated air-handling unit and generate an alarm activated. Update the control logic ladder diagram that is typically included with the controls submittal.
11. Verify that the emergency shutdown device and its wires at the BAS controller end have been labeled. The device may come with labeling to indicate its purpose.
12. Verify that the facets of the binary input device are correctly displayed for each state. Emergency shutdown devices typically display "Normal/Alarm" facets.
13. If status or alarm delays are used, they should be verified and documented. Emergency stop devices typically have no delays.
14. Activate the emergency shutdown switch to verify that it functions and to verify that the interlocked air-handling units are indeed shut down and the appropriate alarms are generated. Enter the observed operating status on the equipment list as the operation of each unit is physically verified.
15. Upon resetting the emergency shutdown device, verify that all listed equipment restarts as expected and resumes normal operation. Occasionally, resetting a virtual reset button on the BAS graphics may also be required in order to restart the equipment.
16. Once the emergency shutdown device has been proven to function and display properly, this would also be a good time to verify and document any collateral sequences of operation that initiate as a result of its activation.
17. Verify that a trend has been configured and enabled for this data point using the change of state criteria. The emergency stop will not activate during the course of a normal day, so manual actuation will be required to verify and document that the emergency stop status trend functions. This trend will allow the BAS operator to determine when the emergency stop activation occurs.
18. Document the results of all testing. Screenshots of the emergency shutdown device point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the emergency shutdown device.

10.5 Review

1. True or False: The emergency HVAC shutdown switch is typically located at the entrance to the mechanical equipment room. Answer: ________
2. True or False: The contacts of the ESS are typically wired to the _________________ before ultimately connecting to the air-handling unit VFD or motor starter control circuit.
3. National Fire Protection Association (NFPA) Standard ____________ requires a manual means of de-energizing all air moving equipment
4. Multiple ___________________ provide a means of multiplying the number of devices that can be shut down from the single Estop device.
5. _______________________ are an EStop accessory that prevents tampering by shielding the device and by generating an audible pre-alarm warning tone once it is removed.
6. Utilizing ___________ status contact of isolation relays ensures that the run-permissive signal only exists when power is available, the safety devices are in their normal state, and its wires are intact.
    A. Normally Closed
    B. Normally Open
    C. Neutral

10.6 References

1. American Society of Heating, Refrigeration, and Air Conditioning Engineers. 2019. Standard 15: Safety Standard for Refrigeration Systems.
2. American Society of Mechanical Engineers. 2018. Controls and Safety Devices for Automatically Fired Boilers
3. National Fire Protection Agency. 2018. Standard for the Installation of Air-Conditioning and Ventilating Systems

Chapter 11 - Current Sensing Relays (BI)

11.1 Description

Current Sensing Relays (CSRs) are used to determine the operating status of electrically driven equipment (fans, compressors, pumps, and electric resistance heat. It does so by actuating a set of status contacts when the current flow through the monitored electrical conductor exceeds the minimum current threshold of the CSR. CSRs are passive devices that do not require power to operate and are also referred to as Current-Operated Relays, Current-operated Switch, or simply Current Switches. CSRs are used on both single-phase and three-phase electrical motors. It is typically only necessary to monitor one of three conductors on three phase loads because the amperages are typically equal or balanced. CSRs must be carefully selected, installed, and adjusted (or tuned) to provide reliable operating status indications of the monitored loads. In general, when the commanded state does not match the status feedback of the CSR for a specified period, then an alarm is generated. Additionally, PID loops are often enabled while fan or pump status is proven by CSR.

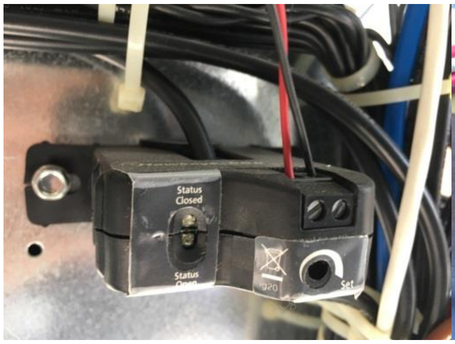


Photo 205 - CSR on a Hot Water Pump


Photo 206 - Additional Loops Around CSR Core

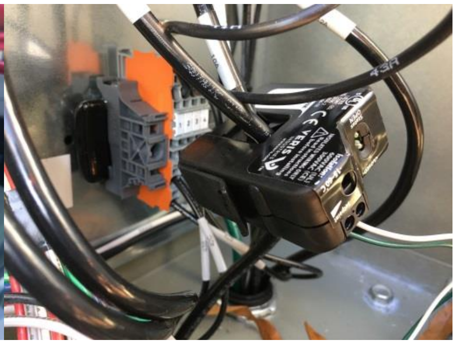


Photo 207 - CSR on a Condenser Water Pump

CSRs are constructed with either a solid-core or split-core design. Because solid-core CSRs require that the monitored conductor be removed from its terminal, passed through the CSR core, and reconnected to its terminal, they require more time to field install. Split-core CSRs are more flexible because they are more easily installed and removed without disconnecting any of the electrical terminals. When the current flowing through the monitored conductor surpasses the current threshold (setpoint) of the CSR, its status contacts close and an LED is typically illuminated. This is interpreted by the BAS as the load being in its energized state. When the current flow drops below the minimum current threshold, the CSR status contacts open and the BAS interprets this as an indication that the electrical load is no longer operating.


Photo 208 - Split-core Current Sensing Relay


Photo 209 - Solid-Core Current Sensing Relay


Photo 210 - RIB® Relay With Internal Current Sensing Relay

Air Differential Pressure Switches (ADPS) and Hydronic Differential Pressure Switches (HDPS) used to be the standard status monitoring devices for fans and pump status, respectively. When the fan or pump did not produce the minimum pressure differential, this was interpreted by the BAS as the de-energized state. CSRs have largely replaced ADPSs and HDPSs for status monitoring, but it is not because they provide a more accurate and reliable status indication. It's because CSRs do not require the installation of the tubing, valves, and fittings that connect the ADPS and HDPS units to the monitored systems. Monitoring electrical current to determine the operating status of a driven load is a perfect application for electric resistance heaters and direct-drive fans, pumps, and compressors. Direct-drive refers to the motor and driven load being secured to the same shaft. Hence, there is no belt or coupling to fail. All that is required to verify operating status is to verify motor current flow. However, when monitoring belt-driven fans and pumps with couplings, ADPSs and HDPSs still provide a more accurate and reliable status indication because they directly monitor the differential pressure produced by the monitored load which is a superior indicator of its operating status. CSRs monitor the current through the motor that drives the fan or pump to determine its operating status. In other words, the operating status of the fan or pump is inferred by monitoring the electrical current flow whereas ADPSs and HDPSs directly monitor the operating status of the fan or pump by monitoring differential pressure.

Small direct-drive equipment such as exhaust fans, inline pumps, terminal unit fans, fan coil unit, etc. are typically equipped with fractional horsepower motors with low current draw. Measure and document the normal operating current with a True RMS clamp meter and confirm the CSR type and its location along the monitored conductor. Occasionally, the current draw is below or right at the minimum current threshold of the CSR. As a result, the status either does not change or does not reliably indicate the correct operating status. To increase the sensed current, the electrical conductor must be looped around the CSR core. Each loop around the CSR core multiplies the sensed current flow. Two loops double the sensed current flow. Three loops triple the current flow and so on. Each loop requires additional wire length, so a longer wire is often required. Photograph 206 shows a CSR with three loops around its core. Equation 87 can be used to determine the minimum number of loops that are required when the current flow is below the CSR current threshold. The first part of the equation (the fraction) determines the number of loops required for the sensed current to equal the minimum current threshold. The extra loop (+1) further increases the calculated number of loops to the next whole number. If in doubt, round the answer up to the next whole number. This procedure ensures that the current sensed by the CSR is well above the minimum current threshold, minimizes the possibility of nuisance alarms, and minimizes the probability of having to repeat this process.

(Equation 87) $$\#Loops\ Around\ Core = \frac{Amps_{Minimum\ Threshold}}{Amps_{Measured}} + 1$$

For example, if the minimum current threshold of the current sensing relay is 0.5 Amps and the measured normal operating current is 0.2 Amps, then at least three loops around the core are required. It's your choice as to whether to round up or down. Three or four loops should work well. Adjust the number of loops until reliable status indications are obtained.

(Equation 88) $$\#Loops\ Around\ Core = \frac{0.5}{0.2} + 1 = 2.5 + 1 = 3.5$$

11.1.1 CSRs with Fixed Current Threshold

CSR with fixed current thresholds (or setpoint or trip point) have a current sensing core. When the sensed current exceeds its threshold, its status contacts close to indicate to the BAS controller that the fan or pump is enabled. The current thresholds are typically low (~0.25-0.5 Amps) for CSRs with fixed setpoints. In general, the minimum current threshold increases as the current rating of the CSR increases. The rated minimum current threshold of CSRs with fixed current thresholds should be verified. The normal operating current flow of the electrical load must surpass the minimum current threshold in order to actuate its status contacts. If it does not, additional loops around the CSR core are required to multiply the sensed current. If the speed of the fan or pump is variable, set the system to its minimum load and verify that the status indications are accurately indicated and adjust CSR installation accordingly.

11.1.2 CSRs with Adjustable Current Threshold

CSRs also come with the option of an adjustable minimum current threshold which allows the setpoint or trip point to be set to a specific current flow that is within the adjustment range. A screw attached to a 20-turn potentiometer provides a low current to revolution ratio that allows accurate setpoint adjustment. This feature is important when detection of belt or coupling failure is required. Should the belt or coupling break, the CSR should also be able to detect this condition even though the electrical motor continues to operate. The setpoint adjustment screw allows the minimum current threshold to be set to a specific amperage level (75%-90% of the normal operating amperage). This process is commonly referred to as "tuning" or "calibrating" the CSR setpoint. Paragraph 11.2.1 explains at what level the trip point is to be set to allow the detection of belt or coupling failure.

11.2 CSRs with Self-Tuning Current Threshold

The next type of CSR is commonly referred to as "self-tuning" or "auto-calibrating" CSR. They are equipped with circuitry and memory which allows them to detect the operating speed (Hertz) of the VFD and store a current versus speed profile to determine operating status and whether a belt or coupling has failed at any operating speed. These CSRs are manufactured specifically for use on the load-side of VFDs. If the current in the monitored conductor exceeds the learned current profile by ±20% (or similar) at the current operating speed, the status contacts open to indicate that the driven load has been disabled or failed. These units have limitations, so review of the manufacturer's specifications and installation instructions is recommended. Issues are encountered when the learned current versus operating speed profile does not match the actual profile. Many of these self-calibrating units are removed from service and replaced with a CSR with adjustable setpoint when the Control Technician reaches the limits of their patience. Typically, the CSR just needs to be retrained with a new load profile.

11.2.1 Tuning a CSR

To help understand how the CSR is able to detect belt or coupling failure it is useful to review a graph of the current versus time for a motor that operates at constant speed. Under normal operating conditions, we see the current draw is in the 10 Amp range and the graph shows the Full Load Amps at 12.5 Amps. Should a belt or coupling fail, the fan/pump ceases to rotate and the motor continues to operate with no connected load. As a result, its current flow drops to the No Load Amps (NLA) level which is estimated at 35% of FLA for motors with a synchronous speed of 1,800 Revolutions per Minute (RPM). This is where the current threshold or setpoint of the CSR comes into play. If the CSR setpoint is below the NLA, it will continue to indicate to the BAS that the load is still operating. The operating status of the driven fan or pump is what is important, not the motor. Therefore, the trip point of the CSR must be higher than the NLA.

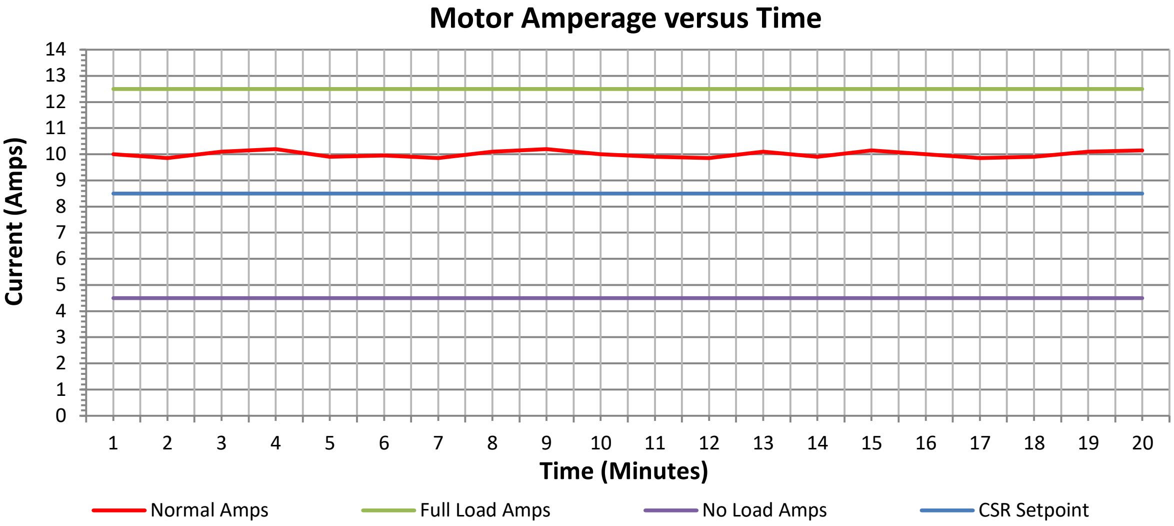


Figure 141 - Current Graph for Current Sensing Relays

In order to provide a reliable indication of the operating status and detect failure of the fan belt or pump coupling, the setpoint of the CSR must be higher than the No Load Amps and just below the normal operating current. The optimum setpoint is 75%-90% of normal operating amperage, but not so close that nuisance alarms are generated. Anywhere in this window can potentially work, but the highest reliability of the status indication occurs when the minimum current threshold is closer to the normal operating current. While the driven load is operating, adjust the minimum current threshold or setpoint to just above the actual operating amperage as indicated by the status contacts opening and the resulting "Off" status (loss of the "On" status) indication. Once this point is found, reduce the setpoint until the status contacts close and the "On" status is restored. Then reduce the CSR current threshold further by 0.5-2 revolutions of the setpoint adjustment screw. Test and adjust the setpoint by cycling the fan or pump a few times to verify that it reliably detects the correct operating status. Change the operating modes of the air/hydronic system to verify that CSR provides reliable status indications.

11.2.2 Locating a CSR

Location is perhaps the most important factor to consider when installing CSRs. Where it is installed affects how it functions. Electrical loads are typically controlled with either relays, contactors, motor starters, or VFDs. Electrically, relays, contactors, and motor starters have essentially the same function. Therefore, we will limit the discussion to the differences in placement of the CSRs on motor starters and VFDs. CSRs are installed in the motor starter, disconnect switch, motor control center, wire trough, or junction box and monitor electrical current flow through live wiring, so be sure to de-energize the power and lock-out and tag-out the equipment power prior to opening any electrical enclosure.

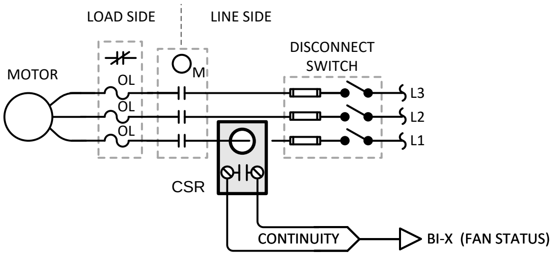


Figure 142 - Line Side of Starter CSR Installation

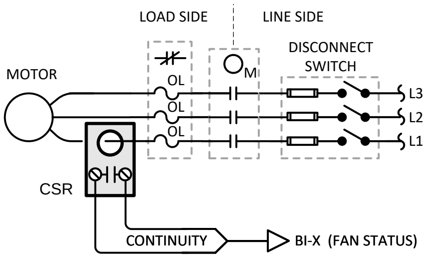


Figure 143 - Load Side of Starter CSR Installation

11.2.3 Electrical Characteristics in a Motor Starter

Motor starters engage or disengage electrical power to the driven loads through contactors whose coil circuit is controlled by the BAS or other source. It acts very much like a light switch in our homes interrupting current flow. It does not matter whether the CSR is located on the load side (downstream) or the line side (upstream) because the Voltage, Current, and Frequency are the same through each conductor's path. Because of this characteristic, CSR may be installed anywhere space can be found in a combination motor starter/disconnect switch or motor control center bucket. The only real limitation on the location of the CSR is that it be placed downstream of the circuit breaker or disconnect switch that supplies the monitored electrical circuits.

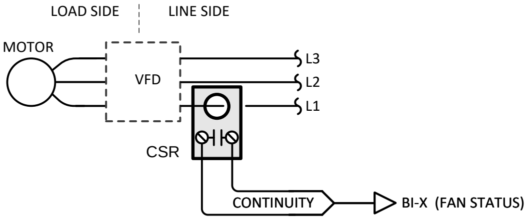


Figure 144 - Line Side CSR Installation

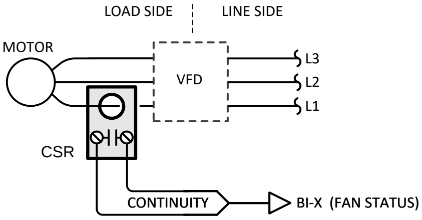


Figure 145 - Load Side CSR Installation

11.2.4 Electrical Characteristics in a VFD

When CSRs are used to monitor the operating status of a compressor, fan, or pump driven by a VFD, we must be especially cognizant of its location and how a VFD functions. This understanding is required, so that the correct CSR is selected and is properly located to provide the required status indications. On the line-side (upstream) of the VFD, voltage and frequency remain constant while the current varies proportionally with changes in load/operating speed in a very predictable fashion. On the load-side (downstream) of the VFD, voltage, frequency, and current are changing due to the operation of the VFD. The voltage supplied to the motor is proportional to the operating speed. The current flow is inversely proportional to the voltage at a given power output. Therefore, current is not proportional to the load/operating speed on the load-side of the VFD. The following table summarizes the characteristics of the voltage, frequency, and current signals on the line-side and load-side of motor starters and VFDs.

Parameter	Motor starter		VFD	
	Line-Side	Load-Side	Line-Side	Load-Side
Voltage (VAC)	Constant	Constant	Constant	Varies with Load
Frequency (Hertz)	Constant	Constant	Constant	Varies with Load
Current (Amps)	Varies with Load	Varies with Load	Varies with Load	Varies with Voltage

Table 68 - Line-Side/Load-Side Characteristics of Motor starters and VFDs

In variable-volume air and water distribution systems, false-off status indications are encountered during low-speed operation. To prevent/minimize false-off status indications when the load side of a VFD is monitored with a CSR with adjustable setpoint, the speed of the driven load should be set to its lowest “normal” operating speed (typically 40% to 60% of maximum speed), not the minimum VFD operating speed (10 Hertz to 15 Hertz). This condition can be simulated in a variable-air-volume supply air system by overriding the terminal units to their minimum supply airflow setpoint. The CSR current threshold is set to 75-90% of the current draw at this minimum supply fan operating speed. If the monitoring CSR is not set to the minimum flow conditions, there may be transient false-off status indications during at low speed operation. Operation of the various damper and valve PID loops in the air-handling unit control logic typically requires proof by CSR or ADPS of positive fan status. Consequently; if fan status is lost, the air-handling unit control logic stops working and it assumes an idle state. Therefore, reliable and accurate operating status indications are essential to maintaining system control.

11.2.5 CSR Types and their Applications

It is a good practice to verify and document the fan/pump drive package (direct-drive or belt/coupling), flow characteristics (constant or variable) of the monitored system, and motor drive type (motor starter or VFD) when considering the CSR type and its installed location. These factors significantly impact the accuracy of the CSR's status indication. In all cases, the CSR should reliably indicate the operating status of the monitored load. The type of CSR installed and its location are critical to ensuring accurate and reliable operating status indications. The following table was constructed to help understand where the various CSR types are most applicable. This table is based on the assumption that belt/coupling failure should be detected in addition to normal operating status. It indicates that CSRs with fixed setpoint are most applicable to direct drive fans, pumps, and compressors because there is no belt or coupling to fail. It also indicates that CSRs with adjustable setpoint are the most flexible because they can be used in all locations. It further demonstrates that auto-calibrating CSRs are only used on the load-side of the VFD. This example emphasizes the importance of knowing CSR types, where they should be installed to provide the required status indications, and the electrical characteristics of the motor starters and VFDs.

Parameter	Motor starter		VFD	
	Line-Side	Load-Side	Line-Side	Load-Side
Direct Drive	CSR(Fixed) CSR(Adjustable)	CSR(Fixed) CSR(Adjustable)	CSR(Fixed) CSR(Adjustable)	CSR(Fixed) CSR(Adjustable) CSR (Auto)
Belt/Coupling	CSR(Adjustable)	CSR(Adjustable)	CSR(Adjustable)	CSR(Adjustable) CSR (Auto)

Table 69 - CSR versus Location for Motor starters and VFDs

11.2.6 CSRs and Two-Speed Motors

Locating CSR in two-speed motors can be a challenge. Two-speed motors have two sets of windings which permit them to operate at two different speeds. Power is directed to one set of windings for low-speed operation and then is switched to the other set of windings for high-speed operation. The CSR must be installed in a location that permits the status monitoring of the load regardless of which operating speed is currently being used. Therefore, the CSR must be located upstream of the split in the wiring where it proceeds to the two motor starters. Alternatively, two CSRs could be installed to monitor each set of wires.

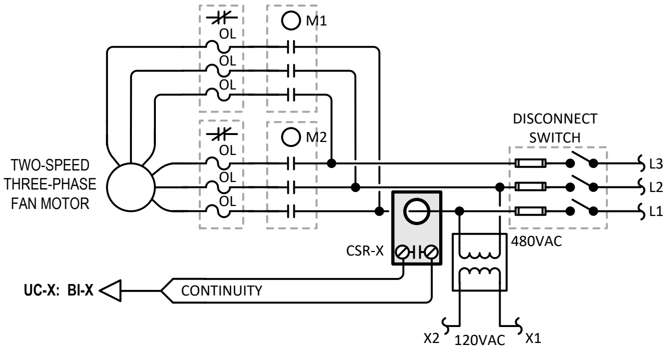


Figure 146 - CSR Location for Monitoring a Two-Speed Three-Phase Motor

11.2.7 CSRs and VFDs with Bypass

Locating the CSR in VFDs with the bypass option presents yet another challenge. In the VFD mode, contactor coils M1 and M2 are energized and contactor coil M3 is de-energized. In the Bypass mode, contactor coil M3 is energized and contactor coils M1 and M2 are de-energized. If the VFD is inoperable, the operating staff will put the VFD in the bypass mode which effectively bypasses the electrical power around the VFD through a parallel motor starter. To provide operating status through either the VFD or the bypass, the CSR must be installed on the common electrical conductors upstream or downstream of both the VFD and the bypass.

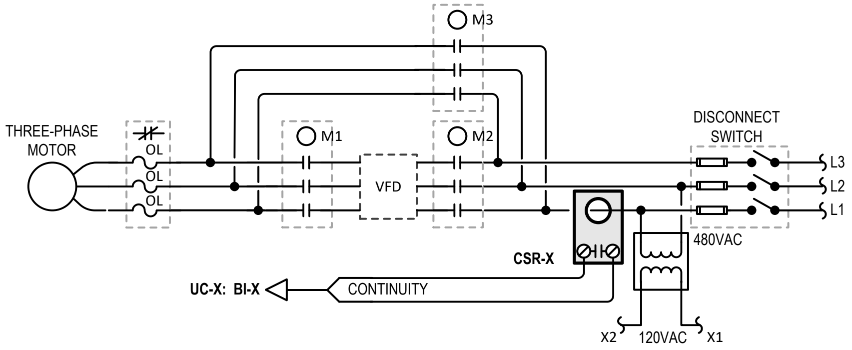


Figure 147 - CSR Location for Monitoring a VFD with a Bypass Option

11.2.8 CSRs and EC Motors

Electronically Commutated (EC) motors are a highly efficient type of electric motor that utilizes direct current instead of alternating current. It is powered by either a single-phase Alternating Current (AC) source (120 VAC, 208-240 VAC, 277 VAC) or three-phase AC source (208 VAC or 480 VAC) which is rectified to produce Direct Current (DC) potential which is used to drive a DC motor. This type of motor is typically utilized in small horsepower fan and pump applications (under 10 HP). The rotor is equipped with permanent magnets which rotate within the stator which increases motor efficiency because power is not required to create the magnetic fields in the rotor. The EC motor may have an alternate design where the rotor rotates around the stator. The stator is composed of multiple sets of windings which are energized at precise intervals to create the magnetic fields which push and pull against the magnetic fields of the permanent magnets on the rotor to create rotation and torque. The energization and timing of the magnetic fields is called commutation. The microprocessor controls the commutation of the stator's magnetic fields to drive the rotor at the desired speed and power. Like VFDs, their speed can be controlled by an external reference signal provided by a potentiometer (knob or screw) for constant speed operation or an analog output of a BAS controller for variable speed operation. In addition, the microprocessor is programmed to provide soft starting which increases motor life and reduces stress on the windings, bearings, and belts. The EC motor utilizes permanently lubricated ball bearings for very low mechanical losses and long service life. EC motors have a high turndown ratio (~80%) which allows them to operate at much lower speeds than the conventional permanent split capacitor electric motors.

When it is necessary to monitor the operating status of EC motors, a current-sensing relay is installed on the Alternating Current (AC) conductors – not the Direct Current (DC) conductors. A Functional Devices, Inc. RIBXGTA-ECM (or similar) is often selected to monitor the operating status of fans and pumps driven by EC motors. It has a minimum threshold of 0.25 Amps to change the status contacts. The following diagram shows the speed controller separate from the EC motor, but many designs have the speed controller located within the end bell of the motor. The maximum operating current of most commercially-available EC motors is under 20 Amps. While operating at lower speeds, the current draw is proportionately lower, so status monitoring of EC motors can present status monitoring opportunities for you to overcome.

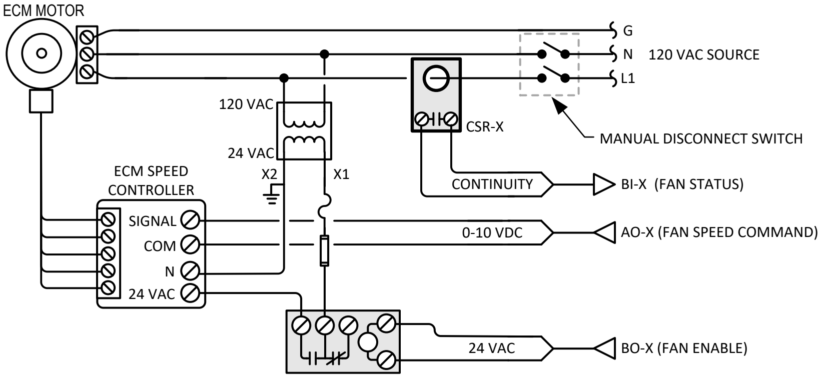


Figure 148 - CSR Location for Monitoring and Controlling an Electronically Commutated Motor

The microprocessor that controls the speed of the rotor draws a small amount of current even when the motor is not driven. This residual current flow is also referred to as "keep-alive" or "standby" current. Using a clamp meter, take standby current readings (with no motor rotation) and full-load current readings (at full or normal operating speed) on the

AC conductors and compare to the current threshold of the CSR. Some EC motors have keep-alive current that is higher than the current threshold of the CSR. Therefore, it will indicate positive operating status even though the motor is not rotating. The current threshold required to actuate the CSR status contacts should be lower than the normal operating current and higher than the standby or keep-alive current flow. Monitoring the operating status of variable speed EC motors can be challenging, but not impossible.

11.3 Applications

1. **Equipment Operating Status**: The most frequent application of CSRs is the monitoring of operating status of electrical loads (fan, pump, compressors, and electric heat). This data is critical to identifying when these HVAC system components are not performing as commanded. Most sequences of operation require that alarms be generated when the operating status of a system component does not match its command for some specified time period (typically 30-60 seconds). If a load has been enabled, but the CSR does not indicate that it is operational, a fail-to-start status alarm is generated. Likewise, if the same motor is operating, but it has not been commanded to operate, a fail-to-stop or unit-in-Hand status alarm is generated. PID loops are often interlocked (through control logic) with the fan or pump operating status, so it is important that they indicate correctly.
2. **Equipment Run-Time Accumulation:** CSRs can be used to totalize equipment run time which is useful when maintenance activities are based on run time. Compressors, fans, pumps, bearings, motors, and filters are examples of equipment that must be maintained at certain run-time intervals. You should verify that the operating status point and not the command point is used to totalize run time because there can be a significant difference. This is especially true when the H-O-A switches of starters are put in Hand or Off modes. In addition, you want to be sure that the run time data is stored at the network controller level - not in the BAS controller because the run-time data stored in the controller will reset and start from zero when the BAS controller is downloaded for programming changes or software updates.
3. **Equipment Interlocking:** Safety devices are typically hard-wired for increased reliability. Other devices, whose interlocking is not of a critical nature, can either be software or hard-wire interlocked. Once the operating status of the primary component or system is proven by the CSR, the dependent system is enabled or disabled. For example, the exhaust fan of an ERV may not be energized until the status of the supply fan has been proven by CSR status. This interlock can be implemented either through programming or hard-wired connections.

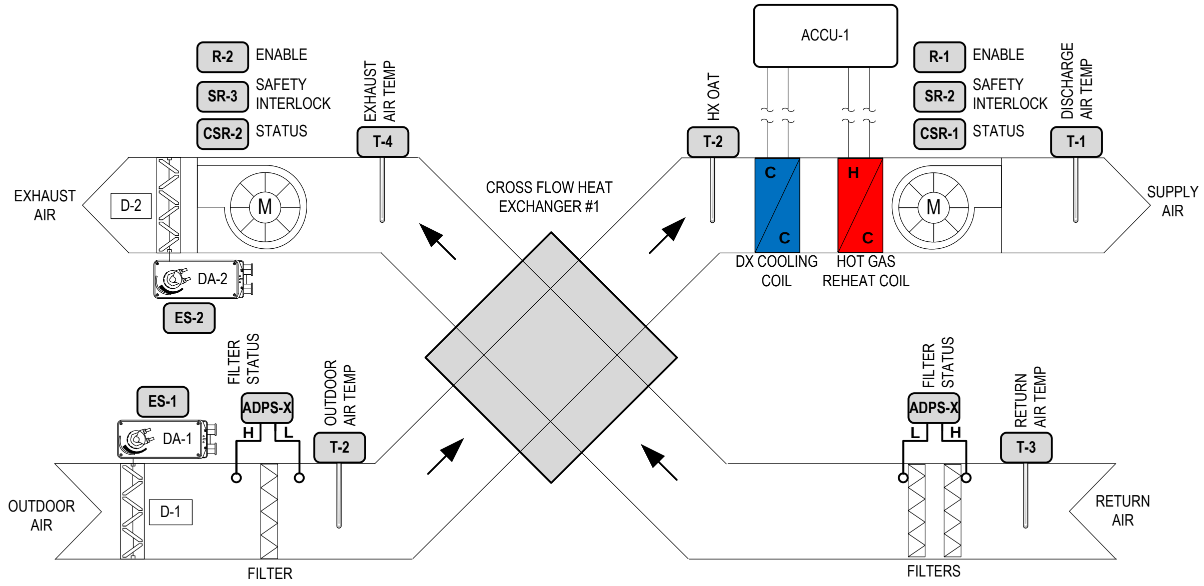


Figure 149 - Current Sensing Relay to Monitor Supply & Exhaust Fan Status

11.4 Typical Control Wiring

The following diagram is an example of the low-voltage wiring commonly utilized for current sensing relays. Typically, current sensing relays provide a set of normally-open contacts that actuate to the closed position when the current through the monitored conductor exceeds a fixed or adjustable current threshold.

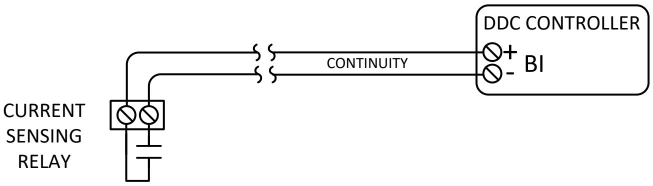


Figure 150 - Typical Current Sensing Relay Wiring Diagram

11.5 Binary Input Testing and Verification

Testing and verification of CSRs may pose an electrical hazard because of the potential exposure to high-voltage (120 VAC and higher) electrical conductors. De-energize the electrical power whenever possible. Use the appropriate personal protective equipment to ensure your safety and those around you when access to live electrical enclosures is required. The general test procedures for CSRs relays include the following:

1. Verify that the CSR has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The manufacturer, mounting, amperage rating, current threshold, solid or split-core, number of output contacts, and the normal position of the available contacts are some of the features that should be verified.
2. Verify that the CSR has been installed at the correct or optimum location. Typically, this step consists verifying whether the CSR will be installed on the line side or load side of the VFD or EC controller because the voltage, current, and frequency will be different at these locations.
3. Verify that the CSR has been installed per the manufacturer's installation recommendations. If entry to an electrical enclosure is required to review the installation, de-energize the power before entering. Utilize the proper PPE and take the appropriate electrical safety precautions prior to accessing live enclosures. If a split-core CSR is installed, verify that the core is fully closed and that the monitored conductor is at the center of the core.
4. While the monitored equipment is operating under normal or simulated test conditions, measure the current flow with a calibrated True RMS clamp meter on the same conductor that the CSR is installed and on the same side of the VFD (line-side or load-side).
5. Compare this current measurement to the specifications of the CSR to verify that it is within its current threshold range. If the measured current is below the minimum CSR current threshold, lower the current threshold (if adjustable) or provide additional loops around the CSR core. If the measured current is above the minimum CSR current threshold, the setpoint will be adjusted to the optimum level (if adjustable). CSRs with fixed current threshold may require replacement if the standby (or keep-alive) current is higher than the minimum current threshold.
6. Verify that the BAS controller's binary input has been properly configured to match the state of the CSR contacts. This typically consists of verifying whether the CSR contacts are normally-closed or normally-opened. CSRs typically have normally-open status contacts. An open circuit typically signifies the "Off" state and the closure of the CSR contacts signifies the "On" state.
7. Verify that the CSR has been correctly wired. The status contacts of the CSR are connected to the binary input contacts of the BAS controller. Drawings or sketches are typically best for documenting the wiring strategies used.
8. Verify that the CSR is connected to the correct BAS controller binary input. This step can be performed by making or breaking the electrical circuit at the CSR terminals (not at the BAS controller). This step may require the removal of a wire from a terminal or the use of a jumper wire or Magjumper to make electrically continuous a set of normally-open contacts.
9. At the same time that the CSR contacts are opened and closed, verify and document that the data point bound to the BAS graphics also changes.
10. Verify that the CSR generates an alarm in the alarm console upon activation. A status alarm is generated when the commanded state does not match the sensed state (as indicated by the CSR) for a specified period of time.
11. Verify and document how the CSR is interlocked (if applicable) with additional equipment. Update the control logic ladder diagram as appropriate.
12. Verify that the CSR and its wires at the BAS controller end have been labeled.
13. Verify that the facets of the CSR are correctly displayed for each state. The facets for CSRs are typically defined to indicate the operating status of the equipment they monitor. Because current sensing relays monitor fans, pumps, compressor, and electric resistance heat, the following facets are typically used: "On/Off," "Running/Off,"

"Energized/De-Energized," and "True/False.". For clarity, the facets for the status indication should not be the same as the facets for the command ("Enabled/Disabled," "Run/Stop," or "Start/Stop").

14. If the load is monitored by a CSR with a fixed current threshold, verify that the number of loops around the core is sufficient to establish proper status monitoring. If the standby current flow of EC motors is above the CSR minimum current threshold, the CSR should be replaced with an appropriately rated or adjustable unit. Otherwise, it will always indicate that it is operating. Make the appropriate changes and cycle the load and verify that the status is correctly indicated.
15. If the constant speed load is monitored by a CSR with an adjustable current threshold, adjust the setpoint to 75%-90% of the normal operating amperage. If the monitored load is variable, then set the load to its minimum system operating capacity (not VFD minimum speed) and adjust the CSR current threshold to 75%-90% of this value. Verify that the CSR has been adjusted to provide reliable operating status indications. Follow the manufacturer's installation recommendations. The final current threshold should be above the NLA for the motor.
16. If the electrical load is driven by a VFD and monitored by an Auto-Calibrating CSR, prepare the system for testing by opening all downstream dampers or valves. Set the VFD speed to 18 Hertz (30%) and hold this speed for 30 seconds. Increase the speed in 6 Hertz (10%) increments holding the speed setting for 30 seconds. Verify that the status indication is correct at each speed increment. Continue this sequence until the VFD reaches full speed (≥60 Hertz). If the status indication is lost at any speed increment, then the CSR needs to be retrained or replaced.
17. If reliable CSR performance cannot be provided by the CSR, then an alternative status monitoring device (ADPS or HDPS) should be considered.
18. If status alarm delays are used, then they should be verified and documented. Equipment (fan, pump, compressor, electric resistance heaters, etc.) operating status points are typically given a status delay of 30, 60, 90, or 120 seconds, depending on the application, prior to generating the status alarm. This is done to ensure that the alarm condition is true and to minimize nuisance alarms.
19. Once the CSR has been proven to function and display properly, verify and document any collateral sequences of operation that initiate as a result of changes in the equipment operating status. For most air-handling units, the programmed logic requires that the supply fan and return fan (if applicable) prove operation prior to allowing the rest of the control logic to execute.
20. Review the trend data to verify that the current sensing relay reliably and consistently reports the operating status of the monitored equipment to the BAS controller. Change-of-State trends are typically utilized to minimize memory requirements.
21. Document the results of all testing. Screenshots of the binary input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the equipment operating status through the CSR.

11.6 Review

1. True or False: CSRs with _________________ trip setpoints are best suited to detecting belt and coupling breakage in constant-speed loads.
2. True or False: A time delay of 30 to 60 seconds is typically programmed prior to generating a status alarm to prevent false and nuisance alarms. Answer: ________
3. True or False: CSRs provide an analog output signal to the BAS controller that is proportional to the motor's operating speed. Answer: ________
4. _____________ are typically generated when the operating status does not match the commanded state.
5. True or False: Totalization of equipment run time based on the indicated operating status (via CSR) provides a more accurate representation of a load's run time than the command. Answer: ________
6. In general, the minimum current threshold should be between _________ and ________ to be able detect the failure of a fan belt or pump coupling.
7. At what amperage range should the CSR setpoint in order to detect belt/coupling failure if the constant speed motor operates at 51.5 Amps in the monitored conductor. Answer: ______________
8. True or False: CSRs provide the same performance whether installed on the line side or load side of a VFD. Answer: ________
9. True or False: The current setpoint (or minimum current threshold) of CSRs with adjustable setpoints should be set when the VFD-driven load (fan, pump, compressor) is operating at its normal minimum speed. Answer: ________

10. CSRs with fixed current thresholds are best suited to monitoring which of the following:

    A. Belt driven fans
    B. Direct Drive fans
    C. Inline pumps and circulators
    D. B and C
    E. All of the above

11. How many loops would be required to exceed the minimum current threshold of 5 Amps if the current in the conductor was measured at 0.35 Amps? Answer: ________
12. CSRs should be installed on the supply fan/VFD conductors when the following is/are true: Answer: ________

    A. Load is operating at minimum capacity
    B. Load is de-energized
    C. Load is operating at maximum capacity

13. Which parameters are constant on the line-side of a VFD? Answer: ________

    A. Voltage
    B. Frequency
    C. Current
    D. A and B
    E. All of the above

14. Adjusting the setpoint of the CSR must be performed with the appropriate ________________ because this can only be performed while the monitored conductor is energized.

11.7 References

1. https://easa.com/Portals/0/Accreditation/PDFs/NoLoadCurrentBasics_0205.pdf
2. https://www.functionaldevices.com/support/downloads/datasheet-generator/?SKU=RIBXGTA-ECM
3. https://www.ebmpapst.us/media/content/technical_articles/us_published_articles/EC_Motors_Explained.pdf

Chapter 12 - Air Differential Pressure Switches (BI)

12.1 Description

Air Differential Pressure Switches (ADPS) are used to determine whether the sensed differential pressure has exceeded its minimum or maximum threshold (or setpoint). Differential pressure drop provides useful data that may be used to determine the operating status of a piece of equipment, the need to replace filters or clean a heat exchanger (heating and cooling coils), or when a high-limit or low-limit pressure threshold has been reached. When the pressure differential setpoint of the ADPS is exceeded, its electrical status contacts actuate (close or open). The ADPS contacts are connected to a binary input of a BAS controller either directly or through an intermediate relay (RIBMNLB or isolation relay). The BAS controller logic is then programmed to interpret the change in contact position as a change in state.

Photo 211 - Automatic Reset
ADPS for Fan Status Monitoring

Photo 212 - Manual Reset
High Static Safety Switch

Photo 213 - Automatic Reset
ADPS for Filter Monitoring

To set the differential pressure switch to the required threshold, a setpoint adjustment knob or screw is provided. It typically provides an increase in setpoint when turned clockwise and a decrease when turned counter clockwise. This requires that the positive port of the ADPS be pressurized until the status contacts actuate. The low-side pressure port of the ADPS is left open to the atmosphere. These devices should be tested with a controlled pressure source and calibrated manometer. Its setpoint is adjusted to the required level. This testing may take place while atop a ladder, out on a rooftop in the weather, or inside an AHU depending on its location and installation conditions. Retesting is recommended to verify that the setpoint is repeatable.

ADPSs are used either to indicate operating status by detecting a minimum differential pressure which would indicate a change in operating status or to indicate an unsafe or high-limit condition when a maximum differential pressure threshold has been reached. For example, if the ADPS were used to indicate the operating status of an exhaust fan, then the ADPS would be set to the minimum differential pressure that would reliably and accurately indicate that the exhaust fan is operational. If the ADPS were used to monitor the discharge static pressure of an air-handling unit, then the ADPS would be set to actuate when a maximum allowable static pressure threshold has been reached. This would be consistent with a High Static Safety which disables the supply fan when the supply duct static exceeds the setpoint. A low-static safety switch is used on return air and exhaust air duct systems to detect low static pressures.

Extra care must be taken with Variable Air Volume (VAV) systems that are monitored by differential pressure switches. Low speed operation can sometimes lower the duct static pressure to the ADPS setpoint causing it to trip (or actuate). When this occurs, the BAS interprets the change in status contacts as a failure of the fan when it is actually still running and nothing is wrong. Operation of the air-handling unit control programming typically depends on the supply and/or return fan status indications. Be sure to verify that the fan status indication is reliable and repeatable by testing it several times at minimum system operating speed (not the VFD minimum speed – 10-15 Hertz). Occasionally, two sensor inputs (ADPS and CSR) are required in order to reliably monitor the status of a variable speed fan.

ADPSs come in both manual and automatic reset types. The project documents must be reviewed to confirm which is required. The operating characteristics of each and its impact on the system operations must be understood. The automatic reset type differential pressure switches will automatically reset when the pressure differential reduces to below its setpoint. The status contacts of the manual reset type ADPS remain in the tripped position until its reset button is pushed. The need for a manual reset ADPS should be carefully considered, especially if it prevents the system from operating.

ADPSs must sample the static pressure of the system it is monitoring. Static pressure probes or "pickups" are mounted in the air-handling unit or ductwork by drilling holes large enough for the probes to pass and secured with sheet metal screws. Some probes have a magnetic mount instead of screws. Occasionally, you may discover the pneumatic sensing lines simply inserted into the duct system through holes drilled in the side of the duct or air-handling unit enclosure. This is not at all the proper way to terminate pneumatic sensing lines. Duct static and space static pressure probes are specifically designed to minimize the influences of turbulence in the static and velocity pressure measurements. Static pressure pickups are designed to sample only the static pressure when properly located and installed. This ensures that velocity pressure component is eliminated from the static pressure measurement. If proper static pressure probes are not utilized, the sensed static pressure will be inaccurate and susceptible to the effects of turbulence. This is especially true when they are installed in the fan compartment or downstream of fans because of the turbulence created by the discharging air.

Photo 214 - Static Pressure Probe (Type 1)

Photo 215 - Magnetic Static Pressure Probe (Type 2)

Photo 216 - Static Pressure Probe (Types 3 & 4)

The tubing connections are also very important to the proper function of ADPSs. If the tubing connections are reversed, then the ADPS will not change its status indication. The positive port of the ADPS must be exposed to the high static pressure of the system or component to be monitored. This means that the discharge of fans and the upstream side of filters and coils would be connected to the positive port. Likewise, the negative port of the ADPS must be connected to the lower static pressure of the system or component. Therefore, the suction side of fans and the downstream side of the filters and coils would be connected to the negative port of the ADPS.

12.2 Applications

1. **Fan status monitoring**. Fans are used to propel conditioned air through the air-handling unit and connected duct distribution system. Fans generate the pressure differential required to push and/or pull the conditioned air through the filters, coils, dampers, ductwork, and air devices. When the high- and low-pressure sensing lines of an ADPS are installed across a fan, it can detect when the fan is operating. For many, this method is preferred over current sensing relays to monitor the operating status of fans. Failed drive belts and low operating speeds (in variable volume applications) can cause false indications with CSRs if they have not been properly selected, installed, and tuned. Status indication of fans is typically more reliable with ADPS than CSRs, but CSRs are easier to install because the installation of tubing, pickups, and fittings is not required. An automatic reset ADPS is typically used for fan status monitoring.

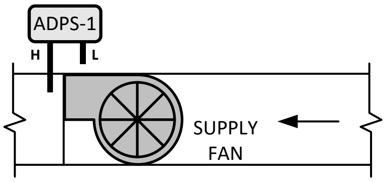


Figure 151 - Fan Status Monitoring (Supply only)

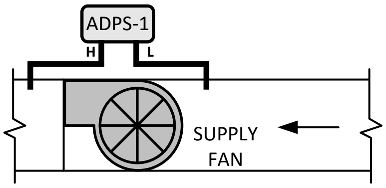


Figure 152 - Fan Status Monitoring (Inlet & Outlet)

2. **Filter differential pressure monitoring**. When the high- and low-pressure sensing lines of an ADPS are installed across a filter bank, it can monitor its condition. As dust and debris accumulate in the filter media, the differential pressure across the filter bank increases. When the differential pressure across the filter bank exceeds the ADPS setpoint, its status contacts actuate to indicate that the filter is dirty and requires replacement. An automatic reset ADPS is typically used for this application. Verify that there are no paths for the air to bypass the filter media. Sheet metal inserts are typically used to block any openings between the end of the filter and the inside of the air-handling unit enclosure. If they are not installed, air will bypass the filter media. If a bypass path exists, the differential pressure

across the filter media will never reach the setpoint of the ADPS.

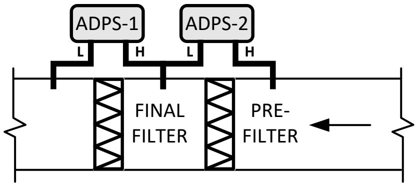


Figure 153 - Individual Filter Monitoring

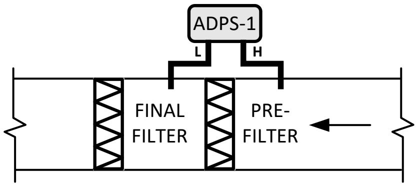


Figure 154 - Single Filter Monitoring

Occasionally, review of the controls submittal indicates that a single filter is to be monitored by the BAS. Upon inspection of the air-handling unit, there may be a pre-filter as well as a final filter. In some instances, the pneumatic sensing lines were installed such that both filters are monitored. On other occasions, only one of the two filters was monitored. If this situation is encountered, document the findings, review the project requirements (controls submittals, specifications, mechanical design drawings, etc.), and request the input of the Engineer-of-Record and/or Owner. The pre-filter is typically monitored since it will load more quickly with debris.

3. **High Static Safety (HSS) Switch**. When the positive pressure sensing line is connected to the discharge of a fan, it can detect a sudden increase in duct static pressure due to damper closure (fire/smoke damper) to avoid over-pressurizing the duct system. The low-pressure port of the ADPS is typically open to the atmosphere or references the outdoor air conditions. The status contacts of the high-static safety switch are typically wired to cause automatic shutdown of the supply fan either directly or indirectly through a fan safety alarm circuit. In this application, a manual reset ADPS it typically utilized because it ensures that the cause of the event is identified and corrected prior to manually resetting the ADPS.

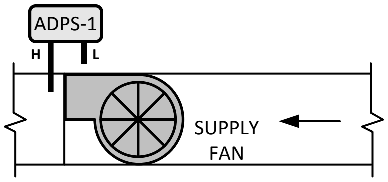


Figure 155 - High Static Safety Switch

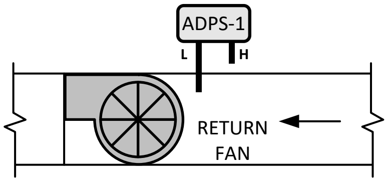


Figure 156 - Low Static Safety Switch

4. **Low Static Safety (LSS) Switch**. When the low pressure sensing line is installed on the inlet side of a fan, it can detect a sudden decrease in duct static pressure due to damper closure (fire/smoke damper) to avoid collapse of the exhaust or return duct system. The high-pressure port of the differential pressure switch is typically open to the atmosphere or references the outdoor air conditions. The status contacts of the low-static safety switch are typically wired to cause automatic shutdown of the return/exhaust fan either directly or indirectly through a fan safety alarm circuit. In this application, a manual reset ADPS it typically utilized because it ensures that the cause of the event is identified and corrected prior to manually resetting the ADPS.
5. **Airflow proving**. Differential pressure switches are typically used to “prove” that the air distribution system is operational prior to allowing the equipment (electric resistance heaters, humidifiers, etc.) to energize. In this application, airflow is proven when the duct differential pressure setpoint has been exceeded. Airflow may also be proven by monitoring the differential pressure across a restriction or electric coil opening. An ADPS with automatic reset is typically utilized to provide a run-permissive signal to equipment that would catastrophically fail if it were to operate without airflow. Electric heaters are a prime example of equipment that proves airflow before allowing the heating circuits to energize. Steam humidifiers are another example whose operation is interlocked with an airflow proving device.
6. **Space Pressure Monitoring**. Air differential pressure switches may also be used to monitor and control space pressurization. During economizer operation (or free cooling), the building or zone may become positively pressurized. Over-pressurization of the building can cause difficulty with door closure which typically poses a security concern. To avoid over-pressurization of buildings, an ADPS with automatic reset may be used to energize pressure relief fans or open relief air dampers to relieve excess building pressure when the space pressurization exceeds its high-limit threshold. The same strategy can also be used on negatively pressurized zones.

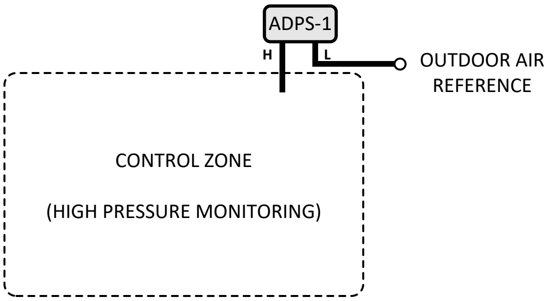


Figure 157 - Positive Space Pressure Monitoring

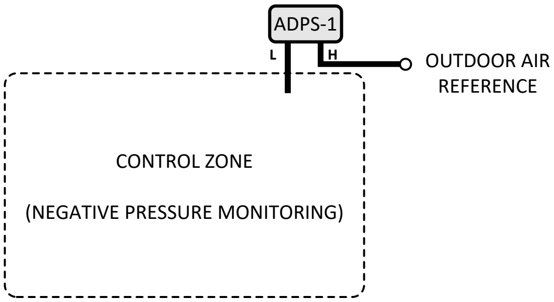


Figure 158 - Negative Space Pressure Monitoring

12.3 Typical Control Wiring

The following diagram is an example of the low-voltage wiring typically used for ADPSs. They typically come with normally-closed and normally-open contacts. The following diagram shows an ADPS whose Normally-Open contacts are monitored by the BAS controller. When the differential pressure setpoint is exceeded, the ADPS status contacts actuate and assume the opposite state (contacts closed). This change is interpreted by the BAS control logic as a change in state. When the differential pressure drops below the setpoint, the status contacts revert to their normal position (open) and this change is interpreted by the BAS as a change back to the original state. When the ADPS is used as a safety device such as a high-pressure or low-pressure safety switch, the normally-closed status contacts will typically be hard-wired to a safety circuit that directly or indirectly disables the system to avoid equipment damage or the creation of safety hazards. Refer to Chapter 6: Wiring Practices for Safety Devices.

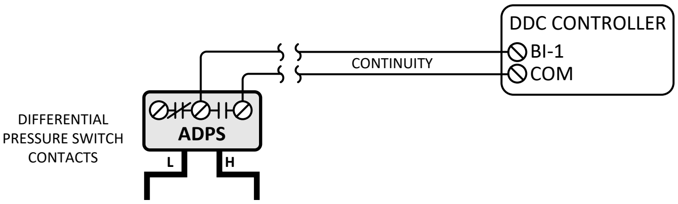


Figure 159 - Air Differential Pressure Switch Wiring

12.4 Binary Input Testing and Verification

Testing and verification of ADPSs may pose an electrical hazard because of the potential exposure to high-voltage (120 VAC and higher) electrical conductors. De-energize the electrical power whenever possible. Use the appropriate personal protective equipment to ensure your safety and those around you when access to live electrical enclosures is required. The general test procedures for ADPSs include the following:

1. Verify that the ADPS has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The manufacturer, mounting, location, orientation, operating range, number of output contacts, normal position of the available contacts, tubing connections (barbed fitting or compression fittings), and type of reset (manual or automatic) are some of the features that should be verified.
2. Verify that the ADPS has been installed at the correct or optimum location. The location of the ADPS sensing lines and static pressure pickups is critical to their proper operation. They should be located to minimize turbulence.
3. Verify that the ADPS has been installed per the manufacturer's installation recommendations. The pressure sensing lines should terminate at properly located static pressure pickups.
4. Verify that the BAS controller's binary input has been properly configured to match the specifications of the ADPS status contacts. This typically consists of verifying whether the binary input device contacts are normally-closed or normally-opened. For example, if the ADPS were monitoring the operating status of a supply fan and the normally-open contacts were monitored, an open circuit typically signifies the "Off" state and the closing of the contacts signifies the "On" state.
5. Verify that the ADPS has been correctly wired. The ADPS may have multiple sets of normally-open and normally-closed contacts which must be properly landed and coordinated to provide the desired control logic. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify that the pneumatic tubing, fittings, pickups, etc. are correctly located and tightly fitting. The high-pressure port

of the ADPS should be connected to the high-side of the system and the low-pressure port should be connected to the low-side of the system.

7. Verify that the ADPS is connected to the correct BAS controller binary input. Simulate the ADPS activation by making or breaking the electrical circuit at the ADPS (not at the controller). When the electrical connection is made or broken, the status of the binary input point should change.
8. At the same time that the electrical contacts are opened and/or closed, verify and document that the data point bound to the BAS graphics also changes. ADPSs that are used as safety devices typically display a color change (red typically) to clearly and prominently indicate its status.
9. Verify that the ADPSs that are used as safeties generate an alarm in the alarm console upon activation.
10. Verify and document how all binary input devices that are used as safeties (smoke detectors, low-temperature detectors, high/low static pressure switches, low/high temperature switches, etc.) are interlocked with fans, damper actuators, and valve actuators. Safety devices are typically connected to the fan safety alarm circuit to disable the associated air-handling unit and generate an alarm. Update the control logic ladder diagram that is typically included with the controls submittal.
11. Verify that the ADPS and its wires at the BAS controller end have been labeled.
12. Verify that the facets of the ADPS point are correctly displayed for each state. The facets should be consistent with the binary states of the monitored equipment. The ADPS may have "On/Off," Enabled/Disabled," or "Energized/De-Energized" facets when it is used to monitor the operating status of a fan, pump, compressor, or electric resistance heater. If a high-pressure condition at the discharge of an air-handling unit is monitored, then "Normal/Alarm" facets may be utilized. If the ADPS is monitoring the status of a filter bank, it may have "Clean/Dirty" facets.
13. If status or alarm delays are used, they should be verified and documented. Equipment (fan, pump, compressor, electric resistance heaters, etc.) operating status points are typically given a status alarm delay of 30, 60, 90, or 120 seconds, depending on the application, prior to generating the status alarm. This is done to ensure that the alarm condition is true and to minimize nuisance alarms. High-static and low-static pressure safeties typically have no delays.
14. Verify the setpoint of the ADPS. Simulate the static pressure with a calibrated instrument and low-pressure calibration pump that causes the ADPS contacts to actuate. Determine the current setpoint of the ADPS and adjust it to the setpoint required by the project contract documents or application.
    - A. If the ADPS is used to monitor the operating status of a fan used in a variable-volume system, set the supply fan to its minimum operating speed (not the VFD minimum speed).
    - B. Remove the cover to expose the electrical contacts. Remove both wires from the ADPS status contacts.
    - C. Disconnect all pneumatic tubing connections from both high- and low-pressure ports of the ADPS to avoid the influence of any residual pressures.
    - D. Connect a multimeter or continuity tester to the ADPS electrical contacts monitored by the BAS controller. The use of an instrument with a magnetic hanger and alligator clips is recommended to free your hands and allow constant monitoring. You may need to use a pair of short wires to make the hands-free connection to the ADPS with the alligator clips. Verify that the instrument reading is appropriate for the current state. Occasionally, you may be inside an AHU or in a noisy and/or dark environment when testing the ADPS. The Extech CT-20 continuity tester is very useful for these situations because it provides both visible and audible indication of continuity.
    - E. The test gauge and calibration pump are now connected to the ADPS in preparation of pressure testing. A hose adapter may be required for some ADPSs to connect the test hose to the positive connection fitting. Leave the negative or low-pressure port open to the atmosphere. The Dwyer A-396A calibration pump (or similar) and a Magnehelic® pressure gauge are used to apply test pressure. The range of the Magnehelic® gauge should be close to twice the intended setpoint for maximum accuracy. Alternatively, a digital manometer may also be used.
    - F. Slowly pressurize the positive pressure sensing port of the ADPS in a controlled fashion until the status contacts actuate. Note the pressure at which the ADPS contacts actuate and compare to the required or desired setpoint. ADPSs used to monitor filter status can also be tested with cardboard installed on the upstream side of the filter media. Block larger sections of the filter to create higher pressure differentials and monitor it with a calibrated digital manometer or Magnehelic® gauge using the test tees. Cardboard is actually a very good method to determine the ADPS setpoint. For example, the differential pressure that results when half (or some other percentage) of the filter is blocked can be the dirty filter differential pressure setpoint. This provides a real-life condition that is practical and repeatable.

G. Relieve the test pressure by disconnecting the tubing from the ADPS.
H. Adjust the setpoint up or down using the ADPS setpoint adjustment knob or screw, reconnect the ADPS, and retest until the ADPS status contacts actuate at the desired setpoint at least twice. If monitoring the operating status of a fan, adjust the setpoint to the lowest differential pressure that reliably and accurately indicates its operating status. If the fan is capable of variable flow, measure the fan's differential pressure while operating at its minimum supply fan operating speed (not the VFD minimum operating speed) and adjust the ADPS setpoint to just below this differential pressure threshold, but not so close that nuisance alarms are caused. If monitoring for a high-limit or low-limit condition, adjust the setpoint to the required differential pressure setting.
I. Following the successful testing and setpoint adjustment, disconnect temporary test tubing, hose, and fittings and reconnect the permanent pressure-sensing connections. In addition, remove any temporary wiring and restore the permanent electrical connections.

15. Upon resetting the manual reset ADPS, verify that all equipment restarts as expected and resumes normal operation. Occasionally, resetting a virtual reset button on the BAS graphics may also be required in order to restart the equipment.
16. Once the ADPS has been proven to function and display properly, this would also be a good time to verify and document any collateral sequences of operation that initiate as a result of its activation.
17. Review the trend data to verify that the ADPS reliably and consistently reports its status to the BAS controller. Change-of-State trends are typically utilized to minimize memory requirements. If the ADPS is used as a safety device, its operation will not be seen in a daily trend log. Manual activation will be required to verify that this event is recorded in the alarm log.
18. Document the results of all testing. Screenshots of the binary input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the ADPS.

12.5 Review

1. True or False: The low-pressure port of an ADPS used to monitor space pressurization during the economizer cycle should always reference the outdoor conditions. Answer: ________
2. ADPSs are monitored by a ________________ input of a BAS controller to determine the status of a monitored device (fan, filter, space, etc.).
3. True or False: Adjustment of the ADPS setpoint is not required if it is the automatic reset type ADPS.
   Answer: ________
4. True or False: It is not necessary to verify tubing connections because an ADPS automatically adjusts for changes in atmospheric pressure. Answer: ________
5. True or False: The typical unit of measurement for most ADPSs is Inches Water Column. Answer: ________
6. The facets of used to monitor the status of a filter bank are typically _________________.
7. The ADPS will only function properly when the appropriate static pressure ________________ are utilized. Shoving the polyethylene tubing through a hole is not an acceptable termination method.
8. When and ADPS is used as a safety device (High Static Safety Switch or Low Static Safety Switch), it will typically be connected to the _______________________ to facilitate status monitoring by the BAS and hard-wired shutdown of the air-handling unit.

Chapter 13 - Hydronic Differential Pressure Switches (BI)

13.1 Description

Hydronic Differential Pressure Switches (HDPS) activate their status contacts when their differential pressure threshold is exceeded. Water pressure drop provides useful data that may be used to determine the operating status of pumps and compressors, detect an unsafe system condition, or indicate the need to clean a heat exchanger or filtration device. When the pressure differential exceeds the HDPS setpoint, its electrical contacts close (or open) to indicate the new condition. The hydronic system pressure acts on a piston or membrane that is spring-loaded or vapor-loaded. When the hydronic pressure drops below setpoint, the status contacts return to their normal positions by force of the counteracting spring or vapor pressure.

Photo 217 - Differential Pressure Switch#1

Photo 218 - Differential Pressure Switch #2

Photo 219 - Differential Pressure Switch #3

The HDPS status contacts are connected to the binary input of a BAS controller. The controller logic is then programmed to interpret the normal position of the status contacts as one condition (Off or Clean) and the activated position of the status contacts as another condition (On or Dirty). A pump status indication may change from “Off” to “On” when it is energized as long as the pump operation creates a differential pressure that exceeds the HDPS setpoint. Likewise, the status indication may change from “Clean” to “Dirty” when the differential pressure across a piping element (filter, heat exchanger, chiller evaporator, chiller condenser, etc.) exceeds the setpoint of the HDPS.

To set the HDPS to the required setpoint, a setpoint adjustment knob or screw is typically provided. They generally provide an increase in setpoint when turned clockwise and a decrease when turned counter clockwise. These devices should be tested with a controlled pressure source and calibrated instrument. The setpoint is adjusted to the required level. Once the setpoint is set, retesting is recommended to be sure that the setpoint is repeatable. The Ralston Instruments APGV pressure calibrator and test gauge are used to monitor the applied test pressure. It’s an easy, quick, and accurate way to test and verify the setpoint of the typical HDPS.

The HDPS is connected to the hydronic system by ¼ inch piping and compression fittings made of brass, copper, steel, stainless, plastic, etc. The pressures are much higher than air systems, so water-tight connections are required. There must also be isolation valves which facilitate replacement and testing of the HDPS switch without a system shutdown. The piping or pump system connections should not be at the bottom or top of horizontal piping as this is the place most likely for debris and air to accumulate, respectively. The three and nine o’clock positions are recommended. The use of thermal traps as explained in Chapter 6: Essential Equipment, Tools, and Instruments are also recommended.

Extra care must be taken with variable flow systems that are monitored by HDPS. Low-speed operation can cause the differential pressure to drop below the HDPS setpoint causing its status contacts to activate. The BAS interprets the change in the status contacts as a failure of the pump when it is actually still running and nothing is wrong. Be sure to verify that the pump status indication is reliable and repeatable by testing it several times at minimum system load (not the VFD minimum speed).

Differential pressure switches come in both manual and automatic-reset type. The project documents must be reviewed to confirm which is required. The operating characteristics of each and its impact on the system operations must be understood. The automatic-reset type differential pressure switches will automatically reestablish the normal status contact configuration (normally-open or normally-closed) when the pressure differential falls below setpoint. The contacts of the manual-reset type HDPS remain in the tripped position until the reset button is pushed. This ensures that the cause of the event is identified and corrected prior to manually resetting the HDPS. In general, automatic-reset HDPSs are used for status indications while manual reset HDPSs are used for the detection of safety conditions.

13.2 Applications

1. **Pump status monitoring**. When high- and low-pressure sensing lines are installed across a pump, the HDPS can monitor its operating status. The HDPS system connections typically coincide with the suction and discharge pressure gauge connections. For many, this method of operating status monitoring is preferred over current sensing relays. Failed couplings and low operating speeds (in variable volume applications) can cause false-off indications with CSRs if they have not been properly selected, installed, adjusted, and tested.

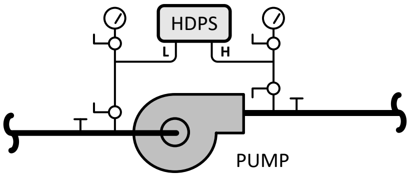


Figure 160 - Pump Operating Status Monitoring Application

2. **Pressure drop monitoring of piping elements**. When high- and low-pressure sensing lines are installed across a piping element such as a chiller barrel, boiler, heat exchanger, separator, etc., the HDPS can detect when a high-limit differential pressure has been exceeded. When hydronic equipment is newly installed, the pressure drop is at its lowest point because the internal surfaces are clean and free of corrosion and debris. It is a good idea to document the initial or baseline system pressure drop. With time, the pressure drop increases due to debris accumulation and corrosion. When the pressure drop increases to a maximum threshold, cleaning of the heat exchanger is required and the HDPS provides this indication.

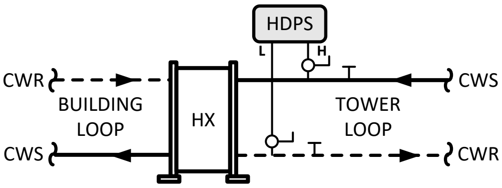


Figure 161 - Differential Pressure Monitoring of a Heat Exchanger

3. **High-Pressure Safety switch**. When the high-pressure sensing line is installed at the discharge of a pump or heat exchanger, it detects an increase in pressure beyond its high-limit setpoint. This type of device is commonly observed on the discharge of boilers, discharge of steam-to-hot water heat exchangers, and the discharge of high-temperature hot-water heat exchangers. The low-pressure port of the HDPS is typically open to the atmosphere. The contacts of the High-Pressure Safety Switch (HPSS) are typically wired in series with the equipment safety circuit (motor starter or VFD) to cause automatic shutdown in the event that an unsafe condition is detected.

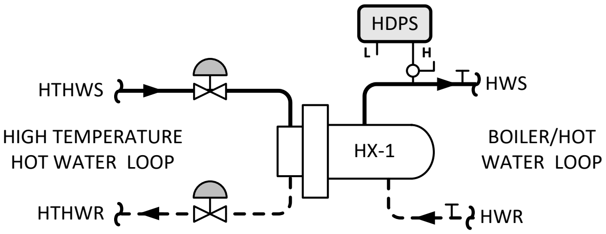


Figure 162 - Heat Exchanger High-Limit Pressure Monitoring Application

13.3 Typical Control Wiring

The following diagram provides an example of the low-voltage wiring typically used to directly monitor the HDPS. This diagram shows an HDPS whose Normally-Open contacts are monitored by the BAS controller. When the HDPS is used as a safety device, its normally-closed contacts will typically be hard-wired to a safety circuit that directly or indirectly disables the system to avoid equipment damage or the creation of safety hazards. Therefore, it is possible to have high voltages (>50 VAC) on the HDPS status contacts. Refer to Chapter 6: Wiring Practices for Safety Devices.

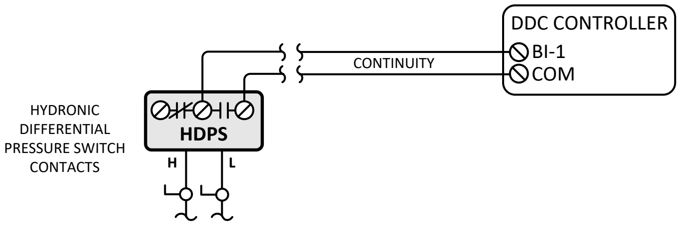


Figure 163 - Hydronic Differential Pressure Switch

13.4 Binary Input Testing and Verification

Testing and verification of HDPSs may pose an electrical hazard because of the potential exposure to high-voltage (120 VAC and higher) electrical conductors. De-energize the electrical power whenever possible. Use the appropriate personal protective equipment to ensure your safety and those around you when access to live electrical enclosures is required. The general test procedures for a Hydronic Differential Pressure Switch include the following:

1. Verify that the HDPS has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The manufacturer, mounting, orientation, operating range, number of output contacts, normal position of the available contacts, and type of reset (manual or automatic) are some of the features that should be verified.
2. Verify that the HDPS has been installed at the correct or optimum location. More importantly, the location of the taps for the sensing lines is critical to the ability to monitor the correct pressure.
3. Verify that the HDPS has been installed per the manufacturer's installation recommendations. Verify that system isolation valves have been installed at the taps to the monitored hydronic system. Without isolation valves, testing of the HDPS will be limited.
4. Verify that the hydronic tubing, piping, probes, valves, and thermal traps are correctly located and tightly fitting. The high-pressure port of the pressure sensing transmitters should be connected to the high-side of the system and the low-pressure port should be connected to the low-side of the system.
5. Verify that the BAS controller's binary input has been properly configured to match the specifications of the HDPS contacts. This typically consists of verifying whether the HDPS status contacts are normally-closed or normally-opened. For example, if the HDPS monitors the operating status of a pump and the normally-open contacts are connected to the BAS controller, an open circuit typically signifies the "Off" state and the closing of the contacts when the pump is energized signifies the "On" state.
6. Verify that the HDPS has been correctly wired. It may have multiple sets of normally-open and normally-closed contacts which must be properly landed and coordinated to provide the desired control logic. Drawings or sketches are typically best for documenting the wiring strategies used.
7. Verify and document how all HDPSs that are used as safeties (high/low static pressure switches) are interlocked with damper/valve actuators and pumps. Safety devices are typically connected to the motor starter or VFD safety circuit to disable the equipment and generate an alarm. Update the control logic ladder diagram that is typically included with the controls submittal.
8. Verify that the HDPS is connected to the correct BAS controller binary input. Initiate the binary input signal by making or breaking the electrical circuit at the device (not at the controller).
9. At the same time that the electrical contacts are opened or closed, verify and document that the data point bound to the BAS graphics also changes. HDPSs that are used as safety devices should also display a color change (typically red) to clearly and prominently indicate its status.
10. Verify that the HDPS that is used as a safety device generates an alarm in the alarm console upon activation.
11. Verify that the HDPS and its wires at the BAS controller end have been labeled.
12. Verify that the facets of the HDPS are correctly displayed for each state. The facets should be consistent with the binary states of the monitored equipment. Equipment monitored by the HDPSs, like pumps, boilers, and chillers typically display "On/Off," "Flow/No Flow," or "Energized/De-Energized" facets. Heat exchangers that are monitored by HDPSs will typically display "Clean/Dirty" to indicate its cleanliness. HDPSs that are used as safety devices typically display "Normal/Alarm" facets. When the alarm state is active, it will typically be prominently

displayed on the BAS graphics.

13. If status or alarm delays are used, then they should be verified and documented. Equipment (fan, pump, compressor, electric resistance heaters, etc.) operating status points are typically given a status delay of 30, 60, 90, or 120 seconds, depending on the application, prior to generating the status alarm. This is done to ensure that the alarm condition is true and to minimize nuisance alarms. HDPSs used as safety devices typically have no delays.
14. Verify the setpoint and accuracy of the HDPS status indication. This can be done in two ways. The methods are explained in the coming sections and depend on whether the setpoint will be set to a specific differential pressure setpoint or if it is set dynamically based on performance.

Dynamic Setpoint Verification and Adjustment Procedure

A. If the HDPS is used to monitor the operating status of a pump used in a constant-volume system, cycle the pump to verify that the status is correctly indicated.

B. If the HDPS is used to monitor the operating status of a pump used in a variable-volume system, set the system to its minimum load which should result in the minimum pump operating speed (not the VFD minimum speed). This may be implemented by overriding the downstream control valves to a minimum position.

C. Increase the HDPS setpoint until the status indication is lost (status contacts open).

D. Lower the HDPS setpoint again until positive operating status is restored (status contacts close).

E. Further lower the HDPS setpoint using your own judgement to avoid false-off indications. Notice that the HDPS was not set to a specific differential pressure setting. It was set dynamically, with the monitored system in operation.

F. Disable the pump VFD and verify whether the status is correctly indicated.

Static Setpoint Verification and Adjustment Procedure

A. Close the system isolation valves on the pressure-sensing lines and/or manifold.

B. Take a photograph or make a sketch of the piping and electrical wiring connections to ensure that they are correctly restored.

C. Remove the HDPS cover to expose its electrical contacts. Remove both wires from the HDPS status contacts.

D. Using flare nut wrenches to prevent damage of the pipe fittings, disconnect all piping connections from both the high-pressure and low-pressure ports of the ADPS or manifold to avoid the influence of any residual pressures.

E. Connect a multimeter or continuity tester to the same HDPS electrical contacts monitored by the BAS controller. The use of an instrument with a magnetic hanger and alligator clips is recommended to free your hands and allow constant monitoring. You may need to use a pair of short wires (wire pigtail) to make the hands-free connection between the HDPS and the multimeter or continuity tester. While testing for continuity, verify that the instrument reading is appropriate for the current state. Typically, the contacts open when sensed differential pressure is below the HDPS setpoint and closed when the sensed differential pressure is above the setpoint.

F. The test gauge and calibration pump are now connected to the HDPS in preparation of pressure testing. Use a ¼" male NPT x male Quick-test adapter (Ralston Instruments QTHA-2MB0) or equivalent to connect to the positive or high-pressure port of the HDPS. Leave the negative or low-pressure port open to the atmosphere. Apply thread sealant or Teflon tape prior to making all connections to avoid leakage of the pneumatic test pressure. The Ralston Instruments APGV pressure calibrator and test gauge are used to monitor the applied test pressure. If you are using a Bourdon-tube pressure gauge, its range should be close to twice the intended test pressure for maximum accuracy. Alternatively, a digital test gauge may also be used.

G. Slowly pressurize the positive pressure sensing port of the HDPS until the status contacts actuate indicating that the differential pressure setpoint has been reached. Slowly lower the applied pressure until the contacts actuate again. The difference in pressures at which the contacts actuate defines the deadband of the HDPS.

H. Adjust the setpoint up or down as needed and retest until the HDPS trips at the desired setpoint at least twice (or more if desired). If the HDPS is monitoring the operating status of a variable-volume pump, measure the pump's differential pressure and adjust the HDPS setpoint to just below this differential pressure threshold, but not so close that nuisance alarms are caused.

I. Following the successful testing and setpoint adjustment, disconnect the temporary test tubing, piping, and fittings and reconnect the permanent pressure-sensing connections. Leave the connections to the HDPS finger tight. Reapply Teflon tape or thread sealant, as needed. In addition, remove any temporary wiring and instrument connections and restore the permanent electrical connections to their original configuration.

J. At this point, the pressure sensing lines must be vented of all air. Most HDPS installations will have one of three typical configurations. They will either have no manifold with only pipe-mounted isolation valves on the pressure sensing lines, a three-port manifold, or a five-port manifold. Avoid using pliers and adjustable wrenches (also called Crescent wrench) because they contact only two of the six surfaces on the fittings and typically damage the fittings. Flare nut and box-end wrenches contact all six sides of the fittings preventing damage.

No Manifold Procedure

Purge the high-side pressure sensing line of air by loosening the compression fitting at the HDPS (not at the isolation valve) and very slowly open the high-side isolation valve until fluid flow is established. When air is no longer observed in the discharging liquid, tighten the compression fitting while the isolation valve is still open. Do not close the isolation valve prior to tightening the compression fitting as this will over-pressurize and damage the HDPS. Once the high-side piping connections are tight, fully reopen the isolation valve. Repeat this procedure on the low-side sensing line.

Three-Port Manifold Procedure

To purge the piping and manifold simultaneously, open all three manifold valves (high, low, and bypass). Loosen the low-side compression fitting at the pipe-mounted isolation valve (not the manifold isolation valve). Slowly open the high-side isolation valve and allow fluid flow until no signs of air remain. This strategy allows the air in both sensing lines and the three-port manifold to be vented at the same time. Tighten the low-side piping connections while the high-side isolation valve is still open. Do not tighten any fittings while the bypass and pipe-mounted isolation valves are closed as this could over-pressurize and damage the pressure sensing element. Open both system isolation valves and close the bypass valve to restore the HDPS to operating status.

Five-Port Manifold Procedure

Start with the pipe-mounted isolation valves closed, manifold isolation valves opened, vent valves opened, and bypass valve closed. Open the high-side system isolation valve until there are no signs of air in the fluid discharging from the high-side vent. Close the high-side manifold vent valve fully. Open the low-side system isolation valve until there are no signs of air in the liquid discharging from the low-side vent. Close the low-side system isolation valve and open the bypass valve to vent any air in the bypass. Close the bypass valve and low-side vent valve to complete the venting process.

15. Upon resetting the HDPS, verify that all equipment restarts as expected and resumes normal operation. Occasionally, resetting a virtual reset button on the BAS graphics may also be required in order to restart the equipment.
16. Once the HDPS has been proven to function and display properly, this would also be a good time to verify and document any collateral sequences of operation that initiate as a result of its activation.
17. Review the trend data to verify that the HDPS reliably and consistently reports to the BAS controller. Change-of-State trends are typically utilized to minimize memory requirements. Be aware that HDPSs that are used as safety devices will not actuate during the course of a typical day. Manual actuation of these devices may be required to create trend data for review.
18. Document the results of all testing. Screenshots of the binary input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the binary input device.

13.5 Review

1. True or False: The ideal location for the taps for the pressure sensing lines is the bottom of the pipe.
   Answer: ________
2. _______________ -port manifold makes it very easy to vent the air from the high-and low-side pressure sensing lines.
3. True or False: Only the high-side pressure sensing line is necessary for monitoring of the pressure drop across a heat exchanger. Answer: ________
4. If the HDPS has only one set of status contacts, then an _______________ with the requisite number of poles can

be used to increase the number of contacts.

5. The sensing lines used to connect the HDPS to the piping system should be equipped with ___________________ to facilitate testing, replacement, calibration, etc. without shutting the hydronic system down.
6. A ________________________ or compressed gas (air, nitrogen, carbon dioxide) source is required to pressurize an HDPS to its setpoint pressure for calibration.

Chapter 14 - Hydronic Flow Switches (BI)

14.1 Description

Hydronic Flow Switches (HFS) are electro-mechanical devices that are used to confirm or prove flow through specific equipment or a system. They are also referred to as “Paddle Switches” or just “flow switches.” Boilers, chillers, and heat exchangers are typically interlocked with a flow proving device such as a hydronic flow switch or hydronic differential pressure switch which provides a run-permissive signal. The equipment or system is allowed to operate only while flow is proven. If the run-permissive signal is lost, then the equipment/system is disabled to prevent catastrophic equipment failure. In many cases, the hydronic flow switch is directly wired to the equipment (boiler, chiller, heat exchanger, etc.) controller. However, in rare cases they may also be connected to the BAS to provide a run-permissive signal in the system’s programmed logic. Typically, the BAS will monitor a separate flow switch or the equipment (boiler, chiller, pump, etc.) operating status contacts through a binary input.


Photo 220 - Chilled Water Flow Switch

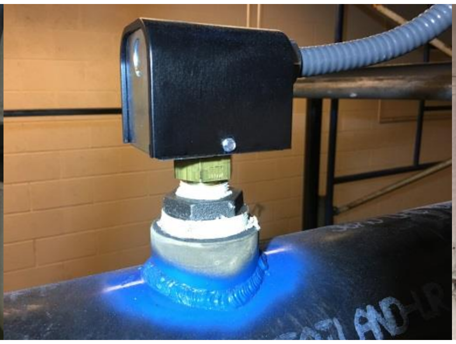


Photo 221 - Condenser Water Flow Switch


Photo 222 - Hot Water Flow Switch

An HFS utilizes a paddle located inside the pipe and in the path of fluid flow. The paddle is mounted to a spring-loaded lever that operates a set of electrical contacts. When there is no hydronic flow, there is no force on the paddle and the force of the spring maintains the flow switch status contacts in their normal state. When flow is established, the force of the water against the paddle causes it to move it the direction of flow which actuates the status contacts to their alternate position which indicates flow. Hydronic flow switches are manufactured to serve a range of pipe diameters by providing a paddle that is long enough to serve the largest pipe diameter and is trimmed to fit the smaller pipe diameters. Others HFS manufacturers provide multiple paddle lengths which may be chosen to fit various pipe diameters. The sensitivity of the switched contact is adjusted by changing length of the paddle and/or adjusting the spring force on the paddle lever by an adjustment screw.


Photo 223 - HFS Threaded Connection and Paddle


Photo 224 - Various Paddle Lengths to Accommodate Pipe Diameter


Photo 225 - HFS Contacts & Sensitivity Adjustment Screw

The HFS is typically mounted in a threadolet at the top or side of the pipe cross section. Other orientations are possible as long as they are acceptable to the manufacturer. The HFS status contacts are connected to the binary input of a BAS controller either directly, through an interlocking isolation relay, or safety circuit. The controller logic is programmed to interpret the closure of the contacts as one condition (On or Flow) and the opening of the contacts as another condition (Off or No Flow). A pump status indication may change from “Off” to “On” when the HFS contacts actuate. Boilers and chillers may display “Flow/No Flow” flow status indications.

Extra care must be taken with variable flow systems that are monitored by an HFS. Low flow hydronic system operation can sometimes lower the force on the HFS paddle to the point that the positive flow indication is lost. To avoid false no-flow indications, one or more of the following measures can be implemented: adjust the sensitivity, adjust the paddle size, or the minimum flow threshold increased. In all cases, the objective is to provide a reliable indication of flow status. Be sure to test it several times at minimum system load, not minimum VFD operating speed.

14.2 Applications

1. **Pump status monitoring**. When the HFS is installed at the inlet or outlet of a pump, it can indicate its operating status. For many, this method is preferred over current sensing relays to monitor the operating status of pumps.

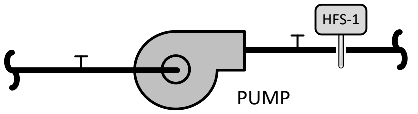


Figure 164 - Pump Operating Status Monitoring Application

2. **Equipment interlocking with flow status**. An HFS may be an integral component of a boiler, chiller, heat exchanger, water-source heat pump, etc. or it may be shipped separately for installation by the installing contractor. Most equipment manufacturers require that the HFS status contacts be directly connected to their onboard controller or hard-wire lockout circuitry. The operation of some equipment without flow can cause catastrophic equipment failure and resulting collateral damage. The following diagram shows a water-cooled chiller with hydronic flow switches in the chilled-water and condenser-water loops. Both must prove flow status prior to allowing the chiller to enable.

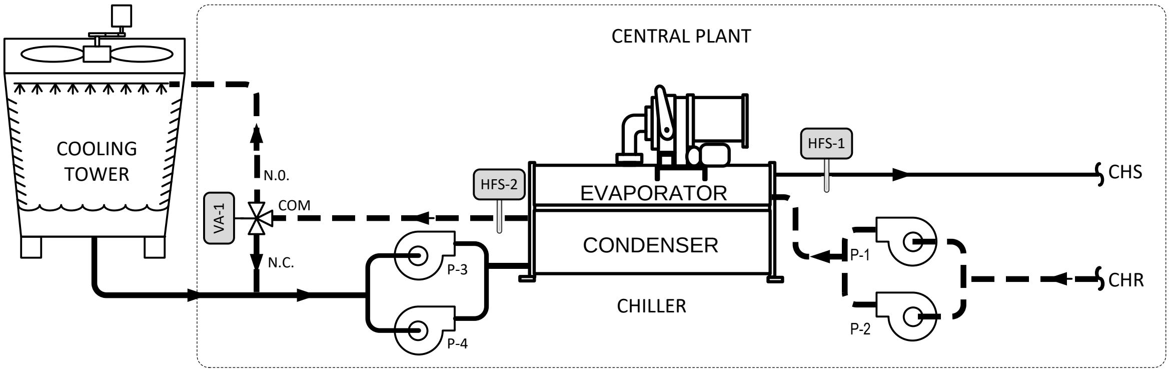


Figure 165 - Hydronic Flow Switches in a Water-Cooled Chiller System

14.3 Typical Control Wiring

The following diagram is an example of the low-voltage wiring typically used for hydronic flow switches. They typically come with a set of normally-closed and normally-open contacts. Activation of the HFS contacts by the monitored flow stream is interpreted as a change in flow status to the opposite state.

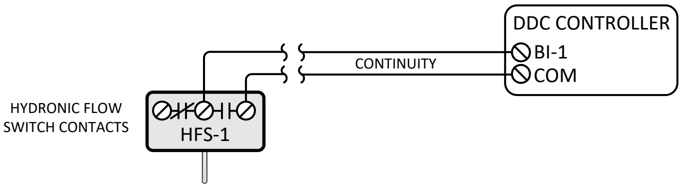


Figure 166 - Hydronic Differential Pressure Switch

14.4 Binary Input Testing and Verification

The general test procedures for a Hydronic Flow Switch include the following:

1. Verify that the HFS has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The manufacturer, mounting, orientation, operating range, and normal position of the available contacts are some of the features that should be verified.
2. Verify that the HFS has been installed at the correct or optimum location. The HFS is typically installed on the high-pressure side of the system or pump.
3. Verify that the HFS has been installed per the manufacturer's installation recommendations. Verify that the flow switch is installed facing the correct direction. The paddle moves in the direction of flow to actuate the status contacts. If it is installed in the reverse direction, its status indication will not change.
4. Verify that the BAS controller's binary input has been properly configured to match the specifications of the HFS contacts. This typically consists of verifying whether the binary input device contacts are normally-closed or normally-opened. For example, if the HFS were monitoring the operating status of a pump and the normally-open contacts were monitored, an open circuit typically signifies the "Off" state and the closing of the contacts signifies the "On" state.
5. Verify that the HFS has been correctly wired. The device may have multiple sets of normally-open and normally-closed contacts which must be properly landed and coordinated to provide the desired control logic. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify that the HFS is connected to the correct BAS controller binary input. Initiate the binary input signal by making or breaking the electrical circuit at the device (not at the controller). When the electrical connection is made or broken, the status of the binary input point in the BAS controller should also change.
7. At the same time that the electrical contacts are opened and closed verify and document that the data point bound to the BAS graphics also changes. HFSs that are used as safety devices should also display a color change (typically red) to clearly and prominently indicate its status.
8. Verify and document how all binary input devices that are used as safeties are interlocked with damper/valve actuators and pumps. Safety devices are typically connected to the motor starter or VFD safety circuit to disable the equipment and generate an alarm. Update the control logic ladder diagram that is typically included with the controls submittal.
9. Verify that the HFS and its wires at the BAS controller end have been labeled.
10. Verify that the facets of the HFS are correctly displayed for each state. The facets should be consistent with the binary states of the monitored equipment. Hydronic flow status is typically displayed as "On/Off," "Energized/De-Energized," "Flow/No Flow," or "True/False." Other options may be encountered. Safety devices typically display "Normal/Alarm" facets.
11. If status or alarm delays are used, then they should be verified and documented. Equipment operating status points are typically given a status alarm delay of 30, 60, 90, or 120 seconds, depending on the application to ensure that the alarm condition is true and to minimize nuisance alarms. When the HFS is used for interlocking of the flow status, shutdown is typically immediate.
12. Verify the setpoint and accuracy of the HFS. Monitoring of flow status in variable-flow systems presents the biggest challenge in achieving reliable flow status indications. Prior to changing the sensitivity adjustment screw, any equipment (boiler or chiller) that is interlocked with the HFS status contacts should be disabled and the hydronic system set to the minimum hydronic flow rate (40%-75% of maximum flow), not the VFD minimum operating speed.

    Setpoint Verification and Adjustment Procedure

    A. Remove the cover to expose the electrical contacts.

    B. Document the current wiring strategy with a sketch or photographs to be sure that it is properly wired.

    C. Remove the wires from the HFS status contacts.

    D. Connect an electrical multimeter or continuity tester to the status contacts of the HFS.

    E. Modulate the hydronic flow from the maximum flow down the minimum flow to verify that the flow status is not lost while operating at the minimum flow rate.

    F. Adjust the HFS sensitivity screw, as required, to achieve reliable flow status indication. If reliable flow status indications cannot be attained through sensitivity adjustments, removal of the HFS from the piping system may be required. Inspect the inside of the pipe for debris which may impact its operation. Construction debris (string, welding rods, plastic bags, weld slag, rope, Teflon tape, etc.) can occasionally make its way into the piping system to collect at or wrap around objects that protrude into the cross section of the pipe. If the HFS status contacts do not reliably indicate flow when it is known to exist, it is also possible that the paddle is too short. If this is the case, then the paddle should be replaced and/or trimmed. In some cases, the HFS switch must be replaced with a switch with different specifications (size, spring force, paddle widths) in order to achieve reliable flow status indication.

G. Following the successful testing and adjustment of the HFS, disconnect the temporary test wiring and restore the permanent electrical connections. Verify that the wires were correctly landed.

H. Reinstall the HFS cover.

13. Once the HFS has been proven to function and display properly, this would also be a good time to verify and document any collateral sequences of operation that initiate as a result of its activation.
14. Review the trend data to verify that the HFS reliably and consistently reports to the BAS controller. Change-of-State trends are typically utilized to minimize memory requirements.
15. Document the results of all testing. Screenshots of the binary input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the binary input device.

14.5 Review

1. True or False: The HFS uses pressure sensing lines to determine whether hydronic flow is present.
   Answer: ________
2. True or False: Equipment manufacturers typically prefer to have the HFS status contacts directly wired to the BAS controller.
3. A _________________ is typically used when the threadolet diameter is larger than the diameter of the HFS connection.
4. Pump operating status monitoring can be problematic while operating at ______________________ conditions in a variable-flow hydronic system.
5. How many electrical conductors are required in order for the BAS to monitor the status contacts of an HFS? Answer: _______________.
6. Which of the following can be performed if the flow switch does not actuate as required? Answer: ________

   A. Change the paddle length
   B. Adjust the sensitivity
   C. Verify the direction of the installed unit
   D. All of the above

Chapter 15 - Occupancy Detectors (BI)

15.1 Description

Occupancy detectors are used by the BAS to detect changes in occupancy. When occupant detection is confirmed by the occupancy detector, its status contacts actuate. Occupant detectors are based on three main technologies. The first is Passive Infrared (PIR) which detects occupants by sensing the heat difference between people and the background. PIR requires a direct line of sight between the infrared sensor and the occupants in a space. As a result, they are more applicable to smaller closed-in spaces such as private restrooms, offices, hallways, conference rooms, and aisle ways (warehouse, computer rooms, library stacks) where occupant detection in a specific area is required.

Photo 226 - Ceiling-Mounted Occupancy Detector

Photo 227 - Ceiling-Mounted Occupancy Detector

Photo 228 - Corner/Wall-Mounted Occupancy Detector

The second type of occupant detector functions on the Doppler principle by sending out high-frequency ultrasonic sound waves into space and detecting frequency changes in the returning signal caused by occupant movements. Ultrasonic detectors do not require a line of sight. The ultrasonic waves cover the entire area and bounce off of walls, ceilings, and objects in the room, so people behind walls and furniture can be detected. This type of sensor is useful in larger open areas that may include some semi-enclosed areas around its border.

The last type of occupant detector utilizes both PIR and ultrasonic technologies and is called dual-technology sensors. They combine the features of both technologies previously discussed to provide more dependable operation. If both technologies indicate the presence of an occupant, then its relay is actuated preventing false-on operation. Once energized, either technology can keep the lights or equipment running reducing the false-off issues.

Occupancy detectors come with various options that include time delay, sensitivity adjustment, manual override, photocells, and LED indicator. Carefully review the wiring and voltage requirements as they can vary significantly. The time delay and sensitivity options are typically adjustable by DIP switches on the back of the unit. For HVAC purposes, the occupancy sensor role is primarily focused on the detection of occupants or the lack thereof for making scheduling (occupancy override), ventilation, airflow, and space temperature setpoint adjustments.

15.2 Applications

1. **Occupancy Schedule Override Control**: Most HVAC equipment operation follows a standard operating schedule. This operating schedule may energize the air-handling units at 5:00 AM and de-energize them at 7:00 PM from Monday through Friday and may be designated as unoccupied during the weekend. Occupancy detectors allow for temporary override of the operating schedule when occupancy is sensed by the occupancy detector.
2. **Standby Temperature Reset**: Occupancy detectors can be used by the BAS during the occupied period to change the space temperature setpoints based on occupancy. In spaces with variable occupancy, the occupancy detector can be used to determine when the standby space temperature setpoints are used. When no occupants are detected during the occupied period for a minimum specified period (5-15 minutes), the standby space temperature setpoints are implemented. The standby space temperature setpoints are typically midway between occupied and unoccupied cooling and heating space temperature setpoints. When occupants reenter the space, the occupancy sensor detects the motion and the BAS reverts to the occupied space temperature setpoints. This control strategy is applicable to conference rooms, classrooms, auditoriums, gymnasiums, waiting rooms, lobbies, and other spaces where the

occupancy varies substantially throughout the day.

3. **Ventilation Control.** Ventilation is required by the International Mechanical Code when the spaces served by the HVAC system are occupied. The airflow quantities are typically adopted from American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62.1. When there are no occupants, ventilation is not required. Occupancy detectors are used by the BAS to detect the lack of occupants so that the ventilation can be reduced. In some applications, it is possible to fully close the air-handling unit outdoor air dampers when no occupants are present. When occupants are detected, the BAS reopens the outdoor air damper to its minimum position or flow setpoint to provide ventilation. This control strategy is applicable to cafeterias, auditoriums, and gymnasiums served by single zone air-handling units. The impact on building pressurization control should be analyzed prior to implementation.

15.3 Typical Control Wiring

The following diagram is an example of the low-voltage wiring commonly utilized for occupancy sensors. This type of sensor requires power to operate. The power source is typically 24 VAC, but other higher voltages are also used.

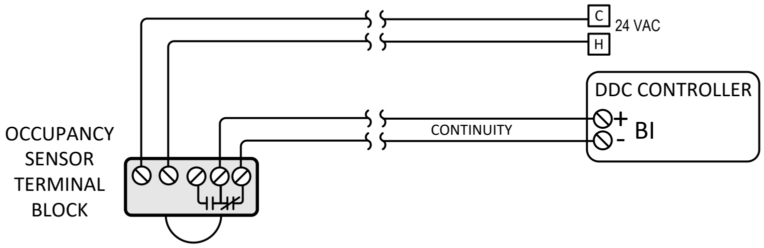


Figure 167 - Occupancy Sensor Wiring Diagram

15.4 Binary Input Testing and Verification

The general test procedures for occupancy detectors include the following:

1. Verify that the occupancy detector has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The manufacturer, mounting, orientation, operating range, voltage, sensor technology, number of output contacts, and normal positions of the available contacts are some of the features that should be verified.
2. Verify that the occupancy detector has been installed at the correct or optimum location.
3. Verify that the occupancy detector has been installed per the manufacturer's installation recommendations.
4. Verify the BAS controller's binary input has been properly configured to match the specifications of the occupancy detector contacts. This typically consists of verifying whether the occupancy detector contacts are normally-closed or normally-opened. For example, if the occupancy detectors were monitoring room occupancy and the normally-open contacts were monitored, an open circuit typically signifies the "Unoccupied" state and the closing of the contacts signifies the "Occupied" state.
5. Verify that the occupancy detector has been correctly wired. The device may have multiple sets of normally-open and normally-closed contacts which must be properly landed and coordinated to provide the desired control logic. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify that the occupancy detector is connected to the correct BAS controller binary input. Initiate the occupancy sensor signal by either causing the occupancy sensor to actuate or by making or breaking the electrical circuit at the device (not at the controller).
7. At the same time that the electrical contacts are opened and/or closed verify and document that the data point bound to the BAS graphics also changes.
8. Verify that the occupancy detector and its wires at the BAS controller end have been labeled.
9. Verify that the facets of the occupancy detector are correctly displayed for each state. The facets should be consistent with the binary states of the parameter monitored by an occupancy sensor. Occupancy sensors are typically assigned "Occupied/Unoccupied" or "Occ/Unocc" facets, but you may see other variations.
10. If status delays are used, then they should be verified and documented. The status delays used for occupancy detector vary according to the control strategy required by the sequences of operation.
11. Verify that the operation of the occupancy detector. Occupancy sensor function by either infrared, ultrasonic, or a

combination of the two technologies. No instruments are required to test the occupancy sensor. Testing for occupancy detection is very easy as it only requires that you move your body while in range of the occupancy sensor. Infrared occupancy sensors require that the occupants be within line-of-sight and range of the occupancy sensor. If ultrasonic or combination unit occupancy sensors are used, additional testing may be required. Locate yourself in an area that is within range of the ultrasonic occupancy sensor and out of direct line-of-sight. Produce movement to verify that the ultrasonic sensor can detect your motion. Testing for the vacancy (absence of occupancy) is a bit more difficult because the area may not ever be unoccupied. A bowl-shaped or concave container with a foam rim (weather stripping works well) and an adjustable extension pole works well for covering a ceiling-mounted occupancy sensor so that it does not sense movement. The adjustable extension pole is used to secure the container in place. Look for signs of false-on and false-off operation. This will require trending of this BAS data point, observations, and interviews with regular occupants.

12. Once the occupancy detector has been proven to function and display properly, this would also be a good time to verify and document any collateral sequences of operation that initiate as a result of the occupancy detector activation.
13. Review the trend data to verify that the occupancy detector reliably and consistently reports to the BAS controller. Change-of-State trends are typically utilized to minimize memory requirements.
14. Document the results of all testing. Screenshots of the binary input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the occupancy detector.

15.5 Review

1. Occupancy sensors that use __________________technology do not require a direct line of sight to detect occupants.
2. Passive infrared occupancy detectors depend on the detection of ___________________ to sense the presence of occupants.
3. ______________________ occupancy detectors utilize both PIR and ultrasonic technologies.
4. ________________________ trends are typically utilized to record occupancy sensor operation.
5. Ultrasonic occupancy detectors utilize the ________________ principle to detect changes in the frequency of the transmitted ultrasonic waves.

15.6 References

1. American Society of Heating, Refrigeration, and Air Conditioning Engineers. 2019. Standard 62.1: Ventilation for Acceptable Indoor Air Quality.

Chapter 16 - Occupancy Override Switches (BI)

16.1 Description

HVAC equipment typically operates under a schedule unless it is occupied 24 hours a day. When operation of the HVAC system outside the normal operating schedule is required, occupancy override switches provide a schedule override signal to the BAS controller that automatically disables when the override period expires. They come in a variety of designs. The most commonly-used timer switch is the wind-up type that comes in many time ranges (2,3,6,12 hours). To activate, the knob is twisted until the pointer reaches the desired override time period. Internally, a set of normally-open status contacts close which signals the BAS that operation of the associated HVAC equipment is required. When the timer switch expires, its status contacts reopen. This signals the BAS that the occupancy override button has expired. As a result, the BAS de-energizes the HVAC equipment and resumes the scheduled unoccupied state. If continued use of the HVAC is required, the override timer switch can be activated again to provide space conditioning for another override period.

Photo 229 - Occupancy Override Button (Side)

Photo 230 - Occupancy Override Button

Photo 231 - Occupancy Override Timer Switch

The occupancy override device may also utilize a momentary push button instead of a wind-up timer switch to change the occupancy command. This type of device provides a momentary closure or opening of its status contacts which are monitored by the BAS. Override push buttons tend to be more durable than other override devices. Closure of the status contacts is interpreted by the BAS as a request to operate the controlled equipment for a predefined period. The occupancy override switch may be incorporated into each space temperature sensor or it may be a separate device centrally located in the spaces served by the associated air-handling unit. Temperature sensors with occupancy override buttons typically come with the option to either provide a separate binary input signal to the BAS controller or interrupt the temperature sensor circuit when the button is pressed. Logic is written to interpret the resultant temperature change as a change in the occupancy status for a specified period of time.

16.2 Applications

Occupancy Schedule Override. Work is often required when the HVAC equipment is scheduled to be de-energized. Occupancy override switches are used by the building occupants to allow them to temporarily override the operating schedule to provide space conditioning. Some energy-conscious operators will implement an unoccupied/occupied mode where the air-handling unit is energized, but its outdoor air damper remains closed and the associated exhaust fans remain de-energized. This is done with the rationale that off-hour work is typically conducted by a single person or a very small number of people. If the full staff is expected, then the normal occupied mode can be enabled.

16.3 Typical Control Wiring

The following diagrams are examples of the low-voltage wiring commonly utilized for occupancy override switches, buttons, and timers. When the occupancy override device is a separate device, the status contacts are typically normally open. When the occupancy override device is activated, the status contacts close indicating to the BAS that equipment operation has been requested. When the override device is configured to interrupt the temperature sensor circuit, the normally-closed contacts allow monitoring of the temperature sensor resistance by the BAS controller. When override of the occupancy schedule is required, the occupancy override button is pressed which opens the temperature sensor circuit and changes to temperature reading. The temperature reading changes to zero when this occurs in Distech controllers. This change in temperature reading is interpreted by the BAS as a request for equipment operation for a prescribed time period. When the override period expires, the equipment resumes its scheduled operating mode.

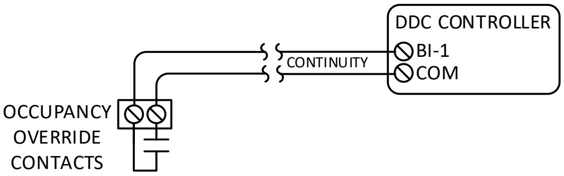


Figure 168 - Occupancy Override Switch Wiring

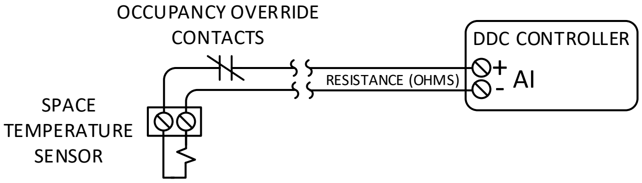


Figure 169 - Combined Temperature Sensor/Occupancy Override Switch Wiring

16.4 Binary Input Testing and Verification

The general test procedures for Occupancy Override Switches include the following:

1. Verify that the occupancy override switch has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The manufacturer, mounting, orientation, actuation type (button, switch, wind-up timer, card-insertion, etc.), maintained or momentary contacts, number of output contacts, signage, and normal position of the available contacts are some of the features that should be verified.
2. Verify that the occupancy override switch has been installed at the correct or optimum location. A single occupancy override switch is typically located at a central location within the area served or conditioned by the air-handling unit. This is not an issue if every space temperature sensor is equipped with an occupancy override button.
3. Verify that the occupancy override switch has been installed per the manufacturer's installation recommendations.
4. Verify that the BAS controller's binary input has been properly configured to match the specifications of the occupancy override switch contacts. This typically consists of verifying whether the binary input device contacts are maintained or momentary and whether they are normally-closed or normally-opened. Dip switches, jumpers, or specific terminal use may be required in order to properly configure the occupancy override device. Verify and document the control strategy used to enable the central air-handling unit that serves the terminal units. To enable the air-handling unit may require a single or a minimum number of terminal unit occupancy requests. The signal may also come from a strategically placed or select occupancy sensors.
5. Verify that the occupancy override switch has been correctly wired. The device may have multiple sets of normally-open and normally-closed contacts which must be properly landed and coordinated to provide the desired control logic. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify that the occupancy override switch is connected to the correct BAS controller binary input. Initiate the override signal by either causing the occupancy override switch to actuate or by making or breaking the electrical circuit at the device (not at the controller).
7. At the same time that the electrical contacts are opened and/or closed, verify and document that the data point bound to the BAS graphics also changes.
8. Verify that the occupancy override switch and its wires at the BAS controller end have been labeled.
9. Verify that the facets of the occupancy override switch are correctly displayed for each state. The facets should be consistent with the binary states required by the occupancy override switch. Occupancy override switches may have any of the following facets, "Occupied/Unoccupied," "Present/Vacant," "Occupied/Vacant," etc.
10. If status delays are used, then they should be verified and documented.
11. Verify the operation of the occupancy override switch and the recognition of the status change by the BAS. No instruments are required to test the occupancy override switch because it only requires manual activation.
12. Once the occupancy override has been proven to function and display properly, this would also be a good time to verify and document any collateral sequences of operation that initiate as a result of its activation.
13. Review the trend data to verify that the occupancy override switch reliably and consistently reports to the BAS controller. Change-of-State trends are typically utilized to minimize memory requirements.
14. Document the results of all testing. Screenshots of the binary input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the occupancy override switch.

16.5 Review

1. The status contacts of wind-up timers are typically _____________ when activated and ____________ when the time expires.
2. True or False: Occupancy override switches are typically incorporated into each wall-mounted space temperature sensor or centrally located within the spaces served. Answer: ________
3. Occupancy switches are typically used to ____________ the associated HVAC system during the unoccupied period.
4. The BAS controller monitors the status of the Occupancy switches with a _______________ input.

Chapter 17 - Position Feedback Switches (BI)

17.1 Description

It is often necessary to monitor and prove the position of dampers, doors, valves and other mechanical system elements prior to allowing other steps in the sequences of operation to advance. This is accomplished with position feedback devices. Position Feedback Switches (PFS) and similar are equipped with electrical contacts which are made or broken when a certain position has been confirmed. These contacts are monitored by a pair of wires which are connected to the binary input of a BAS controller which is programmed to interpret an open circuit as one position and a closed circuit or continuity as the opposite position. The PFS contacts may be part of a safety circuit of a motor starter or VFD either directly or indirectly through a fan safety alarm circuit which disables the driven load if position confirmation is lost.

Photo 232 - Position Switch on Outdoor Air Damper

Photo 233 - Position Switch on Outdoor Air Damper

Photo 234 - Rocker Switch on Air-Handling Unit Door

Position confirmation is accomplished with position feedback switches which may be integral to the actuators, installed on the shaft of dampers and valves, or installed in such a way that the position of doors, dampers, hatches, may be detected. The type of PFS used will depend largely on the configuration of the damper, door, or valve position whose position is to be monitored. Rocker switches, push buttons, and whisker switches are typically used to confirm the position of doors and other system elements that require position verification. They are located and positioned so that they detect or confirm that a certain position has been reached.

The shafts of dampers and valves are often exposed and a position switch may be installed to monitor its position (Photographs 232 & 233). It is oriented and secured on the rotating shaft such that when the position to be detected is achieved, the position switch contacts are made. They have an electrically-conductive ball (or cylinder) inside a slide equipped with status contacts at one or both ends. When the shaft rotates, gravity pulls the ball toward or away from the status contacts. When the ball is fully seated between the contacts, the circuit is made which is interpreted by the BAS controller as confirmation of the monitored position.

Photo 235 - Actuator Auxiliary Contact Switch Notations (S1-S6)

Photo 236 - Chilled Water Control Valves with Auxiliary Contacts

Photo 237 - Whisker Switch for Monitoring Roll-Up Doors

Damper and valve actuators typically have options for integral contacts which open and close at the extreme positions of the stroke. This option is very convenient because nothing additional has to be installed on the damper or valve shaft. In addition, it has a more elegant look. Clamp-on position feedback switches typically look like an after-thought. The position at which these contacts actuate is typically adjustable.

The most precise and repeatable position feedback signals come from actuators with integral auxiliary contacts because their operation is based purely on actuator position. Position feedback switches that are mounted to ends of damper and valve shafts are not 100% accurate or repeatable. They rely on gravity to move the electrically conductive ball from one end of the slide (or tube) to the other. Over time, the friction between the ball and slide increases making position indications less reliable. They are typically set up to detect a position that will provide a high degree of confidence that the valve or damper is open or closed. To maximize the accuracy and reliability of the position feedback signal, they are typically set up to prove the full open position between 85% and 95% open rather than 100% open. Likewise, the position switch is typically set up to prove the fully closed position at 5%-15% open, rather than 0% open. You just cannot rely on the ball being in the correct position at exactly 0% and 100% open, so a range is typically necessary and acceptable to provide a reliable position feedback signal.

17.2 Applications

1. **AHU Smoke Isolation Dampers**: Smoke isolation dampers are used to prevent smoke and fire migration. The AHU energizes only after the smoke isolation dampers have proven fully open. Accessory damper position switches or actuator auxiliary contacts are typically used to provide the fully-open position indications. Their contacts are part of the motor starter control circuit (or VFD safety circuit) which allow operation only when the isolation damper is proven fully open. This method is preferable to relying on the high- and low-static safety switches to protect the air-handling unit and supply/return ductwork because they typically require a manual reset to restore operation should the fire alarm system undergo testing. When these smoke dampers reach the fully open position, the actuator auxiliary contacts or PFS contacts close which completes the supply fan motor starter safety circuit or VFD run-permissive contacts. As a result, the supply fan only operates while the smoke isolation dampers are fully open.

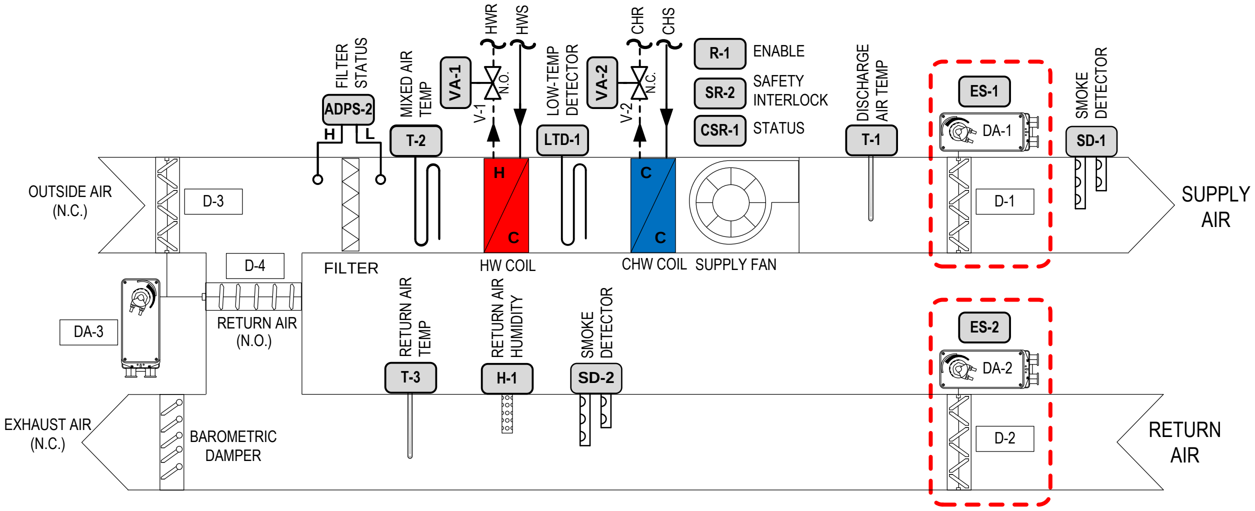


Figure 170 - Air-Handling Unit with Isolation Dampers

2. **Exhaust Fan Isolation Dampers**: Some sequences of operation require that the isolation damper opens fully prior to energizing the exhaust fan. This is often implemented by sending an open command to the damper actuator which is equipped with either an auxiliary contacts or a shaft-mounted PFS which is part of the motor starter or VFD safety circuit. When the contacts of the position switch close, the control circuit for the exhaust fan motor starter or VFD is completed thereby energizing the exhaust fan.

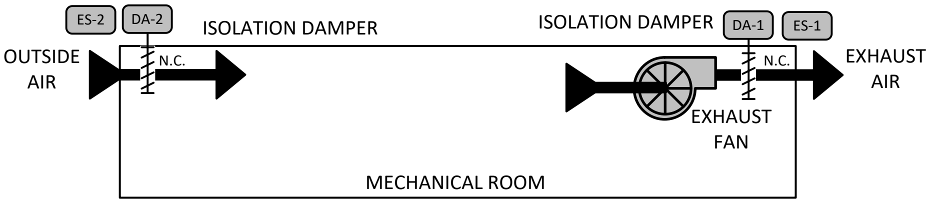


Figure 171 - Exhaust Fan Isolation Damper

3. **Energy Recovery Units (ERUs) & Dedicated Outdoor Air (DOAS) Units**: ERUs, ERVs, and DOAS units typically require proof that the outdoor air and exhaust dampers have fully opened and that recirculation and bypass dampers are in their required positions prior to energizing the supply and exhaust air fans. This ensures that the supply and exhaust air paths are fully open and that any recirculation/bypass dampers are fully closed during normal operation. The proof of damper position is provided by either a shaft-mounted PFS or a set of auxiliary contacts built into the damper actuators.

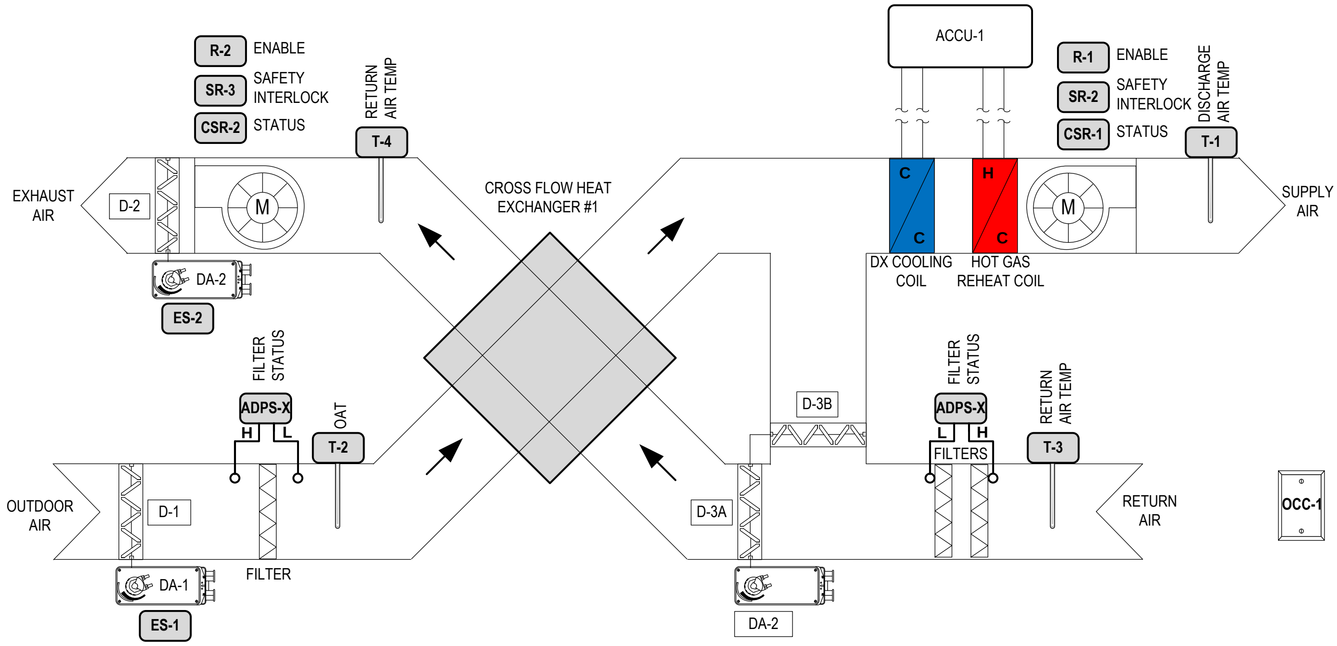


Figure 172 - End Switches on Energy Recovery Ventilator Damper

4. **Combustion Air Dampers**: Boilers require a combustion air source to operate. Combustion air is provided by either combustion air dampers or combustion air fans. When a boiler is enabled, its combustion air dampers open or its combustion air fan energizes. PFSs are used to provide verification that combustion air dampers are fully open prior to energizing the boiler(s) and remain open while it is firing.

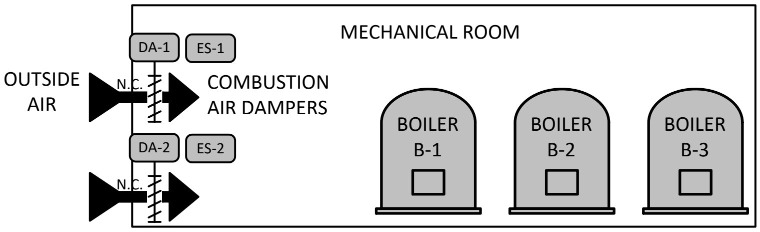


Figure 173 - End Switches on Combustion Air Dampers

5. **Equipment Isolation Valves**: Water-Source Heat Pumps (WSHP) are often equipped with control valves driven with actuators with auxiliary position feedback contacts. These contacts provide confirmation that the condenser water control valve is fully open to the WSHP heat exchanger prior to energizing its refrigeration circuit. The interlock between the WSHP equipment and the position feedback contacts are typically hard-wired, but they may be monitored by the BAS controller. Energizing water-cooled equipment without condenser water flow will result in elevated refrigerant head pressures which typically results in equipment lockout or equipment damage.

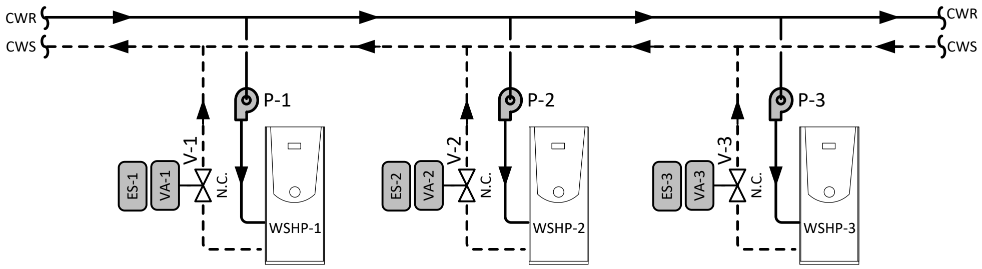


Figure 174 - Water-Source Heat Pump Isolation Valves

6. **Chiller/Boiler Isolation Valves**: Many mechanical designs with multiple chillers/boilers require that the unit prove that its isolation valve is fully open and that flow has been established prior to allowing its operation. The chillers/boilers that are not operating are typically isolated by their automatic isolation valves. Another set of auxiliary switches may be required to prove that the chiller/boiler isolation valves are fully closed after they have been de-energized.

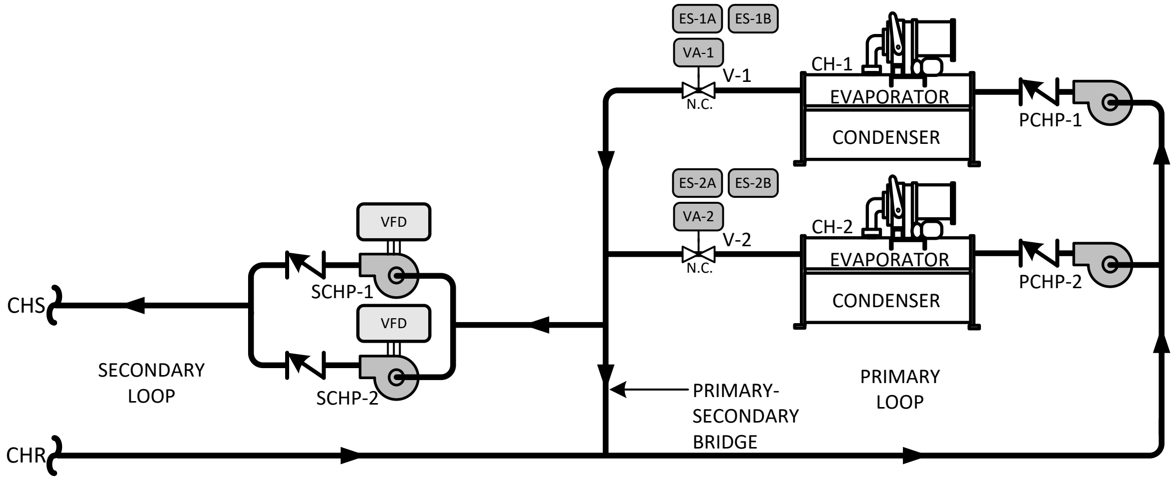


Figure 175 - Chiller Isolation Valves

7. **Door Closure Sensors**: Garages, warehouses, and storage facilities typically have roll-up doors that are monitored by the BAS or interlocked with the HVAC serving that zone. Rocker or whisker switches are often used for this purpose. They are typically installed so that they detect when the door is not fully closed. Sequences of operations often state that if the roll-up door is open, the HVAC equipment serving that space is disabled. This prevents the waste of energy because the HVAC equipment will never satisfy the temperature setpoint with the door open and will run constantly. Access doors to air-handling units are occasionally monitored with a whisker, push button, or rocker switch when it is deemed unsafe to open them while energized and operational.

17.3 Typical Control Wiring

The following diagram is an example of the low-voltage wiring typically used for position feedback switches. They typically come with normally-closed and/or normally-open contacts. The following diagram shows a position feedback switch whose Normally-Open contacts are monitored by the BAS controller. When the position feedback switch is used as a safety or interlocking device, it will typically be hard-wired to a safety circuit that directly or indirectly disables the system to avoid equipment damage or the creation of safety hazards. Refer to Chapter 6: Wiring Practices for Safety Devices.

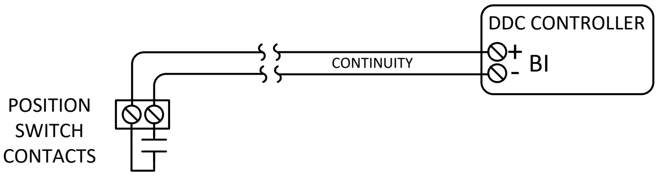


Figure 176 - Position Switch Wiring Diagram

17.4 Binary Input Testing and Verification

The general test procedures for position feedback include the following:

1. Verify that the position feedback switch has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The manufacturer, mounting, orientation, operating range, number of output contacts, NEMA rating, and normal position of the available contacts are some of the features that should be verified.
2. Verify that the position feedback switch has been installed at the correct or optimum location.
3. Verify that the position feedback switch has been installed per the manufacturer's installation recommendations.
4. Verify that the BAS controller's binary input has been properly configured to match the specifications of the position feedback switch. This typically consists of verifying whether the binary input device contacts are normally-closed or normally-opened. Verify and document the controls strategy used.
5. Verify that the position feedback switch has been correctly wired. The device may have multiple sets of normally-open and normally-closed contacts which must be properly landed and coordinated to provide the desired control logic. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify that the position feedback switch is connected to the correct BAS controller binary input. Initiate the binary input signal by either causing the position feedback contacts to actuate or by making or breaking the electrical circuit at the device (not at the controller).
7. At the same time that the electrical contacts are opened and/or closed, verify and document that the data point bound to the BAS graphics also changes. Binary inputs that are used as safety devices should also display a color change (typically red) to clearly and prominently indicate its status.
8. Verify and document how all position feedback switch that are used as safeties are interlocked with fans and damper and valve actuators. Update the control logic ladder diagram that is typically included with the controls submittal.
9. Verify that the position feedback switch contacts and its wires at the BAS controller end have been labeled.
10. Verify that the facets of the position feedback switch are correctly displayed for each state. The facets should be consistent with the binary states of the position feedback contacts. Position feedback contacts typically have the following facets depending on the application: "Opened/Closed," "High/Normal," "Low/Normal," or "Normal/Alarm."
11. Verify that the position feedback switches that are used as safeties generate an alarm in the alarm console upon activation.
12. If status or alarm delays are used, then they should be verified and documented.
13. Verify the operation of the position feedback device and adjust accordingly. The closer to the fully-opened or fully-closed position that the position feedback contacts are set, the higher the likelihood that they will produce false position indications. Optimum performance is typically attained when the PFD is set so that the contacts make or break 5%-15% before the position to be proven.
14. Once the position feedback switch has been proven to function and display properly, this would also be a good time to verify and document any collateral sequences of operation that initiate as a result of its activation.
15. Review the trend data to verify that the position feedback switch reliably and consistently reports to the BAS controller. Change-of-State trends are typically utilized to minimize memory requirements. Keep in mind that the operation of the monitored component may not appear in a daily trend log. Manual activation or override may be required to generate the event in the trend log.
16. Document the results of all testing. Screenshots of the binary input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the position feedback device.

17.5 Review

1. True or False: Position feedback signals are typically used to prove or verify that a damper, valve, or other component is in a certain position before allowing another step to occur. Answer: ________
2. Position switches that are installed on damper and valve shafts rely on ___________________ to actuate an electrically conductive ball within the slide.
3. True or False: The contacts can be directly wired to the motor starter control circuit. Answer: ________
4. True or False: Make-up air-handling units typically prove the outdoor air damper fully open prior to allowing the

_________________to energize.

5. Before allowing a boiler to energize, the position of its isolation valve would be proven fully ______________ by a valve position feedback device.

Chapter 18 - Liquid Level Detectors (BI)

18.1 Description

Condensate formation is the natural consequence of the air cooling process. Air-handling units deliver conditioned air between 50ºF to 60ºF to the spaces served so that it may absorb heat and moisture and provide ventilation air prior to returning to the air-handling unit for reconditioning. As the supply air temperature is reduced by the cooling coil, some of the moisture in the air drops to its dew point and condenses onto the surfaces of the coil fins and tubing. The condensed water droplets coalesce forming larger droplets that flow into the condensate drain pan inside the unit and are drained away by condensate drain piping outside the unit.


Photo 238 - Conductance Detector in an Elevator Pit

Photo 239 - Conductance Detector on a Condensate Drain Pan


Photo 240 - Float Switch in a Condensate Drain Pan

The condensate drain piping typically begins with a trap which is a hydraulic pressure barrier made of the collected condensate that separates the air-handling unit pressure (positive or negative) from the atmospheric pressure. Its purpose is to prevent airflow into or out of the air-handling unit through the condensate drain while allowing the free flow of condensate out of the unit. Condensate drain traps require proper design and installation in order to function properly. The column of water contained in the condensate drain trap must be deep enough to prevent the positive or negative air pressure generated by the air-handling unit from displacing it. In addition, they should be disassembled and cleaned to prevent the condensate drain lines from getting clogged with debris. Even with the best maintenance practices and schedule, they still manage to clog up and this can result in water damage. This is where condensate detectors some into play. They detect the presence of condensate in places where it should not exist or they detect a dangerous or high limit accumulation of condensate.


Photo 241 - Cooling Tower Float Switch


Photo 242 - Cooling Tower Conductance Level Indicator

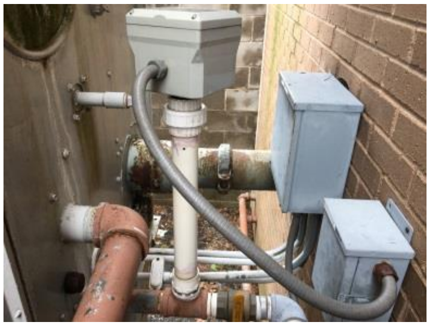


Photo 243 - Cooling Tower Conductance Level Indicator

Condensate detectors indicate the presence of liquid by two main methods: float switches and conductivity detectors. To keep the discussion clear, a distinction is made between liquid detectors and liquid level detectors. Liquid detectors detect the accumulation of fluid in locations where there should not be any fluid such as in an auxiliary drain pan or under floor supply air plenum. Liquid level detectors are used to determine the vertical fluid level in a cooling tower or tank.

Float switches utilize a snap-acting switch that is actuated by a float situated at the end of a lever. The buoyancy of the float produces the upward force that actuates the switch contacts to indicate the presence of water. When placed in a condensate drain pan of an air-handling unit, it can detect the accumulation of condensate. The advantage of float switches is that they are cheap and do not require electrical power to actuate the device contacts. Other designs have internal float mechanisms that actuate a set of contacts. Since mechanical forces are required to actuate the contacts, float type detectors need to be securely mounted or they may be rendered useless.

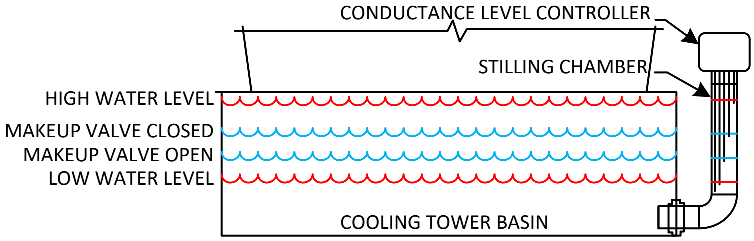


Figure 177 - Cooling Tower Level Controller Installation

Condensate detectors that utilize conductivity probes and tapes are often utilized to detect the presence of condensate. This type of detector requires electrical power (typically 24 VAC or 120 VAC) to power the electronic circuits, probes, and relays. The conductivity probes may either be connected to the base or remotely installed and connected with wires. Conductivity detectors typically have at least two probes and when both are submerged in a conductive liquid, the onboard circuitry detects the current flow between the probes and actuates its status-indicating contacts. Multiple probes may be utilized to monitor liquid level in tanks or basins. The BAS monitors the status contacts and interprets the change in state as a change in liquid level.

When the conductance level detector is used for cooling tower level control applications, the conductance probes are placed within a stilling chamber or standpipe that is typically located outside the cooling tower enclosure for easy access. Both the stilling chamber and the cooling tower are open to the atmosphere, so the water levels of both are exactly the same. In order for this to occur, the top of the stilling chamber should have a hole to allow the air above the water to vent to the atmosphere. Conditions within a cooling tower can be quite turbulent with the condenser water falling and air flowing across the fill material. The stilling chamber provides a calm environment where the condenser water level can be reliably and accurately determined. The length of the seal tight (flexible water-proof wiring conduit) used to connect the conductance probe assembly to the junction box must be long enough to allow its removal from the stilling chamber without damaging the probes, the wiring, or the chamber itself. The end or top of the stilling chamber should be mechanically secured to prevent damage.

18.2 Application

1. Monitoring Supply Air Floor Plenums.

Down-flow Computer Room Air Conditioning (CRAC) units are often utilized to supply under-floor air distribution systems. Should the condensate lines become clogged or the chilled water, hot water, or condenser water lines experience a leak at a fitting, then condensate would spill onto the floor of the supply air plenum. Without a condensate detection system to monitor the under-floor supply air plenum, liquid would accumulate without notice.

2. Monitoring of Sump Pits and Elevator Shafts.

The BAS is often utilized to provide liquid detection in and around sump pits and elevator shafts. Sump pumps are often used to collect ground and rainwater that collects at the lowest levels of buildings in basements, sum pits, and elevator shafts. They may also be used to pump drainage (sanitary, condensate, or other wastes) away that could not be connected to the sanitary system because of distance or elevation differences. Should the sump pump assembly fail to operate, the liquid level would continue to rise and eventually overflow the sump. If left undetected, the liquid will collect at floor level and could cause extensive water damage within the building. Condensate detectors are typically installed to provide detection of this potentially disastrous condition. They are typically installed at the floor level adjacent to the sump pit, but they may also be found just inside and below the top of the sump.

3. Monitoring of Condensate/Auxiliary Drain Pans.

International Mechanical Code section 307 regarding condensate disposal requires that an auxiliary drain pan be provided below air conditioning equipment installed in areas where the overflow of condensate could cause damage. If a drain line cannot be provided for the auxiliary drain pan, then a condensate detector conforming to UL 508 is required to detect the presence of condensate so that the equipment may be de-energized prior to overflow of the pan. If condensate is detected in the drain pan, then either the air-handling unit disabled to prevent the continued generation of condensate.

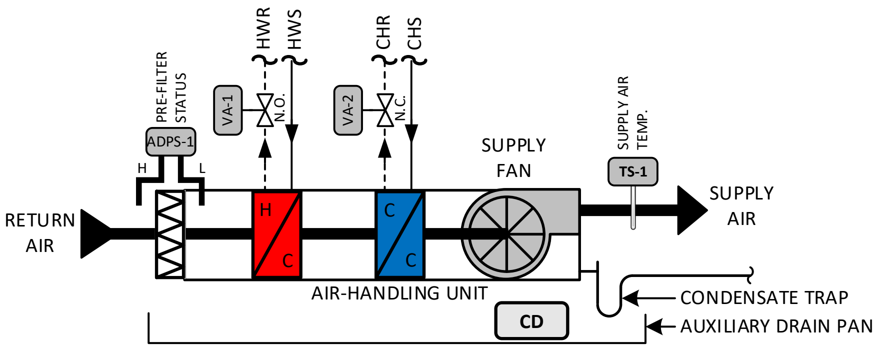


Figure 178 - Auxiliary Drain Pan below an Air-handling Unit

4. Monitoring Areas Below AHUs with Hydronic Coils.

Areas below air-handling units and other leak prone piping elements (control valves, riser piping, equipment connections) equipped with hydronic (chilled, hot, condenser water, etc.) coils are not only at risk of damage from condensate leakage, but also from water leakage from the coil and associated piping, valves, and fittings. If the risk of leakage or the consequence of water damage is high enough, active monitoring of the spaces below air-handling units and hydronic piping may be warranted. They allow early detection of leaks before widespread water damage can occur.

5. Cooling Tower Water Level Control.

The condenser water level in the cooling tower is controlled by either a mechanical float valve or an electrically powered conductance level controller. The cooling tower's condenser water level is typically not controlled by the BAS. The BAS typically only monitors the high water and low water level alarms to alert the operating staff of an unsafe cooling tower condenser water level. The condenser water level within a cooling tower has a normal operating range. This is a perfect application for a dedicated liquid level conductance controller or mechanical float valve.

18.3 Typical Control Wiring

The following wiring diagrams are examples of the low-voltage wiring typically used for liquid level detectors. They typically come with normally-closed and normally-open contacts. Float switches do not require power to operate. These figures show a condensate detector whose Normally-Closed contacts are monitored by the BAS controller. When the condensate detector is used as a safety or interlocking device, it is typically hard-wired to a safety circuit that directly or indirectly disables the system to avoid equipment damage or the creation of safety hazards. Refer to Chapter 6: Wiring Practices for Safety Devices.

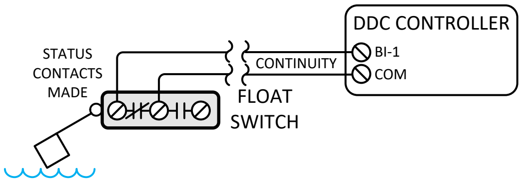


Figure 179 - Float Switch Normal State

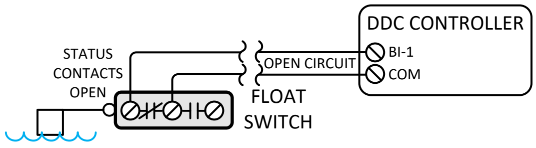


Figure 180 - Float Switch Alarm State

The following wiring diagrams show conductance condensate detectors. They require a 24 VAC or 120 VAC power source to drive the circuitry and relays. The electrodes or probes may be incorporated into the body of the detector or may be on a separate assembly and connected by wires.

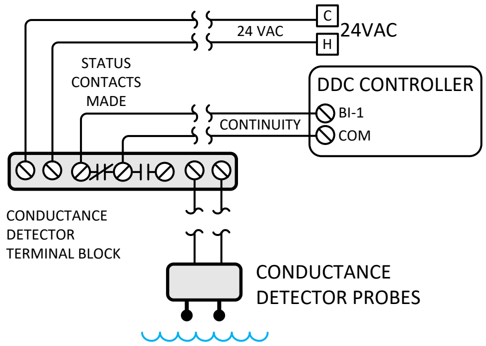


Figure 181 - Float Switch Normal State

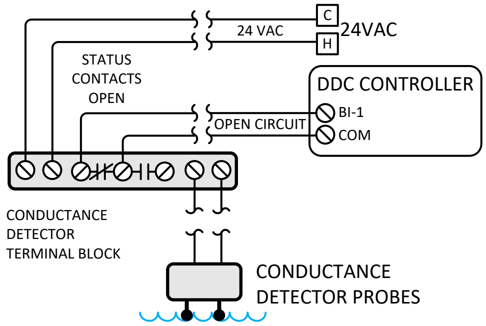


Figure 182 - Float Switch Alarm State

Figure 183 is an example of a multi-point conductance liquid level detector commonly used on cooling towers and liquid storage tanks. This type of conductance detector is typically used as a stand-alone unit (no BAS connection) and the conductance level controller's only function is to maintain the water level at acceptable levels – makeup valve closed and makeup valve open levels. Three conductance electrodes are required to detect these two conditions. In other cooling tower applications, the water level is controlled by a mechanical float valve. If the BAS is used to monitor the high and low water level alarms, float switches and conductance level detectors are often utilized.

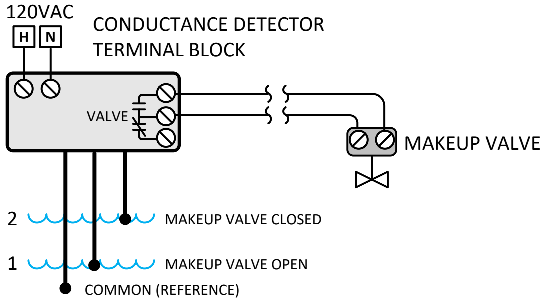


Figure 183 - Conductance Level Detector Wiring Diagram
(No BAS Monitoring)

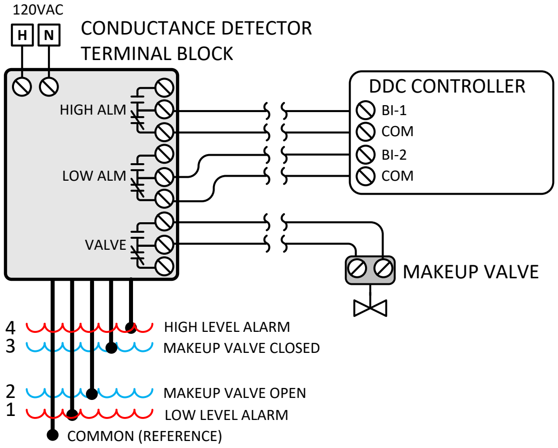


Figure 184 - Conductance Level Detector Wiring Diagram
(High- and Low-Level Alarms)

Figure 184 shows a conductance liquid level detector used to control the liquid level in a typical cooling tower. This self-contained, single-purpose level controller maintains the tower water level between the normal high (3) and low (2) levels which coincide with the makeup water valve closed and makeup water valve open levels, respectively. In addition, it monitors the High-Level (4) and Low-Level alarm (1) levels which are monitored by the BAS. To monitor these four liquid levels, five conductance probes are required. The common or reference probe is compared to probes which are trimmed to monitor specific liquid depths. The liquid level controller maintains the basin water level by controlling when the make-up water valve is opened and closed. If the water level controller was to fail with its control valve in either the fully-open or fully-closed positions, the resulting high-water and low-water alarms would be detected by the BAS and alarms generated to indicate that immediate attention is required.

18.4 Binary Input Testing and Verification

Testing and verification of liquid detectors may pose an electrical hazard because of the potential exposure to high-voltage (120 VAC and higher) electrical conductors. De-energize the electrical power whenever possible. Use the appropriate personal protective equipment to ensure your safety and those around you when access to live electrical enclosures is required. The general test procedures for Liquid Detectors include the following:

1. Verify that the liquid detector has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The mounting, orientation, operating range, number of output contacts, normal position of the available contacts, and type (float or conductance) are some of the features that

should be verified.

2. Verify that the liquid detector has been installed at the correct or optimum location. Float switches are typically mounted on the edge of the condensate drain pan. Liquid detectors are typically installed on or in a condensate drain pan or at specific heights in the wall of the monitored vessel. Conductance detectors are typically mounted at the bottom of the condensate drain pan and it probes are adjusted to the required detection height. They may also be mounted in the side of the container at each level where the level detection is required. Conductance liquid level controllers are typically installed in a stilling chamber or standpipe outside the cooling tower.
3. Verify that the liquid detector has been installed per the manufacturer's installation recommendations. They should be securely mounted so that incidental physical contact will not remove it from its mounted position.
4. Verify that the BAS controller's binary input has been properly configured to match the specifications of the liquid detector contacts. This typically consists of verifying whether the binary input device contacts are normally-closed or normally-opened. For example, if the liquid detectors were monitoring for condensate and the normally-closed contacts were monitored, an open circuit typically signifies the "Alarm" state and the closing of the contacts signifies the "Normal" state.
5. Verify that the liquid detector has been correctly wired. The device may have multiple sets of normally-open and normally-closed contacts which must be properly landed and coordinated to provide the desired control logic. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify that the liquid detector is connected to the correct BAS controller binary input by making or breaking the status monitoring circuit at the device (not at the controller).
7. At the same time that the electrical contacts are opened and/or closed, verify and document that the data point bound to the BAS graphics also changes. Binary inputs that are used as safety devices should also display a color change (typically red) to clearly and prominently indicate its status.
8. Verify that the liquid detector generates an alarm in the alarm console upon activation.
9. Verify and document how all interlock wiring is implemented for liquid detectors used as safety devices. Safety devices are occasionally connected to the fan safety alarm circuit to disable the associated air-handling unit and generate an alarm. In general, a separate low-water cut-off device or flow switch is used for system shutdown. In most applications, the liquid detector does not disable the equipment, but it typically generates an alarm. In other applications, detection of condensate may disable the cooling capacity thus eliminating the generation of more condensate. Update the control logic ladder diagram that is typically included with the controls submittal.
10. Verify that the liquid detector and its wires at the BAS controller end have been labeled.
11. Verify that the facets of the liquid detector are correctly displayed for each state. The facets should be consistent with the binary states of the liquid detector. Normally, "Normal/Alarm" facets are utilized.
12. Verify that the liquid detectors that are used as safeties generate an alarm in the alarm console upon activation.
13. If status or alarm delay is used, then it should be verified and documented. Delays are used to ensure that the alarm condition is true and to minimize nuisance alarms.
14. Verify the setpoint and accuracy of the liquid detector. Measure or simulate the parameter that causes the binary input device contacts to switch.

Float Switch Liquid Detector Procedures

A. Verify that the float switch is securely mounted. The most common failure mode is for the float switch to be physically dislodged from its mounted position. If it is not securely mounted, it will not remain in a position that will allow it to be actuated by the rising water level.

B. Verify that the orientation of the float switch is appropriate to detect a rising water condition.

C. With your fingers or a tool, raise the float until the switch actuates and changes the position of its contacts. An audible click is typically heard. If you are working alone, place a piece of scrap wood, cardboard, or plastic under the float, so that this input point may be reviewed on the controls laptop. You can also monitor the status on your phone or tablet if using the remote desktop software.

D. Verify that the BAS point properly interprets the change in the position of the float switch contacts.

E. Release the float allowing the lever to assume its natural position and verify that the contacts return to their normal positions.

F. Verify that the float switch status indicated by the BAS also returns to its normal state.

Conductivity Liquid Detector Procedures

A. Remove the conductance liquid detector from its mounted position (typically inside a condensate drain pan or on the floor).

B. Place the conductance liquid detector in a shallow pan with water covering its bottom. The water level should be high enough for the conductance probes to contact the water. Alternatively, water may be poured into the condensate pan. Submerge the conductance probes in the water. Do not place the whole conductance sensor in the water.

C. Once the liquid is detected, as indicated by an LED on most units and a change in its electrical status contacts, verify that the BAS point data also shows a change in state.

D. Remove the electrodes of the conductance detector from the water and confirm that its status contacts return to their normal positions. There may be a time delay, so it may not happen instantly.

E. Verify that the condensate detector status indicated by the BAS also returns to its normal state.

Float Switch Liquid Level Detector Procedures

A. Verify that the float switch is securely mounted. The most common failure mode for the float-type liquid level indicators is corrosion of the linkages and the accumulation of water deposits that prevent float lever actuation.

B. Verify that the orientation of the float switch is appropriate to detect a rising water condition.

C. Open the fill valve to fill the tank or cooling tower basin and close the drain valve. As the water level rises, verify that all float-type liquid level indicators correctly indicate the appropriate levels.

D. As each monitored liquid level is reached, verify that the BAS point data indicates a change in the level of the monitored liquid.

E. Lower the water level in the tank or cooling tower basin by closing the fill valve and opening the drain valve. Verify that as the water line drops below each float-type liquid level indicator, the status of each liquid level indicator correctly indicates the liquid level.

F. Test and troubleshoot as necessary to confirm each monitored level and retest until all levels are correctly and reliably indicated.

Conductivity Liquid Level Detector Procedures

A. Verify that the stilling chamber is secured and the conductance liquid level detector is securely mounted. The most common failure mode for the float-type liquid level indicators is corrosion and the accumulation of water deposits that decrease probe conductivity.

B. Disable the cooling tower, if possible. It is easier to observe the testing and water level without the turbulence and noise of an operational cooling tower fan.

C. Conductance level detectors installed in a stilling chamber can be removed from this chamber and placed in a bucket of water (provided sufficient flexible conduit length is provided). By positioning the probes at certain depths in the water, the various level indications can be checked without the need of draining and filling the cooling tower basin or reservoir. If this is not possible, continue with the following steps.

D. To first raise the water level, open the fill valve and close the drain valve. As the water level rises, verify that all conductance liquid level indicators correctly indicate their specific levels.

E. As each monitored liquid level is reached, verify that the BAS point data indicates a change in the level of the monitored liquid. If you are also testing the control of the fill valve and drain valves, note their operation as each level is simulated.

F. Lower the water level in the tank or cooling tower basin by closing the fill valve and opening the drain valve. Verify that as the water line drops below each conductance liquid level indicator, the status of each liquid level indicator correctly indicates the liquid level.

G. Test and troubleshoot as necessary to confirm each monitored level and retest until all levels are correctly and reliably indicated.

15. Once the liquid detector has been proven to function and display properly, verify and document any collateral sequences of operation that initiate as a result of its activation, this would also be a good time to verify and document any collateral sequences of operation that initiate as a result of the liquid detector activation.
16. Review the trend data to verify that the binary input device reliably and consistently reports to the BAS controller. Change-of-State trends are typically utilized to minimize memory requirements. Manual actuation of the condensate detector may be required to create trend data for review.
17. Document the results of all testing. Screenshots of the binary input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the binary input device.

18.5 Review

1. True or False: Analog inputs are typically used to monitor the status of condensate detectors. Answer: ________
2. True or False: The biggest risk to long-term reliability of float switches is it being knocked from its mounted position. Answer: ________
3. True or False: The status contacts of liquid detectors used on residential direct expansion air-handling are wired to interrupt the signal used to energize the direct expansion cooling circuit or the supply fan. Answer: ________
4. Conductivity probes require ____________________ to power its circuitry and actuate its status contacts.
5. True or False: A stilling chamber does not have to be vented because it will naturally acclimatize to its environment. Answer: ________
6. Because of the constant evaporation of condenser water within the cooling tower, __________________ accumulate on the level detector negatively affecting its operation.

18.6 References

1. International Code Council. 2018. International Mechanical Code. Section 307 – Condensate Disposal.
2. https://www.waterlinecontrols.com/level-controls/cooling-tower-level-controls/
3. https://www.baltimoreaircoil.com/parts/water-distribution/electronic-water-level-control
4. https://waterlevelproducts.com/
5. https://www.gemssensors.com/docs/default-source/resource-files/catalog-pages/catalog-e

Section 3: Analog Input (AI) Devices

Chapter 19 - Air Temperature Sensors (AI)

19.1 Description

Air temperature sensors come in a variety of configurations and mounting options depending on where it is to be installed. Air temperature readings are typically required by the BAS to monitor and control the temperatures in conditioned spaces, duct distribution systems, and specific locations in air-handling units. Monitoring of the outdoor air temperature is also required by most environmental control strategies. This chapter focuses on three main types of temperature sensors predominantly used in building automation systems. These are wall-mounted space, probe, averaging, and outdoor air temperature sensors. Air-handling units are typically controlled and monitored to provide supply air and space conditioning. They can utilize all four types of air temperature sensors as shown in the following diagram.

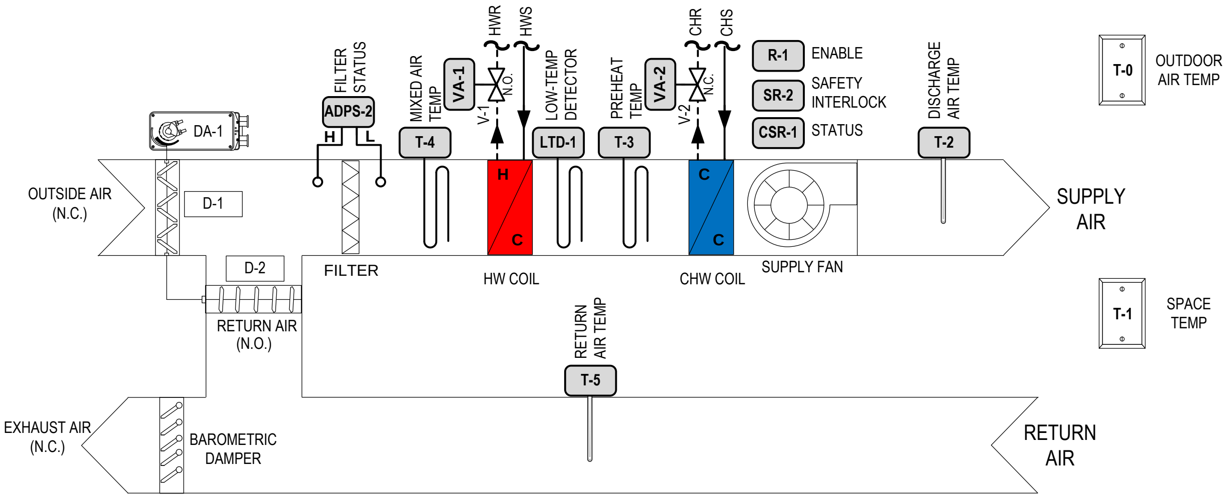


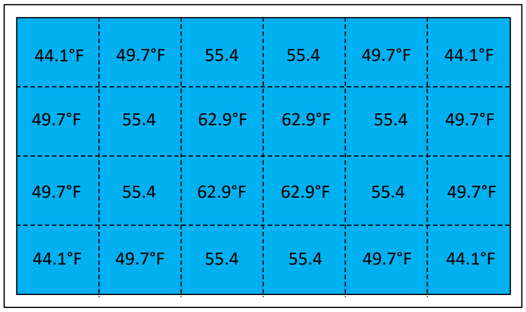
Figure 185 - Typical Air-Handling Unit

It is surprising to many that the air temperatures in the cross-section of an airstream are not the same. As indicated in the following diagram, the air velocities vary substantially across the coil or duct cross section. The air velocities are slower at the outside edges because of the friction with the duct/air-handling unit walls. It is even slower at the corners where the air experiences friction with the horizontal and vertical walls of the duct/air-handling unit. The highest velocities are experienced at the center of the cross section where frictional forces are minimal.

437 FPM	489 FPM	467 FPM	481 FPM	467 FPM	428 FPM
478 FPM	491 FPM	509 FPM	515 FPM	486 FPM	468 FPM
469 FPM	481 FPM	503 FPM	525 FPM	478 FPM	481 FPM
443 FPM	478 FPM	481 FPM	468 FPM	470 FPM	451 FPM

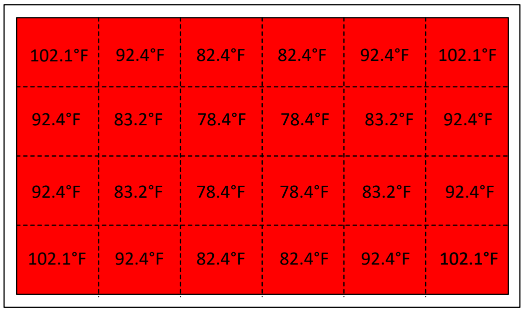
Figure 186 - Cross-Sectional View of Coil Velocity Distribution

Variations in air velocity throughout the coil cross-section dictate that the air flowing through it spends varying amounts of time in the coil being heated and cooled. In cooling coils, lower air temperatures are measured in areas of lower air velocities because the air spends more time in the cooling coil. Higher air temperatures are measured in areas of higher velocities because the air spends less time in the cooling coil. The same concept holds true for heating coils. Higher air temperatures are measured in areas of lower air velocities because the air spends more time in the heating coil. Lower air temperatures are measured in areas of higher velocities because the air spends less time in the heating coil.



44.1°F	49.7°F	55.4	55.4	49.7°F	44.1°F
49.7°F	55.4	62.9°F	62.9°F	55.4	49.7°F
49.7°F	55.4	62.9°F	62.9°F	55.4	49.7°F
44.1°F	49.7°F	55.4	55.4	49.7°F	44.1°F

Figure 187 - Temperature Distribution in Cooling Coil



102.1°F	92.4°F	82.4°F	82.4°F	92.4°F	102.1°F
92.4°F	83.2°F	78.4°F	78.4°F	83.2°F	92.4°F
92.4°F	83.2°F	78.4°F	78.4°F	83.2°F	92.4°F
102.1°F	92.4°F	82.4°F	82.4°F	92.4°F	102.1°F

Figure 188 - Temperature Distribution in Heating Coil

Air-handling units provide ventilation air to the conditioned zone for dilution of contaminants and space pressurization. Outdoor air is introduced to the air-handling unit at the mixed-air plenum where the outdoor air and return airstreams combine to become the "mixed-air" stream. However, the mixed air is rarely fully mixed to the point that the air temperature is the same throughout. This is why averaging temperature sensors are utilized to measure and report the mixed-air temperature. It allows the temperature distribution to be sampled and it reports the "average" temperature reading. Averaging temperature sensors are also used at the discharge of coils because of the air temperatures are typically not uniform. The multi-point sampling provided by the averaging temperature sensor provides a more accurate reading than a probe temperature sensor that provides a single reading.

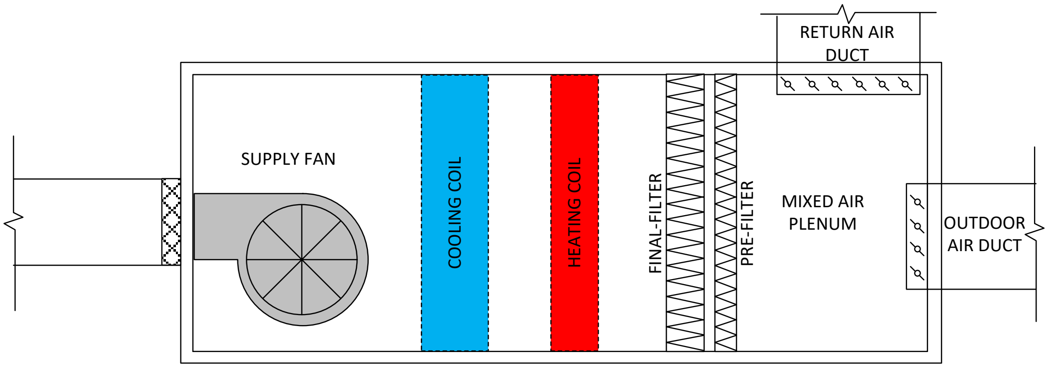


Figure 189 - Sectional View of a Typical Air-Handling Unit

When outdoor air is introduced to the air-handling unit, it can cause significant disruption to the temperature distribution when the outdoor air and return air temperatures are not the same. Air-handling unit manufacturers attempt to minimize its effect by employing various measures such as using parallel-blade damper assemblies which force the return and outdoor airstreams to collide into one another to better mix them. Air blenders force the outdoor and return airstreams to mix by dividing the airstream into smaller streams which are then directed at one another. Some manufacturers utilize a restricted passage through which the mixed air must pass which forces both airstreams to converge and mix. When faced with acquiring a mixed-air temperature reading, the best choice for a temperature sensor is an averaging temperature sensor and the best location is downstream of the filter bank(s) to take advantage of the air mixing that the filters provide as the mixed air passes through it.

Coils whose upstream side has been filled with dust and debris will exhibit wide variations in the air temperatures downstream of the coil. Where the debris accumulations are greatest in cooling coils, the velocity will be the lowest. As a result, the leaving air temperature at these locations will be the lowest. The air temperature will be high at the areas where debris accumulations in the coil are the lowest. The same holds true for heating coils. Where the debris accumulations are greatest, the leaving air temperature at these locations will be the highest. The air temperature will be low at the areas where debris accumulations in the coil are the lowest. Taking velocity and temperature traverses at coils can often shed light on the cleanliness of the coils. Cleaning the coils will produce a more consistent pressure drop across the coil cross section which will provide more consistent air velocities resulting in more consistent discharge temperatures. A clean coil facilitates the even distribution of the airflow across the coil cross section.

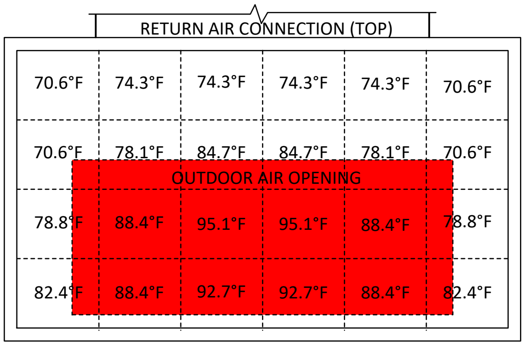


Figure 190 - Temperature Distribution in Mixed-Air Plenum During Cooling Season

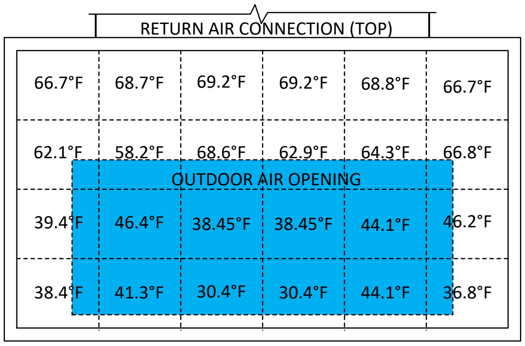


Figure 191 - Temperature Distribution in Mixed-Air Plenum During Heating Season

Velocity distribution and therefore temperature distribution across a cooling coil is further complicated by condensate formation. As the air comes in contact with the tubes and fins of the cooling coil, it cools the air. When the air has cooled to its dew point, some of the moisture condenses on the coil surfaces. The condensate droplets enlarge, coalesce, and form larger droplets which fall down the coil surface. The top of the cooling coil will have the least condensate and the bottom will have the most. As a result, the velocity and temperature distributions between a wet and dry cooling coil can vary significantly. In addition, the pressure drop of a wet coil can be significantly higher than a dry coil.

Photo 244 - Individual Temperature, Humidity, and CO2 Sensors

Photo 245 - Combined Temperature, Humidity, and CO2 Sensor

Photo 246 - Stainless Steel Space Temperature Sensor

Field experience has shown that the distribution headers of heating and cooling coils can significantly affect the discharge air temperature readings. The headers are larger diameter pipes that distribute the supply water across the tubes that traverse the coil cross section. As a result, the air temperatures along the side associated with the coil header can be much higher in heating mode or lower in cooling mode than the actual air temperature. This is especially true of steam piping. It is typically best to locate the probe temperature sensors on the side opposite the coil header to reduce this effect. Longer probe lengths (12-18 inches) can be used to minimize this effect if it is installed on the same side as the coil header pipe, but this does not always work. The high air temperatures along the header-side of the duct cross section will heat the sensor shaft and the heat can flow through conduction toward the tip of the sensor affecting its reading. Locating the probe temperature sensor downstream (at least 6-10 Feet) of the coil can eliminate or significantly reduce this effect and provide a more representative discharge air temperature reading. The further downstream the air temperature sensor is located the more accurate and stable the discharge air temperature reading.

Temperature sensor guards or covers are used when unauthorized tampering or the manipulation of the temperature setpoint is anticipated. While these devices protect the temperature sensor, they also inhibit its ability to sense the condition in the room. When a guard is placed over the temperature sensor it creates an environment that is separate from the room. Vents in the cover reduce this effect, but they cannot eliminate the time lag. With a barrier around the space temperature sensor, its ability to sense the room conditions in real time is impaired. This is why the temperature setpoints are typically lower (in cooling) and higher (in heating) than needed to account for the lag time in sensing the room conditions. Occupants in spaces subject to variable occupancy (waiting rooms, conference rooms, gymnasiums, auditorium, cafeterias, classrooms, etc.) are at the highest risk of discomfort because the space temperature sensor cannot sense the conditions outside the enclosure in real time. A better approach is to install a space temperature sensor that has no adjustment and remove the guard. This will allow the space temperature sensor to monitor the room conditions as intended and provide real-time capacity control to optimize occupant comfort and maximize energy efficiency.


Photo 247 - Space Temperature Sensor with Protective Cover #1


Photo 248 - Space Temperature Sensor with Protective Cover #2


Photo 249 - Space Temperature Sensor with Protective Cover #3

19.2 Wall-Mounted Space Temperature Sensor

Control of the space temperature and humidity is the primary function of the HVAC systems. Monitoring of the space temperatures through a BAS is typically accomplished through the use of wall-mounted space temperature sensors. Two types of temperature sensors are typically used in HVAC applications. They are thermistors and RTDs (Resistance Temperature Detectors). This chapter concentrates on thermistors and RTD temperature sensors as these are the most predominant temperature sensors in use in the commercial HVAC industry. The space temperature sensors are mounted in wall-mounted enclosures of various styles, colors, features, and accessories. Some of the features include setpoint adjustment, space temperature indication, occupancy sensors, and occupancy override buttons. Accessories include covers, insulated base plates, and data connections for interfacing with the controller.


Photo 250 - Space Temperature Sensor


Photo 251 - Space Temp. with Occ. Override and Setpoint Adjustment


Photo 252 - Space Temperature Sensor with Setpoint Adjustment

Space temperature sensors are typically wall-mounted which requires that the wires pass through the wall cavity from the ceiling down to the mounted height in the wall. The typical mounting height for room sensors (temperature, humidity, carbon dioxide, etc.) is 48-54 inches from the finished floor, but this height can vary. Depending on the installation requirements of the project, temperature sensor wires may or may not be installed within an electrical conduit. In addition, depending on the wiring and mounting requirements of the temperature sensors, there may or may not be an electrical junction box behind it. In some cases, the conduits are mounted on the surface of the wall. This is typically done when the BAS is installed as a retrofit after the initial building construction because it is too difficult to install the wires in the wall without damaging them.

The factor that influences the performance of the space temperature sensor and the overall room temperature control most is its installed location. Space temperature sensors should be installed at the point that provides the most representative temperature of the space being controlled. The optimum location is typically below or near the room's return air grill. All of the conditioned air supplied to the space returns to the air-handling unit through the return air grill after conditioning the room(s). This is typically the ideal location, unless it coincides with an area to be avoided. The following diagram provides some general guidelines to keep in mind when locating space temperature sensors. Space temperature sensors with X's across them are locations that are to be avoided and those with a green circle around them are preferred locations. Next to the sensors are numbers which represent the reason(s) why they are to be avoided.

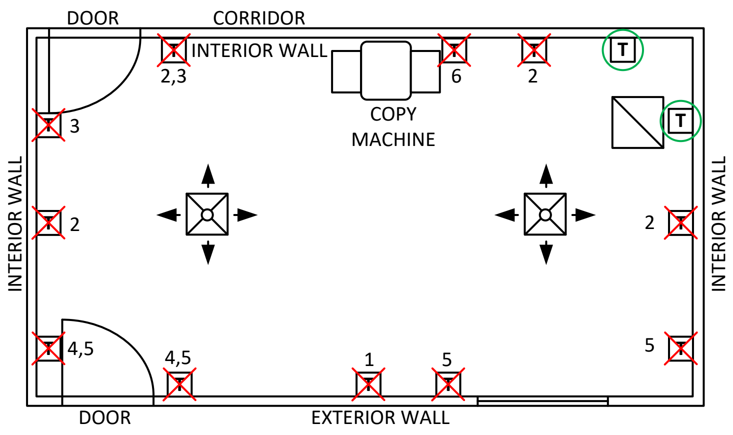


Figure 192 - Space Temperature Sensor Locations Recommendations

It is often difficult to determine the best location for some space temperature sensors. Often, it is necessary to choose the best of several poor locations. In other cases, the planned sensor location is clearly incorrect and should be changed. If modifications in sensor locations can be made prior to installation, it provides a benefit to all involved, especially the future occupants. The following locations are to be avoided, if possible:

1. **Perimeter walls**. Generally, wall-mounted space temperature sensors should not be installed on perimeter walls. Heat loss and gains through walls and windows will cause the space temperature sensor to sense a temperature that is higher than actual room temperature in the cooling season and lower than actual room temperature in the heating season. This typically results in the overheating and overcooling of the interior and core of the conditioned space. If the perimeter wall is the only available location to install a space temperature sensor, be sure that the temperature sensor is installed on an insulated base to minimize the influence of the exterior wall and that the wall penetration and junction box are sealed with spray foam to prevent air leakage through it. Pressure differentials can induce airflow within wall cavities and conduits that can significantly affect the temperature sensor readings.

2. **Within the influence of supply airstreams**. Supply air diffusers are chosen based on their ability to provide the required airflow, mix the room air to provide consistent temperatures throughout the space, and not produce objectionable noise. The throw of supply air diffusers is the primary factor that influences its ability to mix the room air. Throw is the distance that an airstream travels before it reaches a terminal velocity and is key (along with sound) to the selection of supply air diffusers. Due to the Coanda effect, discharging supply airstreams hug the ceiling until it encounters the wall. In cooling mode, the supply airstream is a mixture of supply air and entrained air. This mixture is typically cooler than the space temperature setpoint. The airstream then proceeds down the wall and may flow over the space temperature sensor if it has been installed in its path which can impact space temperature control by causing short cycling. To maximize the accuracy of the space temperature reading, supply airstreams should be avoided when locating space temperature sensors.

3. **Near interior doorways**. When wall-mounted space temperature sensors are located near interior doorways, they are subject to influence of the adjacent space (typically a corridor). This influence tends to slow or retard the sensing of the room's true condition. This is especially true when the door is typically kept open and the perimeter walls and windows are remotely located from the space temperature sensor. The heating and cooling loads at the exterior of the room can be quite different from the environment sensed by the space temperature sensor when it is located by an interior doorway.

4. **Near exterior doorways**. When wall-mounted space temperature sensors are located near exterior doorways they are subject to the influence of the outside air conditions as the door is repeatedly opened and closed. This tends to exaggerate the space's true condition toward that of the outside condition. If the outside air temperature is lower than the desired room temperature, then the interior space may be overheated. Likewise, if the outdoor air temperature is higher than the desired room temperature, then the interior space may be overcooled. The wall-mounted space temperature sensors should be located towards the interior of the space to avoid this issue.

5. **Near walls and floors subject to direct sunlight**. Direct sunlight can quickly heat interior surfaces and objects and then radiate their absorbed heat to the space. If the wall-mounted space temperature sensor is installed in or adjacent to areas heated by direct sunlight, it can cause temperature readings that are not representative of the space conditions. Overcooling of the space is the typical result. The wall-mounted space temperature sensor should be located towards

the interior of the room away from solar influences.

6. **Near sources of heat.** When the wall-mounted space temperature sensors are located during the design phase, the design engineer often has little to no idea where the heat producing equipment (copy machines, printers, ice machines, computers, refrigerators, coolers, etc.) will be located. Heat sources can significantly affect the temperature readings, so their proximity to the space temperature sensor should be avoided. If heat-producing equipment has been indicated in the architectural plan, then these locations should be avoided because of the effect they have on the space conditioning.
7. **In Block or Concrete Walls**. Wall-mounted temperature sensors installed in high-mass walls (concrete, block, brick, etc.) can be a problem if the space is not continuously maintained at the same temperature. When the space is conditioned according to an operating schedule, the walls have the opportunity to gain and lose heat during the unoccupied period. Temperature sensors in high mass (block and concrete) walls take longer to adjust or acclimatize to the room air temperature because they are under the influence of the thermal mass of the wall in which they are installed. There can be several degrees difference between the temperature sensor reading and the air temperature just outside the space temperature housing depending on the sensor design. Walls constructed of low-mass materials (gypsum wall board or similar) have a lower impact on the wall-mounted space temperature sensor reading. The impact of high-mass walls is most evident after an unoccupied weekend during the heating season. Stainless steel plate sensors installed on high-mass walls tend to lag well behind the room temperature when the edge of the plate is in direct contact with the high-mass wall surface. They come with a layer of foam insulation on the back side, but this layer does not extend to the edge where it contacts the block wall. To minimize the influence of the high-mass walls on wall-mounted space temperature sensors, a layer of insulation should be installed to prevent direct contact between the temperature sensor and wall surface. If the temperature sensor is mounted over a junction box, spray foam should also be applied to all penetrations to prevent airflow caused by pressure differentials.

Steady-state conditions are required in order to get accurate temperature calibration readings. The space temperature sensor must be fully acclimatized to the space conditions. If the load and space conditions are constantly changing (door opening and closing, power interruptions, functional testing, etc.), steady-state conditions will not be achieved. Experience has shown that the most accurate space temperature readings are acquired when the system(s) serving the space has been de-energized for several hours. If the air-handling unit and associated exhaust fans can be scheduled to de-energize the night before and energize the next afternoon, you can perform the temperature calibration readings the following morning. This ensures that the space temperature sensors are fully acclimatized to the space conditions and minimizes the effects of changing space conditions, solar loads, and change in heating cooling capacity. It also removes the effects of space pressurization which can negatively affect the accuracy of temperature calibration readings.

Temperature sensors may be combined with other sensors (humidity, carbon dioxide, occupancy override, setpoint adjustment). Combination temperature, humidity, and carbon dioxide transmitters are often used in BAS installations to reduce installation costs and the required wall space. If a combination unit is utilized, the sensor location guidelines associated with each sensor type should be followed to ensure that all sensors report correctly. The down side of combination units comes to light when one of the included sensors fails and you have to replace the entire unit. Individual sensor components are typically not replaceable.

Controls manufacturers have been producing sensors whose data is communicated over a sensor communication bus or link. Distech has the wall-mounted Smart Vue sensors which communicate over a CAT5 Ethernet cable. This two-wire link is polarity insensitive and operates with the power provided by the Sylk bus. Therefore, no 24 VAC power wiring to the wall module is required. These wall modules can provide temperature, humidity, carbon dioxide readings, and other functions in a single module and are equipped with a user interface which is fully configurable through the Niagara Workbench software. They also provide features such as setpoint override, setpoint adjustment, and occupancy override. Likewise, when one of the included sensors fails, the entire unit must be replaced.

Wireless space temperature sensors are becoming more commonplace as the technology advances and costs reduce. They allow the installation of space temperature sensors without the wiring between the controller and sensor. The make or break issue with wireless space temperature sensors is their reliability. Wireless temperature sensors rely on batteries and on a receiver that is within range to effectively communicate its data. The installation cost saved is not always worth the aggravation of poorly communicating temperature sensors and the impact it has on the control sequences that depend on them. The reported operating range for most wireless systems is based on line of sight distance. However, ceilings are typically full of structural elements, electrical cables, communication cables, network wiring, hangers, ducts, piping, lights fixtures, etc. which can significantly reduce the effective range of wireless sensors.

19.3 Probe Temperature Sensor

Probe temperature sensors are typically duct-mounted or equipment-mounted and provide an indication of the various temperatures throughout the air conditioning process. Included in this category of temperature sensor are bullet probes (without a junction box) and button probes. They are typically used in areas where the air is fully mixed and free of air temperature stratification. Return air and exhaust air temperatures are typically acquired with probe temperature sensors. Air temperatures at the discharge of fans are also acquired with probe temperature sensors because the fans fully mix the air. Probe temperature sensors are often utilized when heating and cooling coils are installed next to one another with very little clearance. The probe temperature sensors come in many standard lengths including, but not limited to, the following: 4 inches, 6 inches, 8 inches, 12 inches, and 18 inches. The selected probe length typically depends on the aspect of the duct and through which side the temperature sensor will be mounted. A temperature sensor whose sensing element is located toward the center of a duct will typically have a more representative temperature reading than one installed close to the duct surface.

Photo 253 - Probe Temperature Sensor (Monitoring Exhaust Air Temp.)

Photo 254 - Probe Temperature Sensor (Monitoring Adjacent Chamber)

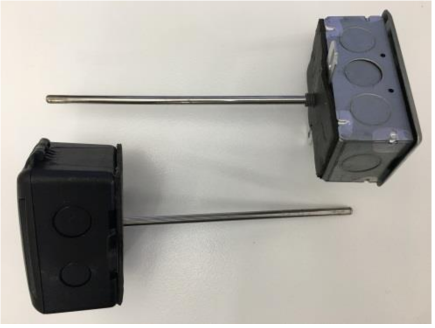


Photo 255 - Plastic and Galvanized Probe Temperature Sensor Enclosures

The factor that influences the performance of probe temperature sensors most is its installed location. They must be installed in the correct location to accurately report the air temperature. Sampling of the fully mixed air condition is ideal, but this cannot always be attained. Probe temperature sensors are typically used where the airstream is homogenous or fully mixed such as after the supply fan or after a significant duct run. Often the duct construction and space limitations preclude locating the probe temperature sensor in the optimum or fully-mixed airstream. For example, if a probe temperature sensor is installed downstream of a heating or cooling coil, then it should be installed as far away as practical to allow the air to fully mix. At least 10 feet downstream of any coil is recommended for discharge air temperature sensors. Even longer distances are recommended for large coils. If the probe sensor fails to provide an accurate reading, it should be documented and alternative locations and/or sensor types considered.

For optimal performance, probe temperature sensors should be located where the airstream flows over the probe sensor tip. It is not good enough to just be in the same compartment. Air takes the path of least resistance and this requires careful placement of probe temperature sensors. If the airflow is not actually flowing over the sensor tip, then changes in the air temperature reading will lag behind the actual changes in the airstream's temperature. Airflow over the probe temperature sensor tip improves the sensor's response time to changes in airstream temperature.

Probe temperature sensors are typically installed through a penetration drilled in the side of the duct or enclosure of an AHU where air temperature monitoring and/or control are required. It may also be located inside the air-handling unit, but monitoring the adjacent chamber (Photograph 254). It is typically secured with nylon zip ties or self-tapping sheet metal screws. The actual temperature sensor is located inside a metal (typically stainless steel) sheath for protection from physical damage and is typically situated at the tip of the probe. Because the sensor is inside a metal shaft, it responds slowly to changes in air temperature. The airflow over the shaft heats or cools the metal sheath by convection. The metal sheath then heats or cools the temperature sensor by conduction. For most comfort applications, the time lag for these heat transfer processes goes unnoticed because changes in HVAC system loads typically occur slowly. Typically, this only presents operational issues during transient conditions such as system startup or during significant load changes.

The importance of probe temperature sensors to monitor equipment discharge temperatures cannot be overstated. This is especially true if you need to troubleshoot a VAV terminal unit, fan coil unit, unit ventilator, etc. that is controlled to maintain a space temperature sensor at setpoint. Because the space is the controlled variable, having a discharge temperature sensor may not seem important. However, discharge air temperature drastically reduces the time required to test, checkout, and troubleshoot the equipment operation because it provides immediate confirmation that other system components (valves, dampers, electric heat, etc.) are functioning correctly. Discharge air temperature sensors provide key information to quickly narrow down the possible culprits of a misbehaving system. Even when a project does not require them, many Controls Contractors will install them because the data they provide saves so much troubleshooting time both during and after initial construction.

19.4 Averaging Temperature Sensors

Averaging temperature sensors are resistance-based sensors and are used to provide temperature readings where the airstream may be stratified at the point of measurement. In these situations, a more accurate temperature reading is obtained when temperature is sampled at several points rather than a single location. Averaging temperature sensors typically come in standard lengths which include, but are not limited to, 8, 12, 16, 24, and 50 feet lengths. The averaging temperature sensor is composed of multiple temperature sensors equally distributed along its length and enclosed in an aluminum or copper sheath or casing.

The arrangement of the temperature sensors is unique. When resistors are wired in series, their resistances are additive. Three 5,000 Ohm resistors in series would have a total resistance of 15,000 Ohms. When two resistors of equal resistance are wired in parallel, the resistance is equal to half the sum of the two resistors because the current has two resistive paths. If the number of parallel circuits equals the number of resistors in series in each circuit, the resultant resistance will be the average of all included resistors. The minimum number of resistors that can be electrically averaged is four. The included temperature sensors are located at equal intervals along the metal tubing which also provides some dampening of temperature fluctuations.

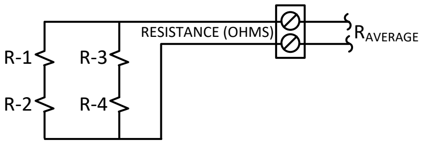


Figure 193 - Averaging Temperature Sensor (4 Sensors)

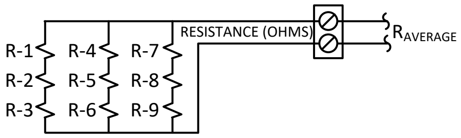


Figure 194 - Averaging Temperature Sensor (9 Sensors)

Flexible averaging temperature sensors are constructed in exactly the same manner, but they are not located within a metal sheath. The wires are protected by a woven nylon fabric and the temperature sensors are protected by an additional layer of heat-shrink tubing. Flexible averaging temperature sensors are a newer product, but they are quickly gaining favor because of the ease of installation.

(Equation 89) $$\frac{1}{R_{Total}} = \frac{1}{R_1} + \frac{1}{R_2}$$

(Equation 90) $$(R_{Total} * R_1 * R_2) * \frac{1}{R_{Total}} = (R_{Total} * R_1 * R_2) * \left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

(Equation 91) $$\mathrm{R_1 * R_2 = R_{Total} * R_2 + R_{Total} * R_1}$$

(Equation 92) $$\mathrm{R_1 * R_2 = R_{Total}(R_1 + R_2)}$$

(Equation 93) $$\mathrm{R_{Total} = \frac{R_1 * R_2}{R_1 + R_2}}$$

The averaging sensors with a metal sheath have minimum bend radius requirements that must be adhered to ensure proper operation and prevent damage of the internal wires. The averaging temperature sensor terminates at an electrical enclosure that can be mounted either inside or outside the AHU or duct and secured with threaded fasteners. The electrical connections between the temperature sensor wires and the BAS controller wires are typically made with wire nuts or a small terminal strip.

Photo 256 - Flexible Averaging Temperature Sensor (Left)

Photo 257 - Averaging Temperature Sensor Element for Supply Air

Photo 258 - Averaging Temperature Sensor Support

Averaging temperature sensors are also recommended when a temperature reading is required of an airstream that is not fully mixed or homogeneous. This makes them ideal for mixed-air temperature measurement. In most air-handling units, return and outdoor airstreams combine in the mixed-air plenum prior to being filtered and conditioned by the heating and cooling coils. Stratification of the airstreams is always a potential at this point, especially at the peak of the heating and cooling seasons when the temperature differences between the outdoor air and return airstreams are at their peak. Averaging temperature sensors provide a more accurate temperature reading than probe type sensors which sample a single point. The optimum location to install an averaging temperature sensor is downstream of the filter bank(s) to take advantage of the air mixing that the filters provide. Air blenders, reduced openings, and parallel blade dampers are often utilized in air-handling unit designs to facilitate mixing of the airstreams and minimize temperature stratification. When temperature readings are required at the discharge of heating and cooling coils, averaging temperature sensors provide a more accurate temperature reading because it samples multiple points rather than a single point (as provided by a probe temperature sensor).

Photo 259 - Flexible Averaging Temperature Sensor at Supply

Photo 260 - Flexible Averaging Temperature Sensor at Filter

Photo 261 - Flexible Averaging Temperature Sensor at Supply Fan

Project specifications typically specify a minimum coverage requirement for averaging temperature sensors. One foot of averaging temperature sensor length per square foot of duct or coil area sampled. Suppose that you have a preheat coil that measures eight feet wide by five feet high and the specified coverage level is one foot of averaging temperature sensor per one square foot of coil area. The coil area is 40 square feet (8 Feet by 5 Feet), so the averaging temperature sensor must be at least 40 feet long to provide the required coverage. This level of coil coverage can be provided by a single 50 feet long averaging temperature sensor.

(Equation 94) $$Coverage_{Min} = A * 1\frac{\mathrm{FT}}{FT^2} = (8\mathrm{FT} * 5\mathrm{FT}) * 1\frac{\mathrm{FT}}{FT^2} = 40\mathrm{FT}$$

19.5 Outdoor Air Temperature Sensors

Building automation systems typically monitor the outdoor air temperature (along with humidity) and use it for a variety of controls strategies. Many pieces of equipment are programmed to energize and de-energize based on the outdoor air temperature. Other pieces of equipment reset their setpoint based on the current outdoor air temperature. Therefore, the accuracy of the outdoor air temperature reading is important. A global outdoor air temperature sensor is utilized in most BAS installations to minimize the installation costs and reduce ongoing calibration requirements. It also eliminates the unnecessary duplication of outdoor temperature sensors. The outdoor air temperature (and humidity sensor) sensor is typically connected to a network controller like a JACE panel to provide a global temperature reading that may be shared with all field controllers (air-handling units, terminal units, fan coil units, unit ventilators, etc.).

The sensors used to monitor the outdoor air temperatures are exactly the same as those used indoors. The main difference is the sensor housing construction which allows it to withstand the rigors of rain, sleet, snow, and temperature extremes. NEMA 3 and 4 ratings and their variants (3R 3S, 3X, 3RX, 3SX, and 4X) are often observed in equipment specifications. In some BAS installations, air temperature and humidity sensors rated for indoor use are installed on an exterior wall with the sensor body or base inside the wall and the temperature/humidity sensor tips located outdoors. However, this requires that an overhang or other architectural feature that prevents snow and rain from falling on it. The annulus between the exterior wall penetration and the shaft of the sensor should be caulked with a resilient sealant to minimize/prevent air leakage and the entrance of insects.


Photo 262 - Combination Temp. and Humidity Sensor


Photo 263 - Combination Temp. and Hum. Sensor (Under Rain Hood)


Photo 264 - Outdoor Air Temp. Sensor Mounted on Rooftop Unit

Like wall-mounted space temperature sensors, outdoor air temperature sensors should not be installed in areas subject to direct sunlight. Most design specifications require that the outdoor air temperature sensors be installed on the northern exposure of the building where sunlight cannot reach. Therefore, sunlight poses no impact to its performance. The ideal place for an outdoor air temperature sensor is typically on the lower floors of a north-facing exposure because it prevents exposure to direct sunlight and utilizes the shade provided by this building and adjacent buildings. Some think that if a sun shield is used, the outdoor air temperature sensor will accurately report the temperature. However, a sun shield does no good if the surfaces surrounding the outdoor air temperature sensor have been heated by direct sunlight.

Outdoor air temperature sensors should also be installed in an area that is well away from any exhaust fan discharges or air-handling unit relief air louvers. During full economizer operation, return air is exhausted and this airstream can affect the outdoor air temperature reading if it flows over the outdoor air temperature sensor. These exhaust airstreams, under the right wind conditions can flow over the outdoor air temperature sensor significantly affecting the reading and the sequences of operation that depend on it. Optimum outdoor air temperature monitoring occurs when it is located away from sunlight and any exhaust air and air-handling unit relief air discharge points. An outdoor air temperature sensor that is properly located, installed, and calibrated will provide superior long-term performance and minimize the doubt, confusion, and lifetime calibration and maintenance costs.

19.6 Applications

1. **Global Outdoor Air Temperature Monitoring**. Global outdoor air temperature readings are typically provided by a temperature sensor that has been specifically designed for outdoor use. Through the BAS, this temperature reading is typically shared with all controllers requiring the outdoor air temperature to implement their programmed control sequences. A global temperature sensor reading minimizes the number of required temperature sensors and associated ongoing calibration costs.
2. **Temperature control and monitoring**. Occupied and unoccupied spaces that are conditioned by dedicated HVAC equipment (fan coil units, unit ventilator, terminal units, air-handling units, ductless split systems, unit heaters, etc.) may be monitored and controlled by the BAS through space temperature sensors. Space temperatures in data closets and IT rooms are often monitored to alert the operating staff to high space temperatures. Probe and averaging temperature sensors are installed to monitor and control the temperatures throughout the HVAC system. System temperatures at key locations are used for the implementation of various control sequences.

The BAS implements the myriad of control sequences required by the project contract documents. The following table provides a summary of some common control sequences that are implemented by temperature sensor type.

Sensor Type	Control Sequence	Control Sequence Description
Space	Space Temp. Monitoring and Control	Heating and cooling capacity are controlled to maintain the space temperature at setpoint.
Space	Space Temp. Set-Up/Set Back	Cooling Set-Up and Heating Set Back of the space temperature setpoints are implemented during the unoccupied period.
Space Probe	Morning Warm-up/Morning Cool-Down	Space temperatures or return air temperatures may be used to determine the need for MWU/MCD. Morning Warm-Up is an enhanced heating mode of operation where supply air at an elevated temperature is delivered to the space while the outdoor air damper remains closed. Morning Cool-Down is a cooling mode of operation where supply air at low temperature is delivered to the space while the outdoor air damper remains closed.
Probe Averaging	Discharge Air temperature Control	Control (Staging or Modulating) of the heat and/or cooling capacity to maintain the unit or coil discharge air temperature at setpoint.
Probe Outdoor Air	Discharge Air Temperature Reset	Air-handling unit supply air temp. setpoint is reset based on return air (or outdoor air) temperature to minimize reheat requirements and reduce the cooling load.
Probe Outdoor Air	Comparative Dry-Bulb Economizer	Economizer operation is enabled when the outdoor air temperature is below the return air temperature by a predefined temperature differential. Once enabled, the dampers modulate to maintain the discharge air temperature at setpoint.
Probe Outdoor Air	Comparative Enthalpy Economizer	Economizer operation is enabled when the outdoor air enthalpy is below the return air enthalpy reading by a predefined enthalpy differential. Return air temperature and return air humidity readings are required to calculate the return air enthalpy. Once enabled, the dampers modulate to maintain the discharge air temperature at setpoint.
Averaging	Mixed-Air Low Limit	The outdoor air damper command is overridden to maintain the mixed-air temperature above the mixed-air low limit setpoint.
Averaging	Coil Discharge Temperature Control	The heating and/or cooling capacity are controlled to maintain a desired discharge air temperature setpoint.
Outdoor Air	Condenser-Water Supply Temperature Reset	The condenser water supply temperature is reset based on the wet-bulb temperature sensor readings. Outdoor air and humidity readings are required in order to calculate the wet-bulb temperature.
Outdoor Air	Hot-Water Supply Temperature Reset	Hot water supply temperature setpoint is reset based on outdoor air temperature to avoid overheating and maximize boiler plant efficiency.
Outdoor Air	Coil Freeze Pump Control	Coil freeze pump is enabled when the outdoor air falls below a minimum setpoint to avoid freezing of the coil.
Outdoor Air	Dual-Temperature Plant Changeover	Dual-temperature central plants change their seasonal operation based on the outdoor air reading.
Outdoor Air	Cooling Lockout	Cooling capacity is disabled when the outdoor air temperature falls below the cooling lockout temperature setpoint.
Outdoor Air	Heating Lockout	Heating capacity is disabled when the outdoor air temperature exceeds the heating lockout temperature setpoint.

Table 70 - Control Sequences per Air Temperature Sensor Type

19.7 Typical Control Wiring

The following wiring diagram is an example of how space temperature sensors are typically connected.

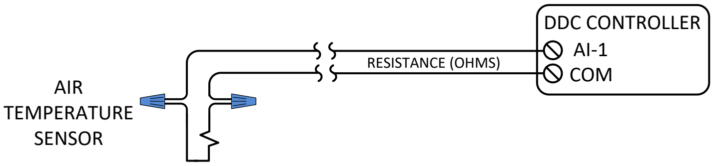


Figure 195 - Temperature Sensor Wiring

19.8 Analog Input Testing and Verification

The general test procedures for air temperature sensors include the following:

1. Verify that the air temperature sensor has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The operating range, mounting, coil/duct coverage requirements, output contacts, wiring specifications, and output signals are some of the features that should be verified.
2. Verify that the air temperature sensor has been installed at the correct or optimum location. When the temperature of mixing airstreams is monitored, the temperature sensor should be installed as far away as possible to provide time for the airstream to fully mix. The choice of temperature sensor type (wall-mount, probe, and averaging type) should be consistent with the desired air temperature location.
3. Verify that the air temperature sensor has been installed per the manufacturer's installation recommendations. Averaging temperature sensors typically have specific requirements for the installation, and mounting of the capillary tube. The averaging temperature sensor should be protected with a grommet or ¼ inch pneumatic tubing where it passes from the outside of the air-handling unit or duct to the inside of the unit or duct.
4. If the calibration of multiple air-handling unit temperature sensors is required, posture the unit for either full recirculation (closed outdoor air damper) or full outdoor airflow (fully open outdoor air damper). The choice will depend on the outdoor air conditions. The closer the outdoor air temperature is to the return air temperature, the more accurate the test results will be. Set all hydronic control valves to zero flow through the heating and cooling coils. Closure of the manual isolation valves is recommended to ensure zero coil flow. Disable any direct expansion coils as well. When the residual heat in the coils is gone (30 to 90 minutes), the temperature sensor readings throughout the air-handling unit should be the same, except for fan heat gains and minor damper leakage.
5. Verify that the air temperature sensor has been correctly wired. Drawings or sketches are typically best for documenting the wiring strategies used. Air temperature sensors are connected to the BAS controller analog input with a pair of wires. Wire nuts are typically used at the temperature sensor to connect the temperature sensor wiring to the two-conductor sensor wire.
6. Verify that the air temperature sensor is connected to the correct BAS controller analog input. Air temperature sensors are typically based on resistance, so opening this circuit will cause a loss of signal. With no signal, the reading will change to a value consistent with an open circuit thus identifying it from the other data points. It is a good idea to make a note or take a screenshot of the data point reading that occurs when the air temperature sensor is disconnected. An alternative method of verifying sensor connectivity is available for pressure-independent terminal units equipped with both space and discharge air temperature sensors. By overriding the heat command to full heat, the discharge air temperature sensor can be verified by observing which temperature reading increases from its current reading. This allows the discharge air and space temperature sensors to be verified without actually breaking the temperature sensor circuits.
7. At the same time that the previous step is implemented, verify and document that the data point bound to the BAS graphics also changes.
8. Verify that the air temperature sensor and its wires at the controller end have been labeled. Air temperature sensors are typically provided with a label that indicates the equipment (air-handling unit, fan coil unit, unit ventilator, terminal unit, etc.) that it served and/or the specific temperature reading that is provided (Preheat, Supply Air, Discharge Air, Cooling Coil Discharge, Mixed-Air, etc.)
9. Verify that the units/facets of the air temperature sensor are correctly displayed. Units of temperature typically either Fahrenheit (°F) or Celsius (°C) for most commercial HVAC applications.
10. Verify that the precision of the air temperature sensor reading is appropriately set. Temperature setpoints should be whole numbers and the precision of temperature readings should be no more than one decimal place for most commercial applications.
11. Verify that the BAS controller's analog input has been properly configured and matches the specifications of the installed temperature sensor. A decade resistance box or variable resistor is also useful for this task. Applying the base resistance across the temperature sensor wires (after disconnecting the installed temperature sensor) will cause the analog input value to display the reference temperature (77.0°F for thermistors and 32.0°F for RTDs) if it is properly configured.
12. Verify that the accuracy of its temperature reading by comparison with readings from a calibrated temperature meter. Equipment or duct-mounted temperature sensors should be calibrated with the system operational.

Space and Outdoor Air Temperature Sensors: Locate a calibrated temperature meter or its temperature probe within 3 inches of the space or outdoor air temperature sensor and wait for the temperature reading to stabilize. This typically requires two to five minutes per temperature sensor.

Probe and Averaging Temperature Sensors: Drill a 1/8 inch or a 3/8 inch penetration in the duct wall 3-6 inches directly upstream or downstream of the sensor. Insert the bead probe (Fluke PK-1) or immersion temperature sensor (Fluke PK-25) through the duct wall to sample the airstream and acquire temperature readings. The Evergreen Telemetry temperature module (S-T-1 or S-T-5) and WristReporter™ may also be used to provide reference temperature readings. A 1/8 inch penetration can be filled with a sheet metal screw and a 3/8 inch penetration is typically filled with a 3/8 inch plastic duct plug following testing. Terminal unit discharge air temperature sensors can be tested by measuring the temperature of the air discharging from a supply diffuser, register, or grill. Equipment summary screens and overrides are very effective at reducing the time required to test and calibrate temperature sensors when there are large quantities of associated equipment. Hundreds of terminal unit discharge air temperature sensors can be evaluated by comparison to the air-handling unit discharge air temperature to determine which require the most attention.

13. Update the calibration offset of the analog input of the BAS controller and retest to confirm proper calibration of the temperature sensor reading. In the Honeywell® Spyder® controller configuration, a sensor calibration module. After entering the field-measured reference value, the required calibration offset is automatically calculated and applied. In the JACE controller, only the offset is adjusted. The scale should not be adjusted for calibration of temperature sensor readings because it is only used in the calibration of sensor transmitters. The offset adds the value entered to all temperature readings. Replacement of poorly performing temperature sensors is recommended whether or not they are used for control. Record the final analog input calibration offset factors.
14. Release all overrides used to posture the system for testing and calibration.
15. Review the trend data to verify that the air temperature sensor reliably and consistently reports to the BAS controller. Numeric interval trend extensions are used to collect trend data at the programmed time intervals. Initial trend data intervals should be short (5 seconds-5 minutes) intervals to allow transient issues (that cannot be identified with longer intervals) to be identified. Once the testing and commissioning stage has concluded, longer time intervals (10-20 minute) can be used to minimize ongoing data storage requirements. There should not be any gaps or omissions in the trend data. The trend data should show that the air temperature readings correspond with the programmed control logic, setpoint, and schedules.
16. Document the results of all testing. Screenshots of the analog input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the air temperature sensor readings.

19.9 Review

1. Thermistors typically used in HVAC control have a ________________ temperature Coefficient.

   Answer: ________

   A. Negative
   B. Positive
   C. Indifferent

2. Simulating the reference resistance of a temperature sensor with a decade resistance box is useful for temperature sensor troubleshooting and ______________.
3. The ________________ Effect is the name of the tendency of the supply airstream to hug the ceiling surface as it discharges from ceiling-mounted supply air grills, registers, and diffusers.
4. Duct-mounted probe temperature sensors should be located so that its probe is __________ the airstream.

   Answer: ________

   A. Outside
   B. Adjacent to
   C. Within

5. Wall-mounted temperature sensors should be installed: Answer: ________

   A. Away from walls and floor surfaces subject to direct sunlight
   B. Away from heat sources
   C. Away from supply air streams

   D. Adjacent/below return grills
   E. All of the above

6. True or False: BAS controllers automatically detect the type of temperature sensor connected to it.
   Answer: ________
7. True or False: Installation of a wall-mounted temperature sensor near a door that opens to a corridor is preferred.
   Answer: ________
8. Posturing the air-handling unit dampers for either full recirculation or full outdoor airflow reduces/eliminates the effects of __________________________.
9. The outdoor air temperature sensor should be located on the _________________ side of the building to avoid direct sunlight.
10. How many 12 feet averaging temperature sensors will be required to provide the minimum coverage of 1 Foot of averaging temperature sensor length per square foot of coil if the coil is 5 feet wide by 4 feet high?
    Answer: ________
11. Air blenders are used to ____________________ the mixed airstream.
    A. Homogenize
    B. Mix
    C. Destratify
    D. All above
12. Convective air currents along the perimeter walls are generated when the outdoor air temperature is _______________ as the indoor air temperature.
    A. Same
    B. Higher
    C. Lower
    D. Both 2 & 3

19.10 References

1. American Society of Heating, Refrigeration, and Air Conditioning Engineers. 2020. Standard 55: Thermal Environmental Conditions for Human Occupancy.
2. Wulfinghoff, Donald R. 1999. Energy Efficiency Manual. Energy Institute Press.
3. https://www.workaci.com/
4. https://www.kele.com/content/home/
5. https://www.bapihvac.com/products/temperature-sensors/
6. https://www.nemaenclosures.com/enclosure-ratings/nema-rated-enclosures.html

Chapter 20 - Space Temperature Setpoint Adjustment (AI)

20.1 Description

Wall-mounted space temperature sensors may come with the ability to manually adjust the space temperature setpoint associated with the air-handling unit or terminal device (VAV terminal unit or reheat coil). This provides the occupant with the means to adjust the space temperature setpoint to their liking. When the knob, slider, or wheel is actuated, it changes the position of a variable resistor between its maximum and minimum resistance values. This resistance signal is monitored by an analog input of the BAS controller. The programming utilizes a ratio block or similar mathematical function or programming to equate the change in resistance to a change in setpoint. Therefore, when the knob, slider, or wheel is manually actuated, the BAS controller interprets the change in resistance to a corresponding change in space temperature setpoint.

Photo 265 - Space Temp. Sensor with Setpoint Adjustment & Override

Photo 266 - Space Temperature Sensor with Setpoint Adjustment

Photo 267 - Close-Up View of Setpoint Adjustment Slider

The change in space temperature setpoint depends on whether the setpoint adjustment is **Relative** to a fixed setpoint or **Absolute**. Some facilities institute global heating and cooling space temperature setpoints, but allow the local setpoint to be modified by the local space temperature adjustment device by a predetermined amount. For example, sites that are not so energy-conscious may allow their occupants a wide space temperature setpoint adjustment range (±5°F of standard setpoint). In other sites where energy use is closely monitored, the occupants will typically have a tighter space temperature setpoint adjustment range (±2°F of standard setpoint).

Other sites implement Absolute space temperature adjustment between maximum and minimum values. As the setpoint adjustment device is adjusted, the actual space temperature setpoint is changed. For example, sites that are not so energy-conscious may allow its occupants a wide space temperature setpoint adjustment range (78°F to 68°F) while other sites where energy use is closely monitored, the occupants will typically have a tighter space temperature setpoint adjustment range (72°F to 76°F).

20.2 Applications

1. **Space temperature setpoint adjustment**. Wall-mounted space temperature sensors with space temperature setpoint adjustment are used to provide the occupants with the ability to adjust the space temperature setpoint to their liking.

20.3 Typical Control Wiring

The following wiring diagram is an example of how space temperature setpoint adjustment device is typically connected.

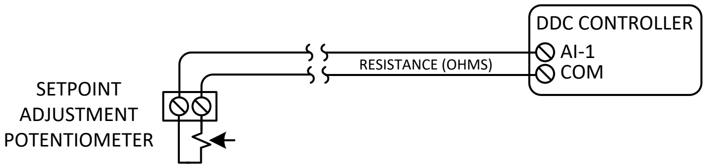


Figure 196 - Space Temperature Setpoint Wiring

20.4 Analog Input Testing and Verification

The general test procedures for Space Temperature Setpoint Adjustment include the following:

1. Verify that the setpoint adjustment device has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The resistance range, mounting, and wiring are some of the features that should be verified. Verify the setpoint adjustment strategy and setpoints required by the contract documents and sequences of operation.
2. Verify that the setpoint adjustment device has been installed at the correct or optimum location.
3. Verify that the setpoint adjustment device has been installed correctly following the manufacturer's installation recommendations.
4. No posturing or overrides are required for the testing and calibration of setpoint adjustment devices.
5. Verify that the setpoint adjustment device has been correctly wired. Setpoint adjustment devices are typically connected to the BAS controller by a two-conductor wire. However, they may also be connected through a communication bus like the Honeywell Sylk bus devices. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify that the setpoint adjustment device is connected to the correct BAS controller analog input. This step is typically performed by ramping the setpoint adjustment device to the maximum and minimum settings and identifying that the temperature setpoint changes. Alternatively, one of the wires at the setpoint adjustment device terminal block can be temporarily removed. It is a good idea to make a note or take a screenshot of the data point reading that occurs when the setpoint adjustment device is disconnected.
7. At the same time that the setpoint adjustment device is manually adjusted or disconnected, verify and document that the data point bound to the BAS graphics also changes.
8. Verify that the setpoint adjustment device and its wires at the controller end have been labeled. A label for the setpoint adjustment device is typically unnecessary because it is integral to the wall-mounted temperature sensor which should have a label.
9. Verify that the units/facets of the temperature setpoint are correctly displayed. Temperature setpoints are typically displayed in degrees Fahrenheit (°F) or Celsius (°C).
10. Verify that the precision of the setpoint adjustment device reading is appropriately set. Setpoints are typically whole numbers (no decimal places).
11. Verify that the BAS controller's analog input point has been properly configured to interpret the change in resistance. The following applies to **absolute** temperature setpoint change. The knob or slider is adjusted from its minimum to its maximum resistance. At the minimum resistance, the space temperature setpoint is at its minimum level. At maximum resistance, the space temperature setpoint is at its maximum level.

	Absolute Setpoint Adjustment	
Reading	Resistance (kOhms)	Setpoint (°F)
Minimum	9.574	55
Maximum	1.426	85

Table 71 - Setpoint Adjustment Configuration

If the analog input configuration of the BAS controller is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs. The following table is the result of a spreadsheet that calculates the scale and offset based on the resistance and setpoint range.

kOhms	Setpoint (°F)
9.574	55
1.426	85

Calculated Scale=	-3.682
Calculated Offset=	90.250

Table 72 - Scale-Offset Calculation

Alternatively, the setpoint adjustment device can also be used to adjust the effective setpoint by a predefined number of degrees **relative** to a base room temperature setpoint. For example, if the room temperature setpoint was 72°F, the setpoint adjustment knob/slider could be configured to adjust the space temperature setpoint up and down by a predefined value. It is 3°F in this example.

Reading	Relative Setpoint Adjustment		
	Resistance (kOhms)	Setpoint Adjustment (°F)	Effective Setpoint (°F)
Minimum	9.574	-3	69
Maximum	1.426	+3	75

Table 73 - Setpoint Adjustment Configuration

If the analog input configuration of the BAS controller is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs. The following table is the result of a spreadsheet that calculates the scale and offset based on the resistance and setpoint range.

kOhms	Setpoint (°F)
9.574	-3
1.426	3

Calculated Scale=	-0.736
Calculated Offset=	4.050

Table 74 - Scale-Offset Calculation

12. Verify that the accuracy of the setpoint adjustment device by measuring the resistance at the maximum and minimum settings and observing the calculated setpoints. Adjust the calibration factors, as required, until the BAS controller accurately reports the resistance and calculated setpoints. This step will require the use of a multimeter to measure resistance in Ohms.

		Setpoint (°F)	
Reading	Resistance (kOhms)	Absolute	Relative
Minimum	9.633	54.78	-3.04
Maximum	1.365	85.22	3.04

Table 75 - Minimum and Maximum Resistance Measurements

13. Update the configuration of the analog input of the BAS controller and retest to confirm the calibration of the setpoint adjustment device. Record the final analog input calibration and correction factors.

Reading	Absolute Setpoint Adjustment	
	Resistance (kOhms)	Setpoint (°F)
Minimum	9.633	55.0
Maximum	1.365	85.0

Table 76 - Updates Absolute Setpoint Adjustment Configuration

If the analog input configuration of the BAS controller is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs. The following table is the result of a spreadsheet that calculates the scale and offset based on the resistance and setpoint range.

kOhms	Setpoint (°F)
9.633	55
1.365	85

Updated Calculated Scale=	-3.628
Updated Calculated Offset=	89.953

Table 77 - Setpoint Adjustment Configuration

Alternatively, the setpoint adjustment knob/slider can also be used to adjust the effective setpoint by a predefined number of degrees **relative** to a reference room temperature setpoint. For example, if the room temperature setpoint was 72°F, the setpoint adjustment knob/slider could be configured to adjust the space temperature setpoint up and down by a predefined value. It is 3°F in this example.

Reading	Relative Setpoint Adjustment		
	Resistance (kOhms)	Setpoint Adjustment (°F)	Effective Setpoint (°F)
Minimum	9.633	-3	69
Maximum	1.365	+3	75

Table 78 - Updated Relative Setpoint Adjustment Configuration

If scale and offset factors are used to configure the parameters of the BAS controller analog input, update them accordingly using the same methodology explained in Chapter 3: BAS Inputs and Outputs. Confirm the accuracy of the analog input configuration by applying test pressures and verifying that the resulting differential pressure readings.

kOhms	Setpoint (°F)		
9.633	-3	Updated Calculated Scale=	-0.726
1.365	3	Updated Calculated Offset=	3.991

Table 79 - Updated Scale-Offset Calculations

14. Release all overrides used to posture the system for testing and calibration.
15. Review the trend data to verify that the space temperature adjustment device reliably and consistently reports to the BAS controller. Numeric Interval trend extensions are typically used to collect trend data at the programmed time intervals. There should not be any gaps or omissions in the trend data. Change of Value trend extensions may also be used to record changes in the monitored value when they exceed a minimum threshold.
16. Document the results of all testing. Screenshots of the analog input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the space temperature adjustment device.

20.5 Review

1. Setpoint adjustment knobs, sliders, and wheels are incorporated into wall-mounted __________________ .
2. The setpoint change is typically related to a change in __________________ when a setpoint adjustment knob, slider, or wheel is actuated by the occupant.
3. If the maximum and minimum resistances of a setpoint adjustment knob are 10,500 Ohm and 500 Ohm, respectively, what are the Scale and Offset value if the maximum and minimum space temperature setpoints are 80°F and 60°F, respectively? Scale: __________________ Offset: __________________
4. Energy conscious facilities with standard heating and cooling setpoints will typically have _________________ setpoint adjustment range.
5. Space temperature setpoints are typically displayed with ___________ decimal places.
    A. One
    B. Two
    C. Three
    D. None

20.6 References

1. https://customer.honeywell.com/resources/techlit/TechLitDocuments/63-0000s/63-1321ES.pdf

Chapter 21 - Hydronic Temperature Sensors (AI)

21.1 Description

21.1.1 Strap-on Temperature Sensors:

As the name implies, this type of temperature sensor is literally strapped onto the pipe surface. While immersion temperature sensors provide the most accurate and reliable temperature readings, strap-on temperature sensors offer a distinct advantage. They do not require that the hydronic system be de-energized, drained, modified (to install the threadolet, thermowell, and immersion temperature sensor), refilled, purged of air, restarted, etc. in order to provide fluid temperature readings. Avoiding system downtime is often the deciding factor in many BAS installations, especially in retrofits. Under steady-state operating conditions, the water temperature is essentially the same as the pipe surface temperature. However, when the fluid temperature is changing, the surface temperature readings will lag behind the actual change in fluid temperature because the water must first heat or cool the pipe material. This inherent delay in the sensing changes in the temperature of the fluid is typically understood and accepted.

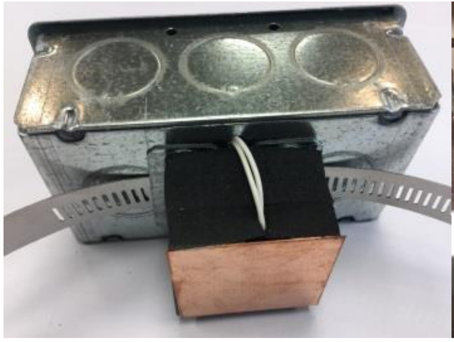


Photo 268 - Strap-On Temperature Sensor


Photo 269 - Strap-On Temperature Sensor on Condenser Water Piping


Photo 270 - Thermowell in Small Diameter Piping

The strap-on temperature sensor is mounted directly to the pipe surface and held in place by a stainless steel strap. The temperature sensor is fused to the back of the copper contact pad. On top of the copper pad is a layer of foam insulation that eliminates the effects of the ambient air on the sensor and provides a cushion for the straps to compress the temperature sensor assembly against the pipe surface. Accuracy and repeatability greatly depend on maintaining constant contact between the temperature sensor and the pipe surface. All insulation, coatings, rust, etc. must be removed from the pipe surface where the strap-on temperature sensors are planned for installation. Air gaps that result from debris that has not been removed will insulate the pipe surface from the temperature sensor contact pad. Most manufacturers recommend a layer of thermal conductive paste to improve heat conduction between the pipe surface and copper contact pad which improves sensor accuracy and reduces the time lag.

21.1.2 Immersion Temperature Sensors:

Immersion temperature sensors are the best option for monitoring fluid temperatures in hydronic systems. They allow the temperature of a liquid under pressure and in operation to be measured without affecting the process, opening the system, or relieving system pressure. Installation of immersion temperature sensors requires coordination with the mechanical contractor who typically installs the taps (threadolets) in the hydronic system. Threadolets provide a place to install the thermowells which provide the access to the hydronic system without releasing any fluid or relieving system pressure. Finally, the temperature sensor probe is installed in the thermowell. There is typically a small air gap between the thermowell and the immersion temperature sensor shaft, so the use of the thermal-conductive paste is always recommended to minimize the amount of time that the temperature reading lags behind the actual change in fluid temperature.

When fluid temperature readings are required where two fluid streams mix, the temperature sensor should be located well downstream of the point at which they combine to allow them to fully mix prior to measuring the temperature. When the immersion temperature sensor is located too close to the point of mixing, the hydronic temperature sensor readings will either be inconsistent or will be under the influence of one fluid stream or the other. Like mixing airstreams, fluids can also be stratified. Therefore, it is a good practice to locate the hydronic temperature sensor well downstream of the point of mixing to maximize the use of piping system elements (pumps, valves, strainers, elbows, tees, and straight runs of pipe) that promote mixing.

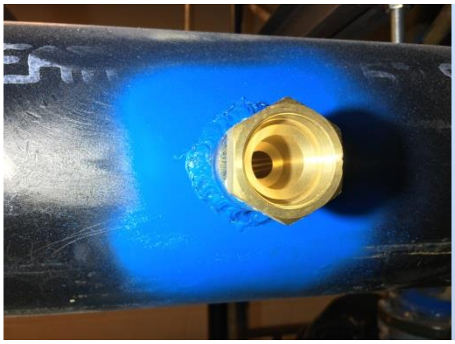


Photo 271 - Thermowell Without Temperature Sensor

Photo 272 - Stainless Steel Thermowell

Photo 273 - Immersion Temperature Sensor (Large Diameter)

The depth of thermowell penetration into the pipe cross section is an important factor to consider. A good rule of thumb is that the tip of the thermowell should penetrate at least two to four inches into the pipe cross-section depending on diameter of the pipe as shown in Figure 197. The smaller the pipe diameter, the smaller the required penetration of the thermowell into the pipe cross-section. This ensures that the flowing water will have good exposure to the thermowell and ultimately the temperature sensor. If the thermowell and temperature sensor do not penetrate sufficiently, the sensed rate of temperature change will lag behind the actual rate of temperature change resulting in poor temperature control.

When installed in smaller pipes, thermowells can actually restrict the water flow because the size of the thermowell relative to the pipe diameter is much larger. To avoid flow restrictions, the thermowell is typically installed so that the tip of the thermowell is at the edge or only slightly within the pipe cross section as shown in Figure 198. Because the fluid does not flow over the body of the thermowell, the temperature indication will lag behind the actual changes in fluid temperature. The lag in temperature indication is preferred to restricting fluid flow.

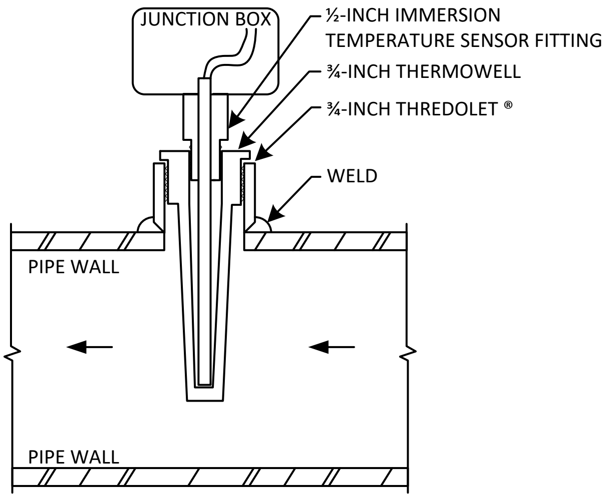


Figure 197 - Typical Large Diameter Thermowell Installation

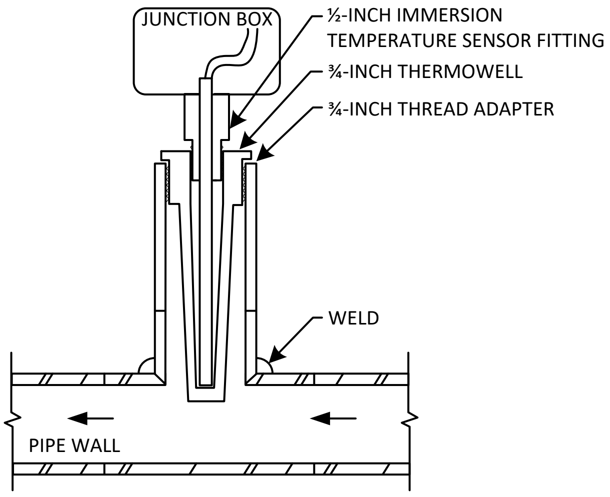


Figure 198 - Typical Small Diameter Thermowell Installation

21.2 Application

1. **Chilled Water Plant Control**. Chillers typically have an integral chilled water supply temperature sensor that is used to control its operation. The Controls Contractor will often install a separate set of chilled water supply (TS-1) and return temperature sensors (TS-2) for monitoring and control purposes. The condenser water side of the water-cooled chiller system is monitored by the hydronic temperature sensors (TS-3,4) to modulate the cooling tower fan speed and condenser water bypass control valve to maintain the condenser water supply temperature (TS-3) at setpoint. Upon startup, the cooling tower fan is disabled and the bypass control valve is postured so that that condenser water bypasses the cooling tower. It operates in this configuration until the condenser water supply

temperature (TS-3) approaches the maximum condenser water supply temperature setpoint which is typically 85°F. As the condenser water supply temperature (TS-3) exceeds the maximum condenser water supply temperature setpoint, the bypass control valve modulates open to the tower to maintain the condenser water supply temperature at setpoint. Once the bypass control valve is fully open to the cooling tower, the cooling tower fan is enabled and its speed is then modulated to maintain the condenser water supply temperature (TS-3) at setpoint.

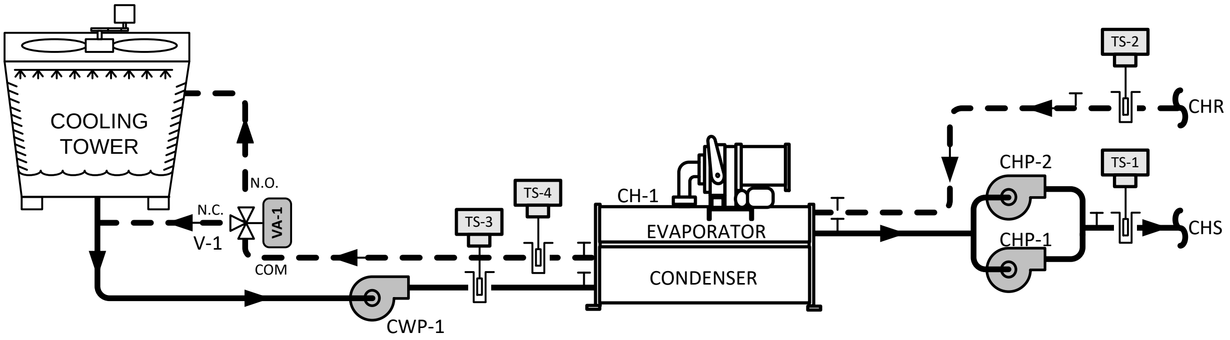


Figure 199 - Chilled Water System with Immersion Temperature Sensors

2. **Central Plant Flow Control**. Chilled/Hot water piping systems utilizing constant-volume primary and variable-volume secondary flow may utilize hydronic temperature sensors to control the staging of chillers and boilers. The bridge (also referred to as the decoupler) is the section of piping that is situated between the primary and secondary loops which decouples the primary and secondary chilled water loops. As long as the primary chilled water flow is higher than the secondary chilled water flow, the secondary chilled water temperature reading (TS-4) will be equal to the primary loop chilled water supply temperatures (TS-3) and the direction of flow in the bridge (decoupler line) will be from the supply toward the return side (downward).

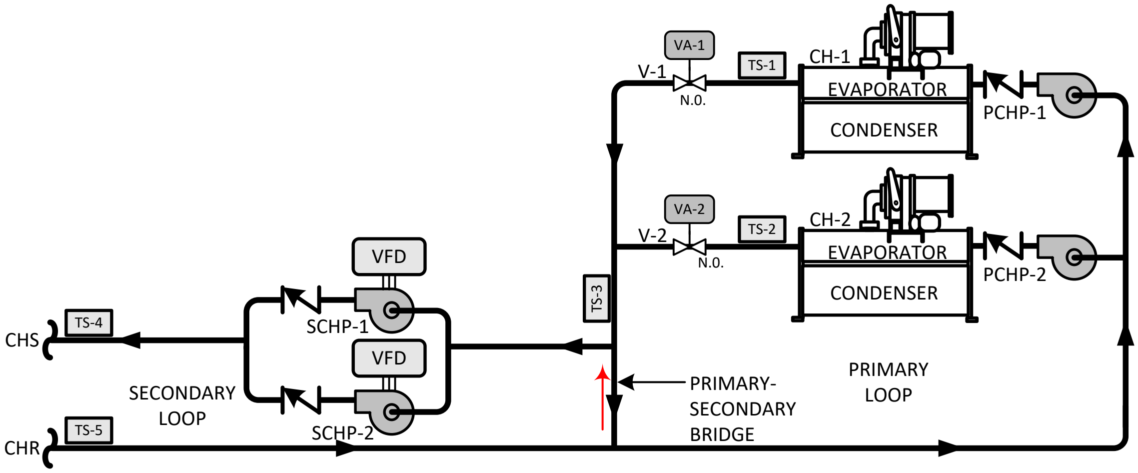


Figure 200 - Strap-on Temperature Sensors in Chilled Water Primary-Secondary Bridge Piping

When the secondary chilled water flow rate exceeds the primary chilled water flow rate, the direction of flow in the primary-secondary bridge piping reverses (upward as indicated by the red arrow above). This reversal of flow introduces warmer secondary return chilled water into the secondary chilled water supply line which raises the secondary chilled water supply temperature (TS-4) above that of the primary chilled water supply temperature (TS-3). Therefore, when the TS-4 exceeds TS-3, an additional chiller and primary pump will be enabled to maintain the secondary chilled water supply temperature at setpoint. The same control strategy can be utilized in hot water systems. This control sequence is simple, reliable, economical, and does not rely on multiple hydronic flow meters.

3. **Modular Boiler/Chiller Plant Control**. Hydronic piping systems utilize hydronic temperature sensor readings to control the staging of boilers and chillers. Each boiler/chiller is typically equipped with temperature sensors that are used by its internal controls. Additional BAS immersion temperature sensors (T-1,2,3) may also be installed to monitor the operating status and discharge temperature of each boiler/chiller. The boiler/chiller plant supply temperature (T-4) should be located as far away from the branch connections as possible to ensure a fully mixed temperature reading. Likewise, the hydronic temperature sensor (T-6) that monitors the main hydronic supply temperature will be located

well downstream of the point where the heated/chilled water is mixed with the mainline water stream. This sensor is used to control the staging/modulation of the boiler/chillers.

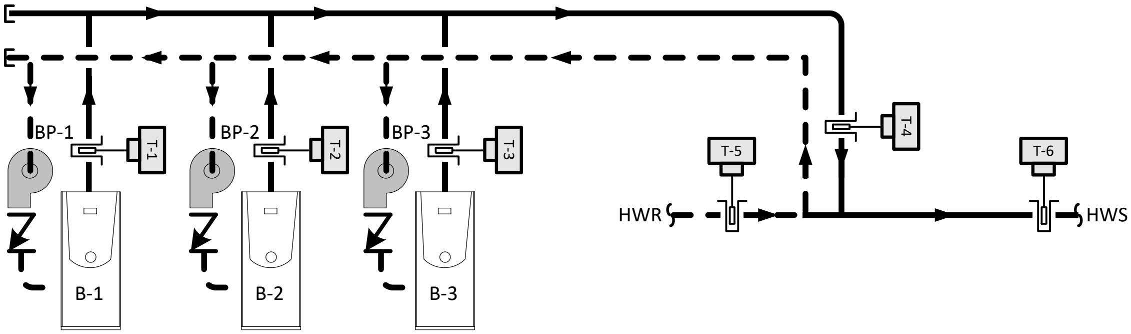


Figure 201 - Immersion Temperature Sensors for Boiler Plant Control

21.3 Typical Control Wiring

The following diagram is an example of the typical hydronic temperature sensor.

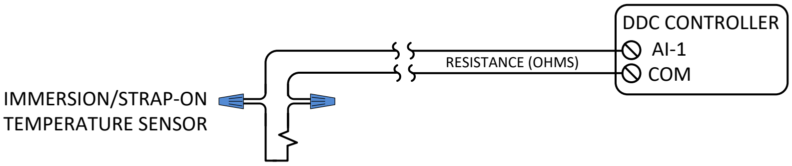


Figure 202 - Hydronic Temperature Sensor Wiring

21.4 Analog Input Testing and Verification

The general test procedures for Hydronic Temperature Sensors include the following:

1. Verify that the hydronic temperature sensor has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The operating range, mounting, output contacts, wiring, and output signals are some of the features that should be verified.
2. Verify that the hydronic temperature sensor has been installed at the correct or optimum location. If the hydronic temperature sensor is measuring the temperature of two intersecting streams of fluid. The immersion temperature probe should be located well downstream to allow time for fluid mixing before temperature measurement.
3. Verify that the hydronic temperature sensor has been installed per the manufacturer's installation recommendations.
4. Posture the hydronic system with multiple immersion temperature sensors for simultaneous testing and calibration. This means that all heating and cooling equipment in the plant should be disabled. Isolation valves should also be closed as permitted by the system design. In addition, the equipment should be bypassed if the piping allows for such operation. When the residual heat from the connected equipment is gone, the immersion temperature sensor readings throughout the hydronic should essentially be the same, except for pump heat gains which are typically small. Leave the pumps running during the calibration process because flowing water yields better calibration results than still water.
5. Verify that the hydronic temperature sensor has been correctly wired. Drawings or sketches are typically best for documenting the wiring strategies used. Temperature sensors are connected to the BAS controller with a pair of wire nuts which are inserted in the temperature sensor enclosure (if equipped).
6. Verify that the hydronic temperature sensor is connected to the correct BAS controller analog input. Temperature sensors are typically based on resistance, so breaking this circuit will cause a loss of signal causing a change in the indicated temperature. It is a good idea to make a note or take a screenshot of the data point reading that occurs when the air temperature sensor is disconnected.
7. At the same time that the previous step is implemented, verify and document that the data point bound to the BAS graphics also changes.
8. Verify that the hydronic temperature sensor and its wires at the controller end have been labeled. Hydronic temperature sensors are typically installed in hydronic systems (chilled water, hot water, condenser water, heat recovery, etc.) to measure temperatures at specific locations. Therefore, labels typically consist of notations of equipment, hydronic system, and whether it is a supply or return temperature.

9. Verify that the units/facets of the hydronic temperature sensors are correctly displayed. Units of temperature typically either Fahrenheit (°F) or Celsius (°C).
10. Verify that the precision of the hydronic temperature sensor reading is appropriately set. The precision of temperature sensor readings should be no more than one decimal place for most applications.
11. Verify that the BAS controller's analog input has been properly configured to match the specifications of the installed temperature sensor. The initial check is to evaluate the current temperature sensor reading to judge its accuracy for the current conditions. A decade resistance box or variable resistor is useful for this task. Applying the base resistance across the temperature sensor wires (after disconnecting the installed temperature sensor) will cause the analog input value to display the reference temperature (77.0°F for thermistors and 32.0°F for RTDs) if it is properly configured.
12. Verify that the accuracy of the hydronic temperature sensor reading by taking temperature readings with a calibrated instrument by using one of the following methods. These methods are ordered in terms of accuracy and preference. The most accurate and preferred methods are listed first and continue in order of decreasing accuracy and preference.
    A. Insert the piercing probe (Fluke 80 PK-25) of a temperature meter into the Pressure/Temperature (P/T) port installed adjacent to the immersion temperature sensor. Measure the hydronic temperature with a calibrated temperature meter and compare to the BAS temperature reading.

    B. The calibration of hydronic temperature sensors can be checked by comparison with a reference immersion temperature sensor that was properly tested and calibrated. Strap-on temperature sensors should only be used as reference readings if the system is operating under steady-state conditions. The system must first be postured so that the test and reference temperature sensors are sensing the same conditions. The two hydronic temperature sensors must be inline.

    C. If no P/T ports are available, remove the immersion temperature sensor from its thermowell. This may require temporarily disconnecting the sensor wiring and removal from the housing cover and conduit. Reconnect the hydronic temperature sensor wiring and place the temperature sensor shaft in a water bath (typically a cup, can, or bucket of water) as shown in Photograph 275. Using a piercing temperature probe with a calibrated temperature meter, measure the water temperature. Agitate or stir the water to get the hydronic temperature sensor and reference temperature readings to acclimatize to the water temperature quickly. Once the required offset has been determined, reinstall the temperature sensor and reconnect the wires.

    D. If no P/T ports are available and if it is not possible or practical to safely remove the hydronic temperature sensor for submersion in a water bath, it is possible to drain water from an available pipe connection such as a drain or gauge connection that is representative of the fluid temperature that the hydronic temperature sensor is monitoring. The temperature of the draining fluid can be measured with a calibrated temperature meter (Photograph 276). A hose connected to a hose-end drain connection can also be used for this purpose. The hydronic temperature probe (Fluke PK-80) can be inserted in the hose to sample the water as it flows. Use a bucket to catch the fluid if a floor drain is not in the immediate area.

    E. If no P/T ports have been installed or connections for draining water are not available, taking a pipe surface temperature reading with a calibrated thermometer may be the only method of validating a water temperature reading from a hydronic temperature sensor. This method is only recommended after the system has reached steady-state conditions.
13. Update the calibration offset value for the analog input of the BAS controller based on the sensor calibration readings and verify that the updated temperature reading matches the reference readings provided by the calibrated meter. Do not update the scale factor. Replacement of poorly performing temperature sensors is recommended whether or not they are used for control. Record the final calibration factor for the temperature sensor.
14. Release all overrides used to posture the system for testing and calibration.
15. Review the trend data to verify that the hydronic temperature sensor reliably and consistently reports to the BAS controller. Numeric interval trend extensions are used to collect trend data at the programmed time intervals. Initial trend data intervals should be short (5 seconds-5 minutes) intervals to allow transient issues (that cannot be identified with longer intervals) to be identified. Once the testing and commissioning stage has concluded, longer time intervals (10-20 minutes) can be used to minimize data storage requirements. There should not be any gaps or omissions in the trend data. The trend data should show that the hydronic temperature sensor correspond with the programmed control logic and schedule.

Photo 274 - Piercing Probe Temperature Readings

Photo 275 - Water Bath Temperature Calibration

Photo 276 - Fluid Drain Temperature Calibration

16. Document the results of all testing. Screenshots of the analog input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the hydronic temperature sensor.

21.5 Review

1. True or False: Strap-on temperature sensors provide more real-time indication of water temperature changes than immersion temperature sensors at the same location. Answer: ________
2. The main advantage of strap-on temperature sensors is that they can be installed without having to ____________ the piping system.
3. True or False: Under steady-state conditions, the pipe surface temperature is nearly equal to the temperature of the water flowing inside the pipe. Answer: ________
4. The thermal lag of strap-on temperature sensors is minimized when ___________________ is applied between the sensor and pipe surface.
5. _________________________ allow the quick, easy, and direct measurement of fluid temperature and pressure in a pressurized hydronic system.
6. When two water streams combine, __________ is the best place to install the immersion temperature sensor to get a fully mixed temperature.
    A. Just upstream of the mixing point
    B. Well downstream of the mixing point
    C. At the point of mixing
    D. None of the above

Chapter 22 - Humidity Transmitters (AI)

22.1 Description

Humidity transmitters provide a humidity reading in units of percent Relative Humidity (%RH), Wet-Bulb Temperature, or Dew Point Temperature. This information is used to control and monitor the humidity level in the spaces served by the air-handling unit. When the humidity level reaches an upper threshold, the dehumidification cycle is enabled to reduce the humidity level. Alternatively, when the humidity level drops to a lower threshold, humidification equipment is enabled. Spaces like museums, libraries, hospitals, manufacturing, and laboratories typically have strict humidity control requirements. Humidity transmitters sample the air with its moisture sensitive polymer sensor and produce an electrical signal that is proportional to the humidity level (0-100% RH). The humidity transmitter output signal is connected to an analog input of a BAS controller. This may be in the form of a direct current voltage (0-5 VDC or 0-10 VDC or other variation) or an amperage signal (4-20 mA). Suppose that we have a humidity transmitter rated for 0-100% RH that provides a proportional output signal that varies from 0-10 VDC. If the humidity transmitter produces analog output signals of 5 VDC, 7.5 VDC, and 10 VDC, then the BAS would interpret these analog input voltages as 50 %RH, 75 %RH, and 100 %RH, respectively.

Photo 277 - Combination Temperature Sensor and Humidity Transmitter

Photo 278 - Duct-Mounted Humidity Transmitter

Photo 279 - Outdoor Air Humidity Transmitter

The key to understanding humidity readings is the term “relative” and that the higher the air temperature, the more moisture the air can hold per cubic foot of air. Air at 50 %RH, contains 50% of the moisture that it can hold “relative” to air that is saturated or at 100% RH at the same temperature. When it rains, it is typically the result of a warm, moist air mass meeting a cold air mass. When the warm, moisture-laden air in the clouds has reduced in temperature to its saturation point (dew point) and is no longer able to hold the moisture in vapor form, it condenses, coalesces into larger droplets, and falls to the ground as rain, snow, or hail. This process is basically what a cooling coil does in an air conditioning system. It lowers the temperature of the warm, moist air passing through it until it reaches its saturation point (100% RH) and cannot hold the liquid in vapor form. At this point, water vapor begins to condense onto the cold surfaces of the coil tubes and fins thus requiring the drain pan to collect the condensate and conduct it away from the unit through the condensate drain piping. The air that exits the cooling coil is typically saturated (90-100 %RH) at the discharge air temperature (50°F-60°F).

According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55 – Thermal Environmental Conditions for Human Comfort, the optimum humidity level in occupied spaces is 40 %RH to 60 %RH. This recommendation has been adopted by the industry and applied such that spaces are controlled to maintain a maximum humidity level of 60 %RH during cooling operation and a minimum of 40 %RH during heating operation. Commercial buildings introduce outdoor air for ventilation and space pressurization to the spaces through the air-handling units. Air handling units with cooling capacity are inherently capable of providing dehumidification. It is a natural consequence of the cooling process. Cooling coils provide sensible and latent cooling capacity. The sensible portion of the coil capacity refers to the capacity to reduce the temperature of the air passing through it. The latent portion of the coil capacity refers to the capacity to reduce the humidity level of the air passing through it. When the cooling coil’s latent cooling capacity is higher than the latent load, humidity is controlled. The introduction of high humidity air into a cool space can facilitate excessive condensation on cold surfaces which can result in water damage, staining of ceiling tiles, mold, and bacteria growth. Low humidity levels during heating operation can cause increased static electricity and dryness during winter operation. Practicality and economy typically dictate the adoption of relaxed space humidity setpoints. Cooling-season dehumidification setpoints typically range from 50 %RH to 65 %RH and heating-season humidification setpoints range from 20 %RH to 40 %RH.

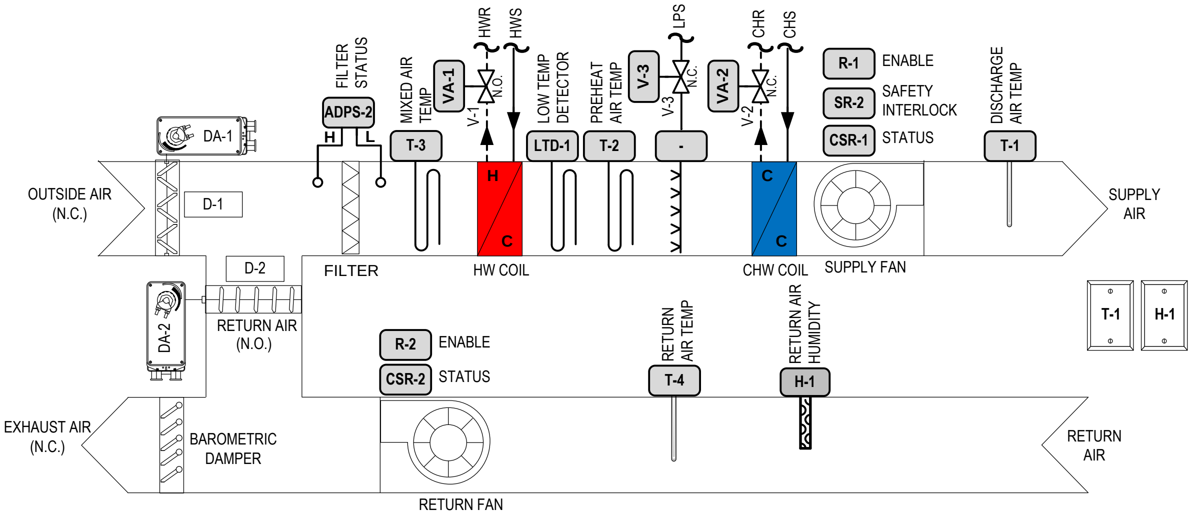


Figure 203 - Typical Air-Handling Unit with Steam Humidification

Humidity control is also very closely intertwined with building pressure control. After performing numerous building surveys and field testing to determine the cause of high humidity levels in various commercial building types, a common thread has surfaced - Negative building pressurization. Commercial buildings should be positively pressurized so that conditioned air leaks out of the building envelope as opposed to unconditioned air leaking in through the building envelope. Negative building pressurization is typically caused by insufficient outdoor air being introduced through its air-handling units to offset the air that is exhausted by its exhaust fans. In other cases, the air-handling units are controlled and monitored by the BAS, but the exhaust fans are not. When the air-handling units de-energize per their operating schedules, the exhaust fans continue to operate drawing unconditioned outdoor air into the building during the unoccupied period. When the air-handling units energize the following morning, they have to deal with a huge humidity load and the condensation of the humid air on cold surfaces. This can significantly impact the comfort and energy efficiency of any building. Kitchen exhaust fans should always be monitored and controlled by the BAS (or time clock). Controlling and monitoring building pressure is key to effective humidity control.

When high humidity issues are encountered, the typical initial reaction is to close the outdoor air dampers of the air-handling units in the hopes of reducing the influx of moisture. However, this only makes the issue worse because it increases the negative building pressurization which draws more unconditioned air into the building through its envelope. The key to resolving high humidity is to establish positive building pressure and increase the dehumidification capacity of the air-handling units. The typical solutions involve increasing outdoor airflow through the air-handling units, reducing exhaust airflow rates, increasing the cooling coil capacity (increased chilled water flow or refrigeration capacity), building envelope sealing, architectural changes (vestibule installations), controlling exhaust fan schedules or making them intermittent, installation of reheat coils, and controls (sensors and sequences of operation) modifications. In older existing buildings, the outdoor and exhaust airflow rates were determined by design criteria observed at the time of the original design and construction. Current outdoor airflow and exhaust airflow requirements have been reduced which provides an opportunity to lower the outdoor air and exhaust airflow rates required to establish and maintain positive building pressurization.

When humidification is required, a steam generating unit is utilized to add moisture to the building air through the air-handling unit and duct distribution system. Air-handling units make great locations for humidification equipment because it is typically located in a mechanical room and the air-handling unit operation enhances absorption of the injected water vapor. Downstream coils are often used to mixed the air and assist in the absorption of the water vapor into the airstream. In addition, any condensate that forms is easily disposed of by the existing condensate drain pans and piping. Duct-mounted humidification units may be used to humidify the supply air downstream of the air-handling unit. These designs incorporate sloped stainless steel ductwork designs that collect condensate that may form downstream of the injection point. In some applications, the moisture is directly delivered to the space through atomizing nozzles which are supplied with high-pressure purified water.

In normal space temperature conditioning, air-handling units heat the air that is delivered to the spaces with heating coils to maintain the space temperature at the heating setpoint. Likewise, air-handling units cool the air that is delivered to the spaces with cooling coils to maintain the space temperature at the cooling setpoint. During the cooling season, there are times when the space humidity exceeds the dehumidification setpoint. This reading may be based on return air or space conditions. Dedicated Outdoor Air-Systems (DOAS) and Heat/Energy Recovery Ventilators (HRV/ERV) may use the humidity reading (expressed as Wet-Bulb or Dew Point Temperature) of the incoming outdoor air as it discharges the energy exchanger (cross-flow or wheel) to enable the dehumidification mode. Once enabled, the dehumidification cycle requires an override of the normal cooling control strategy which reduces or disables the cooling capacity once the space temperature is reduced to setpoint. Continued cooling operation is required in order to reduce the moisture content of the circulated air. At the same time, reheat coil capacity is required to maintain the space or discharge air temperature at setpoint. Without reheat capacity, the spaces would sub-cool from the extended cooling operation. Additional coils and higher horsepower fans are required to implement dehumidification. As a result, dehumidification equipment and operating costs are higher.

System design is critical to the control of humidity. Humidity control is not possible without simultaneous cooling and reheating of the supply air. The cooling coil reduces the temperature and moisture content of the air passing through it and the reheating coil capacity is modulated to maintain the space temperature at either the heating or cooling setpoint (depending on the programming). Therefore, the need for dehumidification must be carefully considered to ensure that the appropriate air-handling unit components are selected and installed. The following diagram shows a typical air-handling unit that is equipped to provide dehumidification. If the air-handling unit was not originally selected to provide dehumidification (no reheat coil), it is much more expensive to modify the air-handling unit and/or its ductwork later to provide it. This will typically require the addition of reheat coils downstream of the air-handling unit to provide the reheat capacity required to provide space temperature control when extended cooling operation is required for dehumidification. It will also require controls modifications to control the heating and cooling capacities. The preheat coil only provides heating of the mixed air up to a minimum preheat temperature setpoint when required. It contributes nothing to the dehumidification process.

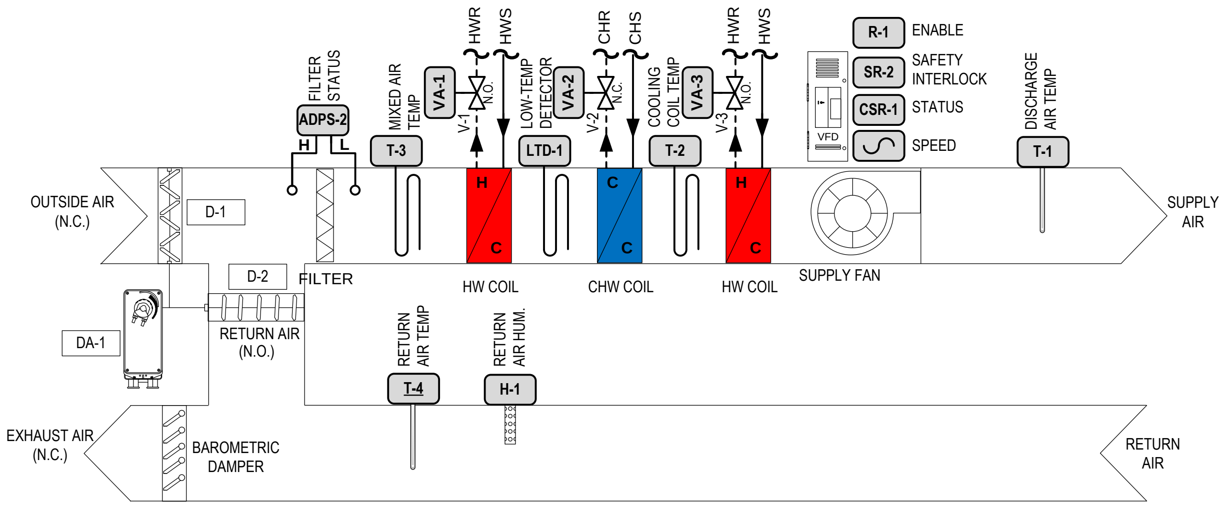


Figure 204 - Typical Dehumidification Air-Handling Unit

System sizing is critical to the control of space temperature and humidity. There is a natural tendency to oversize equipment, but humidity control is a facet of air-conditioning design where caution must be exercised. This is especially true of direct-expansion air-handling units where the cooling capacity cannot be modulated or insufficient cooling stages are provided. Moisture content in the air is only reduced while the cooling coil is actively chilling the air. Oversized air conditioning systems quickly drop the space temperature to setpoint, but when the space temperature is satisfied the cooling capacity is disabled or significantly reduced. When this occurs, the ability to reduce the moisture level also reduces or stops all together and this can lead to cool, but very humid space conditions. It is better in most cases to have an air-handling unit whose cooling capacity is undersized rather than oversized to provide good humidity control. If an air-handling unit has been oversized, the first option may be to reduce its cooling capacity. In addition, the addition of reheat capacity, humidity sensor, and the controls to manage the new configuration should be considered.

How the Heating, Ventilation, and Air Conditioning (HVAC) system is operated is equally important to the control of temperature and humidity. Systems capable of dehumidification require the year-round availability of reheat capacity (hot water or electric resistance coils) to provide the required reheat capacity. Air-handling units equipped with cooling and hot water reheat coils and air-handling units with cooling capacity that supply pre-conditioned air to reheat coils or pressure-independent terminal units with hot-water reheat coils are capable of providing dehumidification. However, there are many locations with four-pipe systems where the operating staff has adopted the policy of disabling the boiler plant when the weather warms and cooling capacity is enabled. Zones served by reheat coils and Constant-Air-Volume (CAV) pressure-independent terminal units are subcooled first because the supply airflow cannot be reduced. As the cooling load reduces in the spaces served by Variable-Air-Volume (VAV) terminal units, their supply airflow reduces to the minimum airflow setpoint. If this airflow rate still provides more cooling capacity than is needed by the space, the space temperature will continue to drop. If there is no hot water to provide reheat capacity, very low space temperatures and high humidity levels will make it uncomfortable for the occupants. This is a typical scenario for spaces that are not continuously occupied (conference rooms, classrooms, auditoriums, cafeterias, gymnasiums, etc.) or loaded (people, plug loads, lights, ventilation, equipment, etc.). Continued operation of the boiler plant is not only required for humidity control, but also for space temperature control during low cooling load conditions.

Humidity transmitters may come as an individual unit or they may be combined with other sensors. Combination temperature, humidity, and carbon dioxide transmitters are commonly used in BAS installations. If a combination unit is utilized, the sensor location guidelines associated with each sensor type should be followed to ensure that all sensors report correctly. While the combined sensor units save wall space, reduce installation costs, and avoid wall clutter, they cost more to replace. In addition, if one of the sensors fails, then the entire unit must be replaced because the individual sensor components are typically not replaceable.

22.1.1 Space Humidity Transmitters:

Wall-mounted humidity transmitters sample the air in the conditioned space to provide the BAS with an indication of the humidity level. Depending on this space humidity reading, the programmed control logic will typically require dehumidification when the humidity level reaches a maximum threshold, humidification when the humidity level reaches a minimum threshold, and neither when the humidity is between the maximum and minimum thresholds. Auditoriums, museums, hospitals, pools, cafeterias, libraries, and other high occupancy spaces are examples of areas where it is important to monitor and control the humidity level.

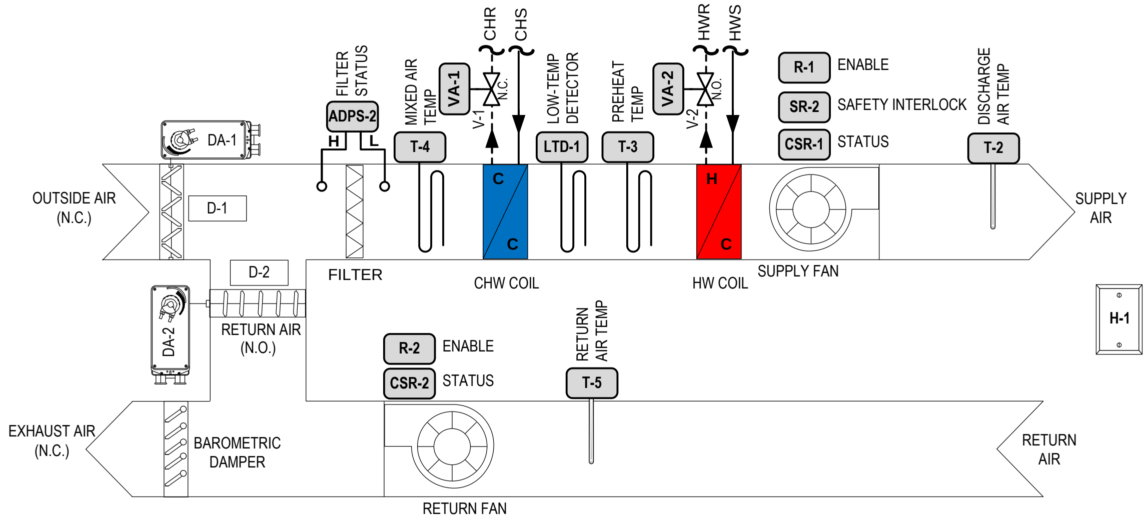


Figure 205 - Typical Dehumidification Air-Handling Unit (no Preheat Coil)

Space humidity transmitters are typically wall-mounted which requires that the wires pass through the wall cavity from the ceiling down to the mounting height in the wall. The typical mounting height for room sensors (temperature, humidity, carbon dioxide, etc.) is 48-54 inches from the finished floor, but this can vary. Depending on the installation requirements of the project, the humidity transmitter wires may or may not be installed within an electrical conduit. In addition, depending on the wiring and mounting requirements, there may or may not be an electrical junction box behind it. In some cases, the conduits are mounted on the surface of the wall. This is typically done when the BAS is installed as a retrofit after the initial building construction.

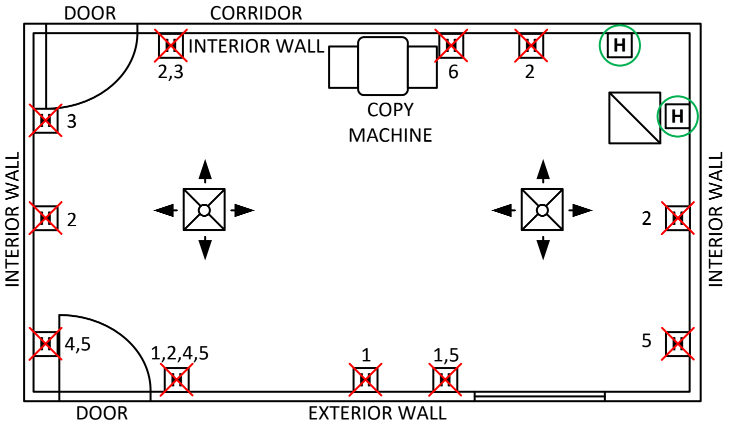


Figure 206 - Wall-Mounted Space Humidity Transmitter Locations

The optimum location of a typical wall-mounted humidity transmitter is below, above, or adjacent to the room's return air device. However, this is based on the return air devices being properly located and the supply air diffusers being properly selected and located to provide complete mixing of the room air to minimize stagnant areas and temperature stratification. After the supply air has been introduced to the room through the supply air devices (diffusers, registers, and grills), it absorbs the heat and moisture in the room and it returns to the air-handling unit through the return air duct system. The return air is typically representative of the room's average humidity condition. It is often difficult to determine the best location for space humidity transmitters. The following locations are to be avoided, if possible:

1. **Perimeter walls**. Generally, wall-mounted space humidity transmitters should not be installed on perimeter walls. Direct sunlight can also heat the walls from the outside. Brick, block, and concrete walls absorb the sun's radiant energy and transfer this heat to the inside of the building enclosure for several hours. Heat loss and gains through walls and windows can cause false space humidity readings by skewing the temperature upon which the humidity reading is based. In cooling mode, the humidity reading will be lower than the actual. In heating mode, the humidity reading will be higher than the actual. This can result in humid environmental conditions during the cooling season and low humidity levels during the heating season. If the perimeter wall is the only available location to install a space humidity transmitter, be sure that it is installed on an insulated base to minimize the influence of the exterior wall and that the wall penetration and junction box are sealed with spray foam to prevent air leakage through it caused by space pressure differentials.

2. **Within the influence of supply airstreams**. When the supply air is discharged from the ceiling-mounted supply air diffuser, it hugs the ceiling until it encounters the wall. The high velocity supply air causes a low-pressure zone next at the ceiling which maintains the airstream at the ceiling level. This is called the Coanda Effect. The airstream reaches the wall and then proceeds down the wall and may flow over the space humidity transmitter if it has been installed in its path. This causes the BAS controller to sense a false room humidity level which can also affect humidity control. If chilled supply air is discharged in the direction of a wall-mounted humidity transmitter during the cooling season it will make the space humidity transmitter read higher humidity levels than actual room conditions. If heated supply air is discharged in the direction of a wall-mounted humidity transmitter during the heating season it will make the space humidity transmitter read lower humidity levels than actual room conditions.

3. **Near interior doorways**. When wall-mounted space humidity transmitters are located near interior doorways they are subject to the influence of the adjacent space (typically a corridor). This influence tends to slow or retard the sensing of the true condition of the room in which it was meant to monitor. This is especially true when the door is typically kept open and the perimeter walls and windows are remotely located from the wall-mounted space humidity transmitter. The humidity level at the interior of the room can be quite different from the environment sensed by the space humidity transmitter when it is located by an open interior doorway.

4. **Near exterior doorways**. When wall-mounted space humidity transmitters are located near the exterior doorways they are subject to the influence of the outside air conditions as the door is repeatedly opened and closed. This tends to exaggerate the space's true condition toward that of the outside condition. If the outside air humidity is lower than the desired room humidity, then the space humidity will appear to be lower than the actual room condition. Likewise, if the outdoor air humidity is higher than the desired room humidity, then the space humidity will appear to be higher than actual room conditions. Even if the doors are kept closed, they negatively impact the humidity transmitter

reading because the doors are typically constructed of materials that have higher heat loss and gains than the adjacent walls as well as the air leakage through them. The wall-mounted space humidity transmitters should be located towards the interior of the space and close to the room return air device.

5. **Near walls and floors subject to direct sunlight**. Direct sunlight on interior surfaces (walls and floors) and objects can quickly absorb heat and then radiate it into the space. If the wall-mounted space humidity transmitter is installed in areas heated by direct sunlight, the resulting relative humidity readings will be lower than actual because the sensed temperature will be higher than the actual room temperature. Wall-mounted space humidity transmitters should be located towards the interior of the room away from solar influences to maximize the accuracy of the humidity readings.
6. **Near sources of heat.** When the wall-mounted space humidity transmitters are located during the design phase, the engineers often have little to no idea where the heat-producing equipment (copy machines, printers, ice machines, computers, refrigerators, coolers, etc.) will be located. However, if heat-producing equipment has been indicated in the architectural plan, then these locations should be avoided because of the effect that they have on the space humidity reading. Heat sources increase the local air temperature causing the humidity reading to be lower than the actual room humidity level.

22.1.2 Duct-Mounted Humidity Transmitters:

Duct-mounted humidity transmitters indicate the humidity level within a duct or air-handling unit. Duct-mounted humidity transmitters are typically installed in return ducts to monitor and control the need for the space humidification and dehumidification cycles. Heat recovery units, energy recovery ventilators, as well as Dedicated Outdoor Air Supply (DOAS) units have opposing airstreams which permit the installation of a humidity transmitter in one compartment to monitor the conditions in the adjacent compartment.

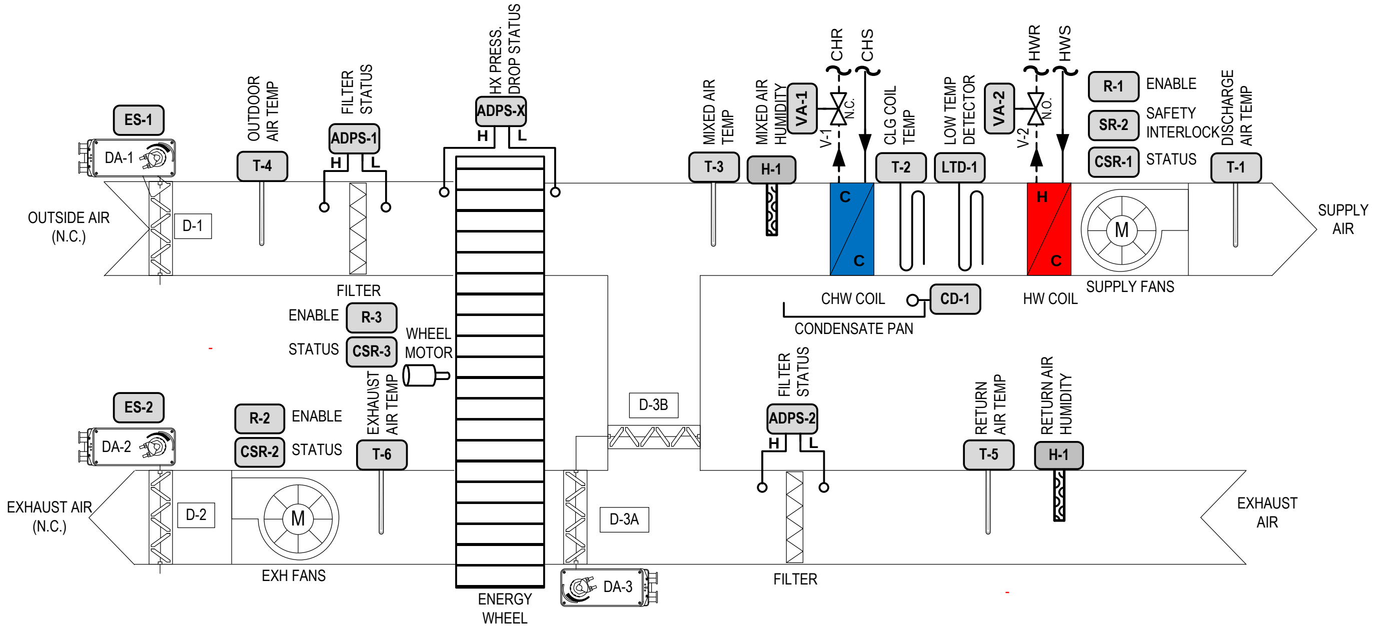


Figure 207 - Typical Energy Recovery Ventilator

If airstreams combine and monitoring of the mixed air is required, the most accurate results are provided if the humidity transmitter is installed well downstream of the point at which they combine. If the humidity transmitter is installed too close to the mixing point, then the humidity level read by the humidity transmitter can vary significantly from the fully mixed condition. If a duct-mounted humidity transmitter is installed to monitor the humidity level downstream of a humidifier, it also should be installed well downstream of the humidifier to give the air time to absorb the moisture and fully mix. This distance is typically 10-30 feet downstream of the humidifier depending on its output and velocity of the air. This information is typically used to control and monitor the humidity level in the duct or to limit the humidifier output to a specific level.

22.1.3 Outdoor Air Humidity Transmitters:

Outdoor air humidity transmitters indicate the humidity level of the outdoor air. This information, in combination with the outdoor air temperature sensor, is used to implement economizer, humidity control sequences, and cooling tower control strategies. Like temperature sensors, the outdoor air humidity transmitters should not be installed in areas subject to direct sunlight. A review of a psychrometric chart indicates that moist air that has been heated by surrounding surfaces under direct sunlight will have a higher temperature, but the same moisture content. As a result, the indicated relative humidity will be lower. This is the reason that most designs require that the outdoor air temperature sensors be installed on a northern exposure of the building where sunlight cannot reach.

Outdoor air humidity transmitters should not be installed in areas where exhaust air from exhaust fans or relief air from air-handling units may flow over it. During economizer operation, up to 100% of the return air can be exhausted. In addition, humidity transmitters should never be installed near cooling towers because the air that is discharged from them is laden with moisture. Depending on the direction of the prevailing wind, this moist air can be carried over the outdoor air humidity transmitter drastically affecting its reading.

Outdoor air humidity transmitters typically require more frequent testing and calibration because they experience a wider variation in humidity levels. They see 100 %RH while it rains and when humidity transmitters operate at the extremes of its sensor range, they tend to degrade at a faster rate than the return duct or space mounted units. The humidity transmitter must be checked at two humidity levels that are sufficiently apart. This means that calibration readings may be required at two different time of the day. When humidity transmitters are checked, the signal (voltage or milliamps) needs to be measured and compared to the amperage calculated by the programmed characteristic curve based on the reference humidity readings. Comparing the BAS reading against the reference instrument reading will not provide the data required to verify that the humidity transmitter is functioning correctly and providing an accurate reading.

22.2 Applications

1. **Humidity Monitoring and Control.** Humidity transmitters are often installed to monitor and control the humidity level of the space, return duct, and outdoor air to determine the need for the Dehumidification and Humidification cycles in air-handling units. Some dehumidification cycles use wet-bulb temperature or dew point temperatures to determine the need for dehumidification. These values are easily calculated once air temperature and relative humidity readings are acquired.

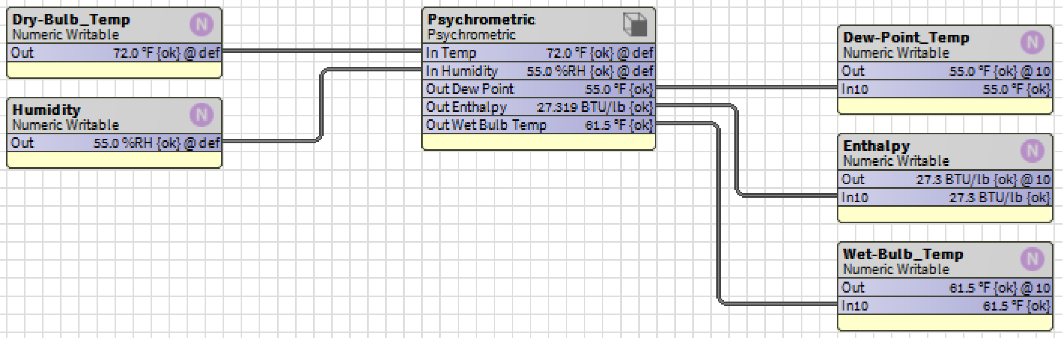


Figure 208 - Psychrometric Calculations from Temperature and Humidity Readings

2. **Comparative Enthalpy Economizer**. Humidity transmitters are utilized to implement the comparative enthalpy economizer cycle which is a form of free cooling provided by the air-handling units. Humidity and temperature readings are used to calculate enthalpy. When the outdoor air enthalpy is less than the return air enthalpy by a minimum threshold, the economizer cycle is enabled. Once enabled, the air-handling unit dampers (OA, RA, and EA) are modulated to maintain the supply air (or space temperature) temperature at setpoint. When the enthalpy of the outdoor air is no longer below that of the return air, the comparative enthalpy economizer cycle is disabled.

3. **Condenser Water Supply Temperature Reset**. Cooling towers are typically controlled to maintain a fixed condenser water supply temperature of 80°F -85°F. Outdoor air humidity (%RH) and dry-bulb temperature are used to calculate the outdoor air wet-bulb temperature. Wet-bulb temperature is used to implement the Condenser Water Supply Temperature Reset control strategy. The cooling tower fan speed is cycled (if not equipped with a VFD) or modulated to maintain the condenser water supply temperature at setpoint. The setpoint is typically maintained at 7°F (Adjustable) above the ambient wet-bulb temperature and above the equipment's (chiller, water-source heat pump, etc.) minimum condenser water supply temperature. This control strategy generates compressor energy savings because the efficiency of water-cooled chillers and water source heat pumps increases as the condenser water supply temperature is reduced. The additional horsepower expended by the cooling tower fan motors to reduce the condenser water supply temperature is significantly overshadowed by the chiller and water-source heat pump

compressor power savings.

22.3 Typical Control Wiring

Explanations of the various wiring strategies have been provided in Chapter 3: BAS Inputs and Outputs. To avoid unnecessary repetition of the typical transmitter wiring diagrams, the following table has been provided. Depending on the installation requirements and the preference of the installing Controls Contractor, the wiring strategies implemented can go in several directions.

Analog Input Device Signal	BAS Input Signal	Signal Wiring Configuration
4-20 mA	4-20 mA	Loop-Powered (Two-Wire) Transmitter
4-20 mA	2-10 VDC	Loop-Powered w/ 500 Ohm Resistor
4-20 mA	1-5 VDC	Loop-Powered w/ 250 Ohm Resistor
4-20 mA	4-20 mA	Three-Wire Transmitter
0-10 VDC	0-10 VDC	Three-Wire Transmitter
2-10 VDC	2-10 VDC	Three-Wire Transmitter

Table 80 - Possible Analog Input Wiring Strategies

22.4 Analog Input Testing and Verification

The general test procedures for Humidity Transmitters include the following:

1. Verify that the humidity transmitter has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The operating range, mounting, color, output contacts, wiring, accuracy requirements, and output signals are some of the features that should be verified.
2. Verify that the humidity transmitter has been installed at the correct or optimum location. If a combination unit is installed, then the sensor placement recommendations of all included sensors should be observed.
3. Verify that the humidity transmitter has been installed per the manufacturer's installation recommendations. Also verify and document all adjustable dip switches, selector switches, dial settings, and jumper settings to ensure the correct signal and range are generated.
4. As applicable, posture the HVAC system or the required components (damper, control valves, fans, VFD speeds, etc.) to prevent unwanted system changes (modulation, staging, cycling) during the humidity transmitter calibration.
5. Verify that the humidity transmitter has been correctly wired. Humidity transmitters are typically connected to the BAS controller analog input by either the two-wire or three-wire configuration. Refer to Chapter 3: BAS Inputs and Outputs for detailed information of the possible wiring configurations. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify that the humidity transmitter is connected to the correct BAS controller analog input. Disconnect the wire conducting the signal or disconnect the 24 VAC wires that power the humidity transmitter. This causes the humidity data point reading to change. It is a good idea to make a note or take a screenshot of the data point reading that occurs when the analog input device is disconnected.
7. At the same time that the humidity transmitter's electrical contacts are opened, verify and document that the data point bound to the BAS graphics also changes.
8. Verify that the humidity transmitter and its wires at the BAS controller end have been labeled.
9. Verify that the units/facets are correctly displayed. The facets for humidity are typically %RH.
10. Verify that the precision of the humidity transmitter reading is appropriately set. Humidity setpoints are typically whole numbers and the precision of humidity transmitter readings is typically no more than one decimal place for most commercial applications.
11. Verify that the BAS controller's analog input point configuration matches the humidity transmitter sensor range and output signal. In this example, a 0%-100% RH humidity transmitter produces an output signal that ranges from 4-20 mA. With the use of a 250 or 500 Ohm resistor across the analog input terminals of the BAS controller, the current signal from the current transmitter is converted to a 1-5 VDC or 2-10 VDC voltage signal, respectively.

Reading	Humidity (% R.H.)	Transmitter Signal (DCV)
Minimum	0	2
Maximum	100	10

Table 81 - Transmitter/BAS Controller Configuration

If the analog input configuration of the BAS controller is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs. The scale and offset values are used to calculate the humidity (%RH) reading from the voltage signal provided by the humidity transmitter. These values will be updated based on calibration readings as explained in later steps.

Volts (DCV)	% RH
2	0
10	100

Calculated Scale= 12.50
Calculated Offset= -25.00

Table 82 - Initial Scale-Offset Calculation

12. Verify the accuracy of the humidity transmitter reading by comparison with reference readings from a calibrated humidity meter. At each calibration point, record the BAS controller reading, humidity meter reading, and the signal generated by the humidity transmitter. Humidity is a parameter that cannot be field simulated (like pressure), but two calibration points can be attained with a little creativity and patience. If the humidity transmitter does not produce the appropriate output signal or does not report across its full range, then it should be calibrated by modifying its zero and span adjustments. If accurate calibration results cannot be attained, then it should be replaced. Single-point calibrations are not recommended because they will not produce the required information to calibrate transmitter readings. Refer to Chapter 2: BAS Calibration and Chapter 3: BAS Inputs and Outputs for more information.

Reading	Test/Instrument (% R.H.)	BAS Data Point (% R.H.)	Signal (DCV)
1	43.7	44.3	5.54
2	58.3	56.8	6.54

Table 83 - Initial Transmitter/BAS Calibration Check

13. Update the configuration of the analog input of the BAS controller and retest to confirm the calibration of the humidity transmitter. The calibration range does not match the sensor range, so the %RH at the maximum and minimum voltages must be calculated based on the test data. Refer to Chapter 3: BAS Inputs and Outputs for details. If the humidity transmitter readings still appear to be inaccurate or it does not provide readings across its full range, then replacement is recommended. Record the final analog input calibration and correction factors.

Reading	Signal (DCV)	Humidity (% R.H.)
Minimum	2	-7.98
Maximum	10	108.82

Table 84 - Updated BAS Controller Configuration

If scale and offset factors are used to configure the parameters of the BAS controller analog input, update them accordingly using the same methodology explained in Chapter 3: BAS Inputs and Outputs. Confirm the accuracy of the analog input configuration by comparing the humidity reading to a reference instrument.

Volts (DCV)	% RH
5.54	43.7
6.54	58.3

Updated Calculated Scale= 14.60
Updated Calculated Offset= -37.18

Table 85 - Updated Scale-Offset Calculations

14. Release all overrides used to posture the system for testing and calibration.
15. Review the trend data to verify that the humidity transmitter reliably and consistently reports to the BAS controller. Numeric interval trend extensions are used to collect trend data at the programmed time intervals. Initial trend data intervals should be short (5 seconds-5 minutes) intervals to allow transient issues (that cannot be identified with longer intervals) to be identified. Once the testing and commissioning stage has concluded, longer time intervals (10-20 minutes) can be used to minimize data storage requirements. There should not be any gaps or omissions in the trend data. The trend data should show that the humidity transmitter corresponds with the programmed control logic and schedule.
16. Document the results of all testing. Screenshots of the analog input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the humidity transmitter.

22.5 Review

1. Humidity transmitters should not be installed near any walls or floor surfaces subject to direct _______________.

2. True or False: If the air in the area of a humidity transmitter is heated, then the indicated %RH will be higher than the actual. Answer: ________
3. If the maximum and minimum humidity signals produced by a humidity transmitter are 2 VDC and 10 VDC, respectively, what are the Scale and Offset values if the humidity range is 0 %RH to 100 %RH?

   Scale: ________________ Offset: ________________
4. Per ASHRAE Standard 55 – Thermal Environmental Conditions for Human Comfort, the optimum humidity level in occupied spaces is between ________%RH and ________%RH.

22.6 References

1. American Society of Heating, Refrigeration, and Air Conditioning Engineers. 2020. Standard 55: Thermal Environmental Conditions for Human Occupancy.
2. Wulfinghoff, Donald R. 1999. Energy Efficiency Manual. Energy Institute Press.
3. https://www.vaisala.com/en/products/instruments-sensors-and-other-measurement-devices/instruments-industrial-measurements/humidity-normal-or-wet-conditions
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5. https://productcatalog.honeywellhome.com/europe/pdf/en-63-1389-as01r0414.pdf
6. https://www.trane.com/content/dam/Trane/Commercial/global/products-systems/education-training/engineers-newsletters/airside-design/admapn003en_0502.pdf
7. https://www.csemag.com/articles/best-practices-for-infiltration-and-building-pressurization/

Chapter 23 - Current Transmitters (AI)

23.1 Description

Current Transmitters, commonly called CTs, provide an indication of the current flow measured in Amps in the conductors powering the pump, fan, and compressor motors as well as electric resistance heat units. A CT is simply a metal core that produces an analog current or voltage signal that is proportional to the sensed flow of current through the monitored conductor. Current readings are used to monitor the load or output of operating electrical equipment because current is typically proportional to the load. The term "CT" is often incorrectly used interchangeably with CSRs. CSRs or Current Sensing Relays (Chapter 11: Current Sensing Relay) provide a binary signal in the form of status contact closure when the operating current exceeds a minimum threshold and are used to determine the operating status of electrical loads (fans, pumps, compressors, electric resistance heat). CTs produce an analog signal that is monitored by an analog input of a BAS controller. This device is ideally suited to monitoring the electrical load on a system. If the monitoring of operating status is required, the use of CSRs, ADPSs, or HDPSs is recommended.

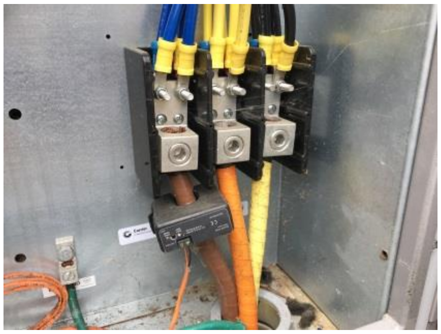
Photo 280 - Current Transmitter Installed on an Air-Cooled Chiller

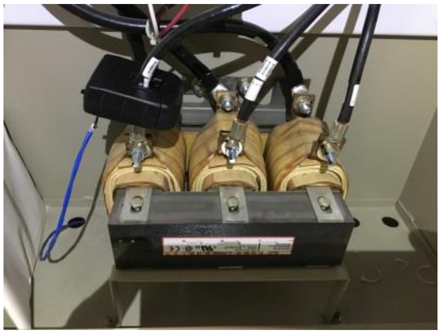
Photo 281 - Current Transmitter Installed on a Water-Cooled Chiller


Photo 282 - Current Transmitter Installed in an Air-Handling Unit VFD

CTs are constructed with either a split-core or solid core. Solid core current transducers require that the electrical conductor be installed through the core before mounting. This means that the conductor must be removed from their wire terminals, inserted through the solid core, and then reinstalled. This is not required for split-core current transmitters. The split-core jaws are opened, the conductor placed in the core, and then it is closed. Split-core current transmitters can be installed any time after the installation of the electrical system (disconnect switch, motor starter, VFD enclosure, etc.) without removing electrical conductors. This is why the split-core current transmitters are more commonly utilized.

CTs come in two main types – Self-powered and Loop-powered. Self-powered units do not require external power. A pair of wires from an analog input of a BAS controller is connected directly to the self-powered CT contacts. The voltage output is induced from the current transmitter's core that is proportional to the current flowing through it. Loop-powered CTs provide the same proportional output signal, but it requires a direct current power source (typically 24 VDC) to generate the 4-20 milliamp signal.

A current transmitter is installed on a conductor that powers the single-phase and three-phase loads such as pumps, fans, compressors, or electric resistance heaters. At least one CT is required to monitor both single-phase and three-phase loads because the current flow through each conductor is assumed to be balanced. CTs should not be installed before or upstream of the manual disconnect switch because the electrical potential cannot be safely disabled for the safe installation without locking out and tagging out the main breaker supplying this combination motor starter or motor control center bucket.

The rating of the current transmitter should be no larger than twice the normal operating current of the monitored electrical load. If you know the Run Load Amps (RLA) or Full Load Amps (FLA) of the electrical load, this can be used to select the rating of the current transmitter. If the current transmitter's rating is lower than the load's normal operating current, then the resultant current reading will be maxed out. If the current transmitter's amperage rating is several times higher than the load's normal operating current, then the indicated current flow may be at the bottom of the operating range and will not provide adequate signal resolution. Adding loops around the current transmitter core can increase the current reading if a current transmitter capacity is too high. However, having a CT with the correct transmitter rating is preferred.

If a current transmitter has multiple current ranges, then the lowest setting that encompasses the normal operating current should be selected and BAS analog input configuration appropriately adjusted. If the normal operating current is 42 Amps, selecting the 50 Amp range will provide better performance and resolution than if the 100 Amp or 200 Amp options were selected.

Current transmitters come in two main types: True RMS and Average-Responding. RMS stands for Root Mean Square. Average-Responding transmitters are ideal for pure sinusoidal waveforms but are not suited to nonlinear, non-sinusoidal, and distorted waveforms (like that found downstream of variable frequency drives). Therefore, this type of current transmitter would only be used on the line side of VFDs and ECMs (Electronically Commutated Motors). The true RMS current transmitter can be used anywhere in the electrical circuit because it is suited to all waveform types. The Average-Responding current transmitters are the lower cost option between the two. True RMS current transmitters typically have prominent labeling indicating they are the true RMS type. If there is no notation indicting that the current transmitter is true RMS type, it is most likely the average responding type. It is a good practice to verify the current transmitter type that has been installed to ensure that it is appropriately located. When an average responding current transmitter tested and calibrated with a true RMS clamp meter, there will be differences in the current reading if the current transmitter is located on the load side of a VFD or similar device.

Constant Speed Loads

Constant speed loads are typically controlled by relay, contactors, and motor starters. Current transmitters used for constant speed loads are typically installed anywhere inside the disconnect switch, combination motor starter disconnect switch, or motor control center bucket that it can fit. In some cases, the current transmitter must be installed in junction boxes or wire troughs because there is no room or enough slack in the wires to install it in the motor control center bucket or combination motor starter/disconnect switch enclosure. No matter where the CT is located in constant-speed power controls, the current reading through the same conductor will be the same.

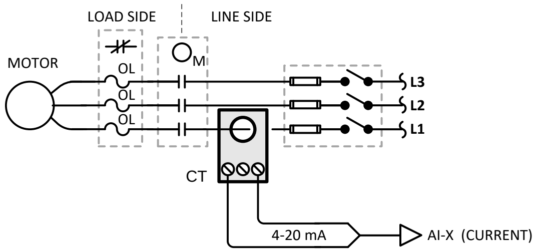

Figure 209 - Line-Side Current Transmitter Installation

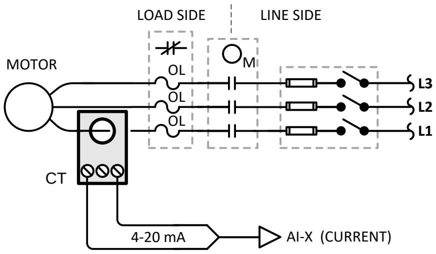

Figure 210 - Load-Side Current Transmitter Installation

To determine the operating status of the load and detect the failure of a belt or coupling, the BAS controller would be programmed to indicate a failed fan or pump when the current flow falls below 75% to 90% of motor current at actual operating conditions (not full-load amps). Therefore, a current reading with a calibrated clamp meter is required. When the fan belt or pump coupling fails, the motor current drops to the No-Load current level. As long as the current threshold or setpoint of the CT is above the No-Load current flow and below the normal current flow, then detection of both the motor operation and the load (fan or pump) operating status is possible. However, if the current threshold of the CT is below the No-Load current flow, it will be able to detect motor operation, but will not be able to detect belt/coupling failure.

Variable Speed Loads with VFDs

Motors that serve variable volume fans and pumps are typically driven by VFDs. When CTs are installed on motors equipped with VFDs, careful consideration is required because its location relative to the VFD significantly affects the current readings. When current transmitters are installed on the line side before of the VFD, the voltage and frequency are constant throughout its operating range while the current varies proportionally with the load/speed of the driven motor. When current transmitters are installed on the load side of the VFD (between the VFD and the motor), the voltage, current, as well as frequency vary as the load/speed command changes.

The VFD takes the incoming 60 Hertz alternating current and converts it to direct current with rectifiers. It then uses inverters to convert the direct current into a simulated alternating current whose voltage, amperage, and frequency vary to meet the speed command from the BAS. When CTs are used to monitor the operating status of a compressor, fan, or pump driven by VFDs, we must be especially cognizant of its location. We must also be aware of how VFDs function, so that the correct CT is selected and is properly located to provide the required status indications. On the line-side (upstream) of the VFD, voltage and frequency remain constant while the current varies proportionally with changes in load/operating speed in a very predictable fashion. This makes the line side of the VFD an ideal place to monitor the electrical load where it is reported as a percentage of the rated FLA or RLA. This value provides a quick and easily understood assessment of the equipment load. If the CT is used for operating status monitoring, then the CT can be installed on either the load side or line side of the VFD.

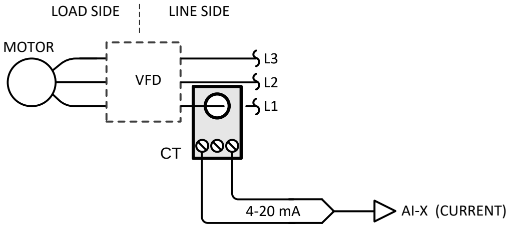

Figure 211 - Line-Side Current Transmitter Installation

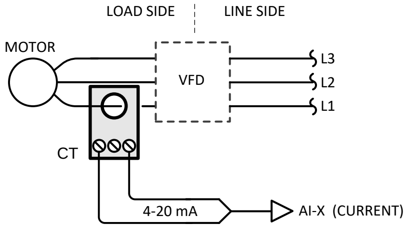

Figure 212 - Load-Side Current Transmitter Installation

On the load-side (downstream) of the VFD, voltage, frequency, and current are changing due to the operation of the VFD. The voltage supplied to the motor is proportional to the operating speed. The current flow is inversely proportional to the voltage at a given power output. Therefore, current is not proportional to the load/operating speed on the load-side of the VFD. Therefore, the use of CTs on the load side of VFDs would be more applicable to operating status monitoring than load monitoring. The following table summarizes the characteristics of the voltage, frequency, and current signals on the line-side and load-side of motor starters and VFDs.

Parameter	Motor starter		VFD	
	Line-Side	Load-Side	Line-Side	Load-Side
Voltage (VAC)	Constant	Constant	Constant	Varies with Load
Frequency (Hertz)	Constant	Constant	Constant	Varies with Load
Current (Amps)	Varies with Load	Varies with Load	Varies with Load	Varies with Voltage

Table 86 - Line-Side/Load-Side Characteristics of Motor starters and VFDs

23.2 Application

1. **Operating Status Monitoring**. Although CTs may be used for operating status monitoring (On/Off, Running/Off, Enabled/Disabled, etc.), the use of other binary input devices such as CSRs, ADPSs, and HDPSs is highly recommended. Using an analog device to provide a binary status indication is not an effective use of DDC resources. Monitoring the status of constant-speed equipment is fairly easy, but monitoring the operating status of variable-speed equipment with CTs can quickly become complicated and unreliable.

2. **Load Monitoring**. Current transmitters are used to determine the operating capacity or output of electrical loads. The capacity or output of most electrical loads is proportional to the current flow. By monitoring current flow, the output capacity of electrically driven equipment can be monitored and/or controlled. Electric utilities utilize current transmitters to monitor electrical loads on generators, transformers, and connected buildings to know when current flows are approaching critical levels. In commercial buildings controlled by a BAS, we are interested in monitoring the output capacity of equipment such as chillers, pumps, fans, electric resistance heat, refrigeration circuits, lighting, etc. as a percentage of the maximum current. Motor nameplates typically have a Full Load Amp (FLA) or Run Load Amps (RLA) ratings which indicate the amperage when fully loaded. By monitoring the electrical current load on equipment, better decisions can be made to increase efficiency, safety, comfort, and equipment life.

23.3 Typical Control Wiring

Explanations of the various wiring strategies have been provided in Chapter 3: BAS Inputs and Outputs. To avoid unnecessary repetition of the typical transmitter wiring diagrams, the following table has been provided. Depending on the installation requirements and the preference of the installing Controls Contractor, the wiring strategies implemented can go in several directions.

Analog Input Device Signal	BAS Input Signal	Signal Wiring Configuration
4-20 mA	4-20 mA	Loop-Powered (Two-Wire) Transmitter
4-20 mA	2-10 VDC	Loop-Powered w/ 500 Ohm Resistor
4-20 mA	1-5 VDC	Loop-Powered w/ 250 Ohm Resistor
4-20 mA	4-20 mA	Three-Wire Transmitter

Analog Input Device Signal	BAS Input Signal	Signal Wiring Configuration
0-10 VDC	0-10 VDC	Three-Wire Transmitter
2-10 VDC	2-10 VDC	Three-Wire Transmitter

Table 87 - Possible Analog Input Wiring Strategies

23.4 Analog Input Testing and Verification

Testing and verification of current transmitters may pose an electrical hazard because of the potential exposure to high-voltage (120 VAC and higher) electrical conductors. De-energize the electrical power whenever possible. Use the appropriate personal protective equipment to ensure your safety and those around you when access to live electrical enclosures is required.

The general test procedures for Current Transmitters include the following:

1. Verify that the current transmitter has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The current range, mounting, True RMS or Average Responding RMS, output contacts, wiring, manufacturer, solid/split-core, loop-powered/self-powered, and output signals are some of the features that should be verified.
2. Verify that the current transmitter has been installed at the correct or optimum location. This is especially important when current transmitters are installed at VFDs. The current readings can vary substantially depending on whether the current transmitter is installed on the line side or load side of the VFD.
3. Verify that the current transmitter has been installed per the manufacturer's installation recommendations. If split-core current transmitters are used, verify that the two halves are fully closed. The CT will not produce the induced voltage if the core is not fully closed.
4. As applicable, posture the HVAC system or the required components (damper, control valves, fans, VFD speeds, etc.) to prevent unwanted system changes (modulation, staging, cycling) during the sensor/transmitter calibration.
5. Verify that the current transmitter has been correctly wired. Current transmitters are typically connected to the BAS controller analog input by either the two-wire or three-wire configuration. Refer to Chapter 3: BAS Inputs and Outputs for detailed information of the possible wiring configurations. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify that the current transmitter is connected to the correct BAS controller analog input. Cycling the monitored equipment through the associated binary output command is typically the easiest and safest method. You can also disconnect the wire conducting the signal or disconnect the 24 VAC wire that powers the current transmitter. This causes the current transmitter reading to change. It is a good idea to make a note or take a screenshot of the data point reading that occurs when the current transmitter is disabled.
7. At the same time that the current transmitter's electrical contacts are opened, verify and document that the data point bound to the BAS graphics also changes.
8. Verify that the current transmitter and its wires at the BAS controller end have been labeled.
9. Verify that the units/facets are correctly displayed. The facets for current are typically Amps.
10. Verify that the precision of the current transmitter reading is appropriately set. Current transmitter readings are typically no more than one decimal place for most applications.
11. Verify that the BAS controller's analog input point configuration matches the current transmitter current range and output signal. In this example, a 0-500 Amp current transmitter produces an output signal that ranges from 4-20 mA. With the use of a 250 or 500 Ohm resistor across the analog input terminals of the BAS controller, the current signal from the current transmitter is converted to a 1-5 VDC or 2-10 VDC voltage signal, respectively.

Reading	Current (Amps)	Signal (VDC)
Minimum	0	2
Maximum	500	10

Table 88 - Transmitter/BAS Controller Configuration

If the analog input configuration of the BAS controller is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs. The scale and offset values are used to calculate the current (Amps) reading from the voltage signal provided by the current transmitter. These values will be updated based on calibration readings as explained in later steps.

Volts (DCV)	Amps
2	0
10	500

Calculated Scale= 62.50
Calculated Offset= -125.00

Table 89 - Initial Scale-Offset Calculation for Analog Input Configuration

12. Verify the accuracy of the current transmitter reading by comparison with reference readings from a calibrated True RMS clamp meter. At each calibration point, record the BAS current reading, clamp meter reading, and the signal generated by the current transmitter. Current is a parameter that cannot be field simulated (like pressure), but two calibration points are typically possible – Normal operating current and the off or de-energized state. If the fan or pump is driven by a variable frequency drive, then multiple calibration points are possible by changing the speed setting. If the current transmitter does not produce the appropriate output signal or does not report across its full range, then it should be calibrated by modifying its zero and span adjustments. If accurate calibration results cannot be attained, then it should be replaced. Single-point calibrations are not recommended because they will not produce the required information to calibrate transmitter readings. Refer to Chapter 2: BAS Calibration and Chapter 3: BAS Inputs and Outputs for more information.

Reading	Test/Instrument (Amps)	BAS Data Point (Amps)	Signal (VDC)
1	0.0	-3.75	2.0
2	257.0	263.8	6.22

Table 90 - Initial Transmitter/BAS Calibration Check

13. Update the configuration of the analog input of the BAS controller and retest to confirm the calibration of the humidity transmitter. The calibration range does not match the sensor range, so the amperage at the maximum and minimum voltages must be calculated based on the test data. Refer to Chapter 3: BAS Inputs and Outputs for details. If the humidity transmitter readings still appear to be inaccurate or it does not provide readings across its full range, then replacement is recommended. Record the final analog input calibration and correction factors.

Reading	Current (Amps)	Signal (VDC)
Minimum	0	1.94
Maximum	487.2	10

Table 91 - Updated BAS Controller Configuration

If scale and offset factors are used to configure the parameters of the BAS controller analog input, update them accordingly using the same methodology explained in Chapter 3: BAS Inputs and Outputs. Confirm the accuracy of the analog input configuration by comparing the instrument readings to the current transmitter readings.

Volts (DCV)	Amps
2	0
6.22	257.0

Updated Calculated Scale= 60.90
Updated Calculated Offset= -121.80

Table 92 - Updated Scale-Offset Calculations

14. Release all overrides used to posture the system for testing and calibration.
15. Review the trend data to verify that the current transmitter reliably and consistently reports to the BAS controller. Numeric interval trend extensions are used to collect trend data at the programmed time intervals. Initial trend data intervals should be short (5 seconds-5 minutes) intervals to allow transient issues (that cannot be identified with longer intervals) to be identified. Once the testing and commissioning stage has concluded, longer time intervals (10-20 minute) can be used to minimize data storage requirements. There should not be any gaps or omissions in the trend data. The trend data should show that the current transmitter corresponds with the programmed control logic and schedule.
16. Document the results of all testing. Screenshots of the analog input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the current transmitter.

23.5 Review

1. ____________________ current transmitters can be installed on the monitored conductor without disconnecting the electrical wiring terminations.
2. The amperage on the line side of a motor starter is _______________ to the amperage on the load side of the motor

starter.

A. Higher
B. Lower
C. Equal

3. To monitor the load on a VFD through the current transmitter, it should be installed on the ________________ of the VFD.
4. Current transmitters (CTs) are often confused with ____________________.
5. In order to detect the failure of a belt or coupling, the current threshold should be set to ________________.

   A. Below the NLA
   B. Above the NLA
   C. Above the current draw at normal operating speed.
   D. Below the current draw at normal operating speed.
   E. Both B and D

6. When a belt or coupling fails, the motor current draw ________________.

   A. Increases
   B. Remains unchanged
   C. Drops to the NLA
   D. None of the above

7. It is best to have a current transmitter rated for no more than __________ time(s) the actual operating current.

   A. One
   B. Two
   C. Three

8. If the maximum and minimum voltage signals produced by a current transmitter are 0 VDC and 10 VDC, respectively, what is the Scale and Offset if the current sensor range is 0 Amps to 250 Amps?

   Scale: ________________ Offset: ________________

23.6 References

1. https://www.fluke.com/en-us/learn/blog/electrical/what-is-true-rms
2. https://assets.kele.com/Catalog/17%20Power%20Monitoring/PDFs/A-CT%20A-SCT%20Datasheet.pdf
3. https://dam-assets.fluke.com/s3fs-public/3850210_6003_ENG_B_W.PDF
4. https://www.fluke.com/en-us/learn/blog/clamps/troubleshooting-4-to-20-ma-process-control-systems-without-breaking-the-loop

Chapter 24 - Carbon Dioxide Transmitters (AI)

24.1 Description

Ambient air is composed of Nitrogen, Oxygen, and trace amounts of many other components. When mammals inhale the air, their lungs absorb the oxygen in the air to create the chemical energy required to continue living. As the air is exhaled it is a slightly different composition as shown in following table. Carbon dioxide (CO2) molecules are a component of the air that all mammals exhale. When people congregate in an enclosed structure, they increase the concentration of carbon dioxide and reduce the concentration of oxygen in the air. As such, the concentration of carbon dioxide in the air can be used as an indicator of the level of ventilation airflow (outdoor air) provided to the sampled zone by the air-handling unit(s).

Components of Air	% (Inhaled Air)	% (Exhaled Air)
Nitrogen	~78	~78
Oxygen	21	16
Carbon Dioxide	**0.04**	**4**
Others	1	2

Table 93 - Chemical Composition of Air

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62.1 Ventilation for Acceptable Indoor Air Quality is a standard that covers the minimum acceptable ventilation and exhaust air rates for commercial structures based on the use, occupancy, and square footage of the various spaces served by the air-handling unit. This calculated outdoor airflow must be provided while the building is occupied and assumes the zone is fully loaded. It does not account for variations in occupancy, natural ventilation that occurs through natural building envelope leakage and infiltration/exfiltration that occurs as the exterior windows and doors are opened and closed. As a result, buildings are very often over-ventilated. Ventilation air is required to dilute the pollutants and odors generated by the occupants and processes in commercial buildings. In addition, it is used to maintain positive building pressurization. ASHRAE 62.1 allows the use of carbon dioxide concentration as an indicator that the required rate of ventilation is provided. This control strategy is typically referred to as Demand-Controlled Ventilation (DCV). The DCV control strategy indicates that if a minimum differential between the indoor and ambient (outdoor air) carbon dioxide concentration is maintained, the "correct" or an "adequate" level of ventilation will be provided.


Photo 283 - Duct-Mounted Carbon Dioxide Transmitter

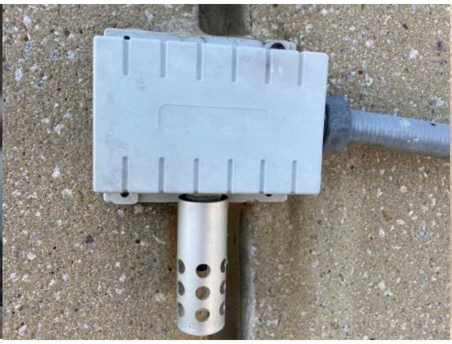
Photo 284 - Outdoor-Air Carbon Dioxide Transmitter


Photo 285 - Wall-Mounted Carbon Dioxide Transmitter

Carbon dioxide transmitters are devices that detect and quantify the carbon dioxide concentration in air and produce an electrical signal (0-5 VDC, 0-10 VDC, 0-10 VDC, or 4-20 mA) that is proportional to the carbon dioxide concentration. When connected to an analog input of a BAS controller, the carbon dioxide level can be used to evaluate and control the ventilation in a building. During times of maximum occupancy, the carbon dioxide concentration will be higher signifying the need for additional ventilation. Outside air carbon dioxide concentration can be assumed to be 350 PPM to 450 PPM depending on the location and time of day. It is typically safe to use 400 PPM and it makes the evaluation of ventilation airflow easy. If the measured indoor carbon dioxide concentration is within 200-300 Parts Per Million (PPM) of the outdoor carbon dioxide concentration, this indicates that the monitored zone is over-ventilated. If the carbon dioxide concentration is 600-800 PPM above the outdoor air carbon dioxide concentration, then you can infer that the correct amount of ventilation air is provided to that zone. If the carbon dioxide concentration is more than 800 PPM above the outdoor air carbon dioxide concentration, then you can infer that insufficient ventilation air is provided to the zone. These differentials are more relevant to office and school settings. According to the ASHRAE 62.1 standard, the activity of the occupants determines the allowable differential between the outdoor and indoor carbon dioxide concentrations.

The carbon dioxide level is proportional to the occupancy of the building. As the occupants begin to fill the spaces served by the air-handling unit, the carbon dioxide concentration immediately begins to rise. When the concentration of carbon dioxide reaches the maximum threshold setpoint, the outdoor air dampers are modulated open beyond their minimum position or minimum outdoor airflow setpoint (if equipped with an outdoor airflow measuring station) to dilute the building contaminants and maintain the carbon dioxide concentration at the setpoint. Because of DCV, the outdoor air damper could potentially be 100% open. As the carbon dioxide concentration reduces to below the maximum threshold, the outdoor air damper modulates toward its minimum position or minimum outdoor airflow. Many sequences of operation prescribe a maximum outdoor air damper command while operating under the DCV mode (30%, 40%, or 50% Open). This is a good idea because when carbon dioxide transmitters fail, they often indicate the maximum value (typically 2,000 PPM) of its operating range which causes the outdoor air damper to go to 100% open (if not limited) in an attempt to reduce the carbon dioxide concentration which can easily overload the cooling coil. It also provides the BAS operator with an indication that there may be an issue with the carbon dioxide reading if the outdoor air damper is always at 50% (or other maximum DCV damper position).

You will surely encounter air-handling units that initially appear to be economizing (fully open outdoor air damper) even though it is in the peak of summer or the middle of winter. Upon review of the BAS graphics, you may discover that the air-handling units were programmed for DCV and the carbon dioxide transmitters are displaying 2,000 PPM CO2 which is likely false because the outdoor air dampers are fully open and the building may also be empty. Under these operating conditions, the CO2 level should approach the outdoor air CO2 level (~400 PPM). The DCV control logic modulates the outdoor air, return air, and relief dampers to maintain the carbon dioxide concentration (in the return air or select spaces) below setpoint (typically 900-1,200 PPM CO2). When carbon dioxide transmitters fail, they often indicate the maximum value of the sensor range. A voltage reading of 10 VDC (or 20 mA) at the carbon dioxide transmitter signal contacts corroborates the 2,000 PPM CO2 reading at the BAS. The BAS controller logic responds to the high CO2 reading by opening the outdoor air damper and closing the return air damper.

The carbon dioxide transmitters may be the stand-alone type or may be combined with a temperature sensor and/or humidity transmitters. Combination units significantly reduce installation costs for the Controls Contractor. In addition, they reduce the number of wall-mounted devices. However, the failure of one sensor may require the replacement of the entire unit. If a combination unit is utilized, then the sensor location guidelines associated with each sensor type should also be followed to ensure that all sensors report correctly. Carbon dioxide transmitters come in various ranges, but the 0-2,000 PPM carbon dioxide range is typically used. If a 0-2,000 PPM carbon dioxide transmitter has an output signal of 0-10 VDC, then it will produce 0 VDC, 5 VDC, and 10 VDC output signals at carbon dioxide concentrations of 0 PPM, 1,000 PPM, and 2,000 PPM, respectively. Most carbon dioxide transmitters have multiple output signals that may be selected by dip switches, jumpers, or wiring terminations. The selected output signal and the BAS analog input must match for it to report correctly.

The programmed DCV control logic should be reviewed to verify that when the DCV mode is disabled, the outdoor air damper is not closed. The building's minimum outdoor airflow from all air-handling units should be 5-10 % higher than the sum of the exhaust airflows to maintain the building at positive pressurization. When DCV is enabled, it overrides the normal minimum outdoor airflow control to increase the outdoor airflow to maintain the carbon dioxide concentration at the DCV setpoint. The coils of air-handling units are designed and selected for a specific quantity of outdoor air which is typically determined by the load calculation using either Trane Trace 700 or Carrier HAP. This calculation takes into account the minimum ventilation and exhaust air requirements on a design day. If DCV is enabled when the outdoor air conditions are not conducive to economizer operation, the cooling load may exceed the cooling coil's design capacity. When this happens, it will not be able to cool or dehumidify the supply air sufficiently to maintain the desired indoor environmental conditions which could lead to a host of other undesirable situations (high temperatures, high humidity, high energy use, mold, etc.) are possible downstream of the air-handling unit. The same could also happen to the heating coil if DCV is enabled while the outdoor air temperatures are low. If excess outdoor air is passed through the heating coil, it could result in damage to the coil and/or piping and insufficient heat delivery to the spaces served by the air-handling unit. There should be additional logic to limit the outdoor air damper command while DCV is enabled to that which the coils capacities can handle. For example, the outdoor air damper command could be limited while the DCV mode is enabled to the point at which cooling control valve (or heating control valve) command reaches 90% open.

24.2 Space Carbon Dioxide Transmitters:

When the carbon dioxide transmitter is installed in the space on the wall, its placement is key to providing a representative carbon dioxide reading. In general, the carbon dioxide transmitter should be installed below the ceiling-mounted return air devices (diffuser, register, or grill) or above/adjacent to wall-mounted return air devices. The supply air is delivered to the space to condition (heat, cool, humidify, dehumidify) and dilute air pollutants generated by the occupants and processes. After the supply air has done its work, it returns to the air-handling unit through the return air duct system.

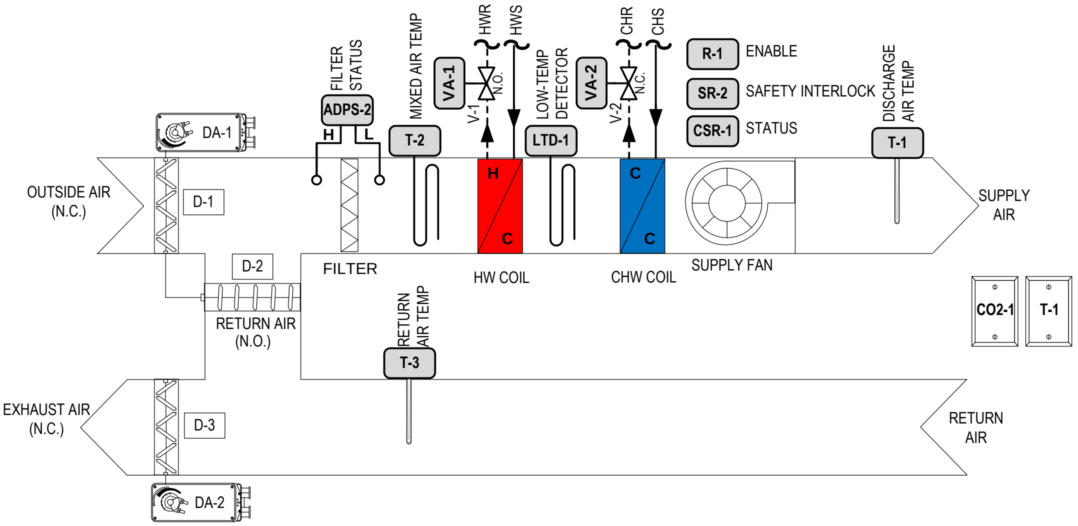

Figure 213 - DCV Based on Space Carbon Dioxide Transmitter Reading

Carbon dioxide transmitters are typically wall-mounted which requires that the wires pass through the wall from the ceiling down to the mounted height in the wall. The typical mounting height for room sensors (temperature, humidity, carbon dioxide, etc.) is 48-54 inches from the finished floor, but this height can vary. Depending on the installation requirements of the project, carbon dioxide transmitter wires may or may not be installed within an electrical conduit. In addition, depending on the wiring and mounting requirements of the carbon dioxide transmitter, there may or may not be an electrical junction box behind it. In some cases, the conduits are mounted on the surface of the wall. This is typically done when the BAS is installed as a retrofit after the initial building construction either because it is too difficult or impossible to install the wires in the wall without damaging them.

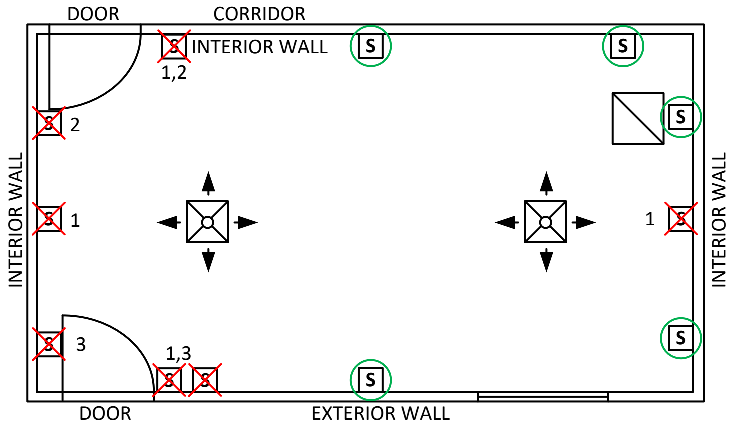

Figure 214 - Carbon Dioxide Transmitter Location Recommendations

The factor that influences the performance of the carbon dioxide transmitter and the overall DCV control most is its installed location. Carbon dioxide transmitters should be installed at the point that provides the most representative carbon dioxide reading of the space being controlled. The optimum location is typically below or near the room's return air grill. All of the conditioned air supplied to the space returns to the air-handling unit through the return air grill after conditioning the room(s). This is typically the ideal location, unless it coincides with an area to be avoided. The following diagram provides some general guidelines to keep in mind when locating carbon dioxide transmitters. Carbon dioxide transmitters with red X's across them are locations that are to be avoided and those with a green circle around them are preferred locations. Next to the carbon dioxide transmitters are numbers which represent the reason(s) why they are to be avoided.

It is often difficult to determine the best location for some space carbon dioxide transmitters. Often, it is necessary to choose the best of several poor locations. In other cases, the planned sensor location is clearly incorrect and should be changed. If modifications in sensor locations can be made prior to installation, it provides a benefit to all involved, especially the future occupants. The following locations are to be avoided, if possible:

1. **Within the influence of supply airstreams**. Supply airstreams have a lower carbon dioxide concentration than the room air by virtue of the fact that it is delivering the ventilation air from the air-handling unit. The supply air will cause the space carbon dioxide concentration reading to be lower than the actual room conditions. Due to the Coanda effect, discharging supply airstreams hug the ceiling until it encounters the wall. The supply airstream is a mixture of supply air and entrained air. The airstream then proceeds down the wall and may flow over the carbon dioxide transmitter if it has been installed in its path which can impact the carbon dioxide control. To maximize the accuracy of the space carbon dioxide transmitter reading, supply airstreams should be avoided when locating space carbon dioxide transmitters.
2. **Near interior doorways**. When wall-mounted carbon dioxide transmitters are located near interior doorways, they are subject to influence of the adjacent space (typically a corridor). This influence tends to slow or retard the sensing of the room's true condition. This is especially true when the door is typically propped open or it is continuously opened and closed. The carbon dioxide concentration at the core of the room can be quite different from the environment sensed by the space carbon dioxide transmitter when it is located by an interior doorway. In addition, it is common in schools for the children to line up at the door before leaving the room. High occupant densities in close proximity to carbon dioxide transmitters can cause spikes in the carbon dioxide level which may unnecessarily enable the DCV cycle.
3. **Near exterior doorways**. When wall-mounted space carbon dioxide transmitters are located near exterior doorways they are subject to the influence of the outside air conditions as the door is repeatedly opened and closed. This tends to dilute the space's true carbon dioxide condition toward that of the outside.

24.3 Duct-mounted Carbon Dioxide Transmitters:

Duct-mounted CO2 transmitters are typically installed in the return duct to sample the return air. This location is generally accepted as representative of the average condition of the zones served by the return duct system. When the CO2 transmitter is installed in the ductwork adjacent to air-handling units, the final location must be carefully considered. The key to keep in mind is that the CO2 reading of the airstream that you want to sample must not be impacted by other airstreams.

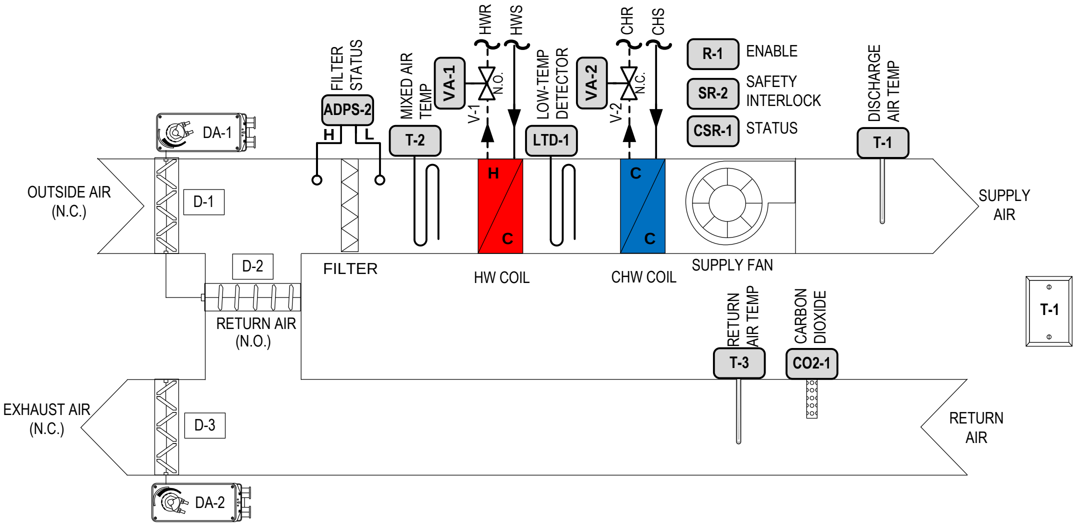

Figure 215 - DCV Based on Return Duct Carbon Dioxide Transmitter Reading

For best results, install the CO2 transmitter in the return duct well upstream of the relief air duct/damper connection. Do not install the carbon dioxide transmitter anywhere between the outdoor air and relief (also called "exhaust") dampers. It is not uncommon for the outdoor air to be drawn into both the outdoor air damper and the relief (exhaust) air damper of an air-handling unit which could significantly lower the return air CO2 reading.

24.4 Outdoor Air Carbon Dioxide Transmitters:

Demand-controlled ventilation is based on maintaining a space/return duct CO2 differential above the ambient or outside air CO2 concentration per ASHRAE 62.1. The ambient CO2 concentration is acquired through the use of an externally-mounted CO2 transmitter. The outdoor air CO2 transmitter should not be installed anywhere near exhaust fans or air-handling unit relief air discharges because these airstreams can affect the outdoor air CO2 reading. Loading docks or areas where automobiles may idle for extended periods should also be avoided. In many BAS installations, the outdoor air reference carbon dioxide level is assumed to be approximately 400 PPM CO2.

24.5 Applications

1. **Demand-Controlled Ventilation**. Carbon dioxide transmitters are utilized to control the flow of outdoor air in air-handling units. The carbon dioxide signal is monitored by the BAS and modulates the flow of outdoor air through the air-handling unit dampers to maintain the CO2 concentration(s) below the maximum CO2 threshold.

24.6 Typical Control Wiring

Explanations of the various wiring strategies have been provided in Chapter 3: BAS Inputs and Outputs. To avoid unnecessary repetition of the typical transmitter wiring diagrams, the following table has been provided. Depending on the installation requirements and the preference of the installing Controls Contractor, the wiring strategies implemented can go in several directions.

Analog Input Device Signal	BAS Input Signal	Signal Wiring Configuration
4-20 mA	4-20 mA	Loop-Powered (Two-Wire) Transmitter
4-20 mA	2-10 VDC	Loop-Powered w/ 500 Ohm Resistor
4-20 mA	1-5 VDC	Loop-Powered w/ 250 Ohm Resistor
4-20 mA	4-20 mA	Three-Wire Transmitter
0-10 VDC	0-10 VDC	Three-Wire Transmitter
2-10 VDC	2-10 VDC	Three-Wire Transmitter

Table 94 - Possible Analog Input Wiring Strategies

24.7 Analog Input Testing and Verification

The general test procedures for carbon dioxide transmitters include the following:

1. Verify that the CO2 transmitter has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The CO2 range, mounting, output contacts, status LED, wiring, manufacturer, and output signals are some of the features that should be verified.
2. Verify that the CO2 transmitter has been installed at the correct or optimum location. If a combination unit is installed, then the sensor placement recommendations of all included sensors should be observed.
3. Verify that the CO2 transmitter has been installed per the manufacturer's installation recommendations.
4. As applicable, posture the HVAC system or the required components (damper, control valves, fans, VFD speeds, etc.) to prevent unwanted system changes (modulation, staging, cycling) during the sensor/transmitter calibration. When building occupants are present, overrides of the air-handling unit dampers (100% outdoor air and then 0% outdoor air (full recirculation)) are often utilized to create two calibration points. Alternatively, calibration gas can be utilized if the carbon dioxide transmitter has a test gas port.
5. Verify that the CO2 transmitter has been correctly wired. Carbon dioxide transmitters are typically connected to the BAS controller analog input by either the two-wire or three-wire configuration. Refer to Chapter 3: BAS Inputs and Outputs for detailed information of the possible wiring configurations. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify that the CO2 transmitter is connected to the correct BAS controller analog input. Disconnect the wire conducting the signal or disconnect the 24 VAC wire that powers the CO2 transmitter. This causes the CO2 transmitter data point reading to change. It is a good idea to make a note or take a screenshot of the data point reading that occurs when the CO2 transmitter is disabled.
7. At the same time that the CO2 transmitter's electrical contacts are opened, verify and document that the data point bound to the BAS graphics also changes.
8. Verify that the CO2 transmitter and its wires at the BAS controller end have been labeled.

9. Verify that the units/facets are correctly displayed. The facets for CO2 are typically PPM CO2.
10. Verify that the precision of the CO2 transmitter reading is appropriately set. Carbon dioxide setpoint and transmitter readings are typically displayed as whole numbers (no decimal places).
11. Verify that the BAS controller's analog input point has been configured to match the CO2 transmitter sensor range and output signal. In this example, a 0-2000 PPM CO2 transmitter produces an output signal that ranges from 4-20 mA. With the use of a 250 or 500 Ohm resistor across the analog input terminals of the BAS controller, the current signal from the CO2 transmitter is converted to a 1-5 VDC or 2-10 VDC voltage signal, respectively.

Reading	Carbon Dioxide (PPM)	Signal (VDC)
Minimum	0	2
Maximum	2,000	10

Table 95 - Initial Analog Input Configuration

If the analog input configuration of the BAS controller is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs. The scale and offset values are used to calculate the carbon dioxide reading from the voltage signal provided by the carbon dioxide transmitter. These values will be updated based on calibration readings as explained in later steps.

Volts (DCV)	CO2 (PPM)
2	0
10	2000

Initial Scale= 250.00
Initial Offset= -500.00

Table 96 - Initial Scale-Offset Calculation for Analog Input Configuration

12. Verify the accuracy of the CO2 transmitter readings by comparison with reference readings from a calibrated CO2 meter or calibration gases. At each calibration point, record the BAS controller reading, CO2 meter reading, and the signal generated by the CO2 transmitter. Carbon dioxide is a parameter that cannot be field simulated (like pressure), but two calibration points can be attained by system posturing (100% outdoor air versus 100% recirculation) or calibration gas. Two concentrations (400 PPM and 1,000 PPM) of CO2 calibration gas can provide an accurate two-point calibration of a CO2 transmitter. These points must be sufficiently separated to verify its performance. This can be a challenge when there are no building occupants to produce CO2. If the CO2 transmitter does not produce the appropriate output signal or does not report across its full range, then it should be calibrated by modifying its zero and span adjustments. If accurate calibration results cannot be attained, then it should be replaced. Single-point calibrations are not recommended because they will not produce the required information to calibrate transmitter readings. Refer to Chapter 2: BAS Calibration and Chapter 3: BAS Inputs and Outputs for more information.

Reading	Test/Instrument (CO2 PPM)	BAS Reading (CO2 PPM)	Volts (VDC)
Minimum	403	437.5	3.75
Maximum	1,012	1,147.5	6.59

Table 97 - Calibration Gas Readings

For best results with a hand-held CO2 meter, do not breathe while placing it next to the CO2 transmitter. It typically takes time for the reference meter to acclimatize to the new local conditions, so it is best to leave the meter in the area (within 6 Inches) of the CO2 transmitter and return after three to five minutes. Some CO2 meters have an internal sampling pump which significantly reduces the time required to acclimatize.

13. Update the configuration of the analog input of the BAS controller and retest to confirm the calibration of the humidity transmitter. The calibration range does not match the sensor range, so the carbon dioxide concentration at the maximum and minimum voltages must be calculated based on the test data. Refer to Chapter 3: BAS Inputs and Outputs for details. If the humidity transmitter readings still appear to be inaccurate or it does not provide readings across its full range, then replacement is recommended. Record the final analog input calibration and correction factors.

Reading	Test/Instrument (CO2 PPM)	Transmitter Signal (VDC)
Minimum	27.7	3.75
Maximum	1743.2	6.59

Table 98 - Updated Analog Input Configuration

If scale and offset factors are used to configure the parameters of the BAS controller analog input, update them accordingly using the same methodology explained in Chapter 3: BAS Inputs and Outputs.

Volts (DCV)	CO2 (PPM)
3.75	403
6.59	1012

Updated Scale= 214.44
Updated Offset= -401.14

Table 99 - Final Scale-Offset Calculation for Analog Input Configuration

14. Release all overrides used to posture the system for testing and calibration.
15. Review the trend data to verify that the CO2 transmitter reliably and consistently reports to the BAS controller. Numeric interval trend extensions are used to collect trend data at the programmed time intervals. Initial trend data intervals should be short (5 seconds-5 minutes) intervals to allow transient issues (that cannot be identified with longer intervals) to be identified. Once the testing and commissioning stage has concluded, longer time intervals (10-20 minutes) can be used to minimize data storage requirements. There should not be any gaps or omissions in the trend data. The trend data should show that the carbon dioxide transmitter corresponds with the programmed control logic and schedule.
16. Document the results of all testing. Screenshots of the analog input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the carbon dioxide transmitters.

24.8 Review

1. True or False: Combination sensors with carbon dioxide, temperature, and humidity sensors in the same housing increase installation costs. Answer: ________
2. True or False: The use of carbon dioxide transmitters in demand-controlled ventilation sequences allows the air-handling unit to take advantage of the natural ventilation caused by building leakage, the opening of doors, as well as the mechanical ventilation. Answer: ________
3. Ambient carbon dioxide concentrations in air are lower in __________________ areas than they are in urban areas.
4. What ASHRAE standard provides guidelines for the minimum acceptable ventilation in commercial and residential buildings? It also explains how carbon dioxide concentration may be used to control the ventilation rate.
   Answer: _________________________
5. Carbon dioxide transmitters with a 0- _______________ PPM range are typically used in HVAC applications.
6. Outside air can be assumed to be __________________ PPM in most ventilation control applications.

24.9 References

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Chapter 25 - Air Differential Pressure Transmitters (AI)

25.1 Description

Air Differential Pressure Transmitters (ADPTs) are devices that sample the air pressure differentials in a system and produce an electrical signal that is proportional to the sensed pressure differential. ADPTs are useful in the control and monitoring of air pressures and differentials in HVAC systems. The typical unit of measure is Inches Water Column (WC). ADPTs may be unidirectional or bidirectional. The bidirectional transmitters indicate both positive and negative differential pressures and are typically used to monitor space pressurization. The Setra model 264 is a commonly used ADPT that comes in many pressure ranges. Test tees are typically provided at pressure-independent terminal units, but they are just as useful at ADPTs utilized for filter differential pressure monitoring and airflow measuring stations. They allow us to verify the BAS differential pressure reading with reference instrument readings in the same pneumatic lines.

Photo 286 - Test Tees in Pneumatic Pressure Sensing Lines

Photo 287 - Filter Differential Pressure Monitoring

Photo 288 - Static Pressure and Current Measurements

The ADPT contacts are connected to an analog input of a BAS controller. The BAS controller is then programmed to interpret the ADPT signal (0-10 VDC, 2-10 VDC, 0-5 VDC, etc.) so that it may be used to control and/or monitor a system differential pressure. To provide accurate and stable control, the operating range of the differential pressure transmitter should be large enough to encompass the normal differential pressure and no more than twice the normal differential pressure. If the normal differential pressure is 1.5 inches W.C., then a differential pressure transmitter with a rating of 0-2.5 inches W.C. or 0-2 inches W.C. should be selected and installed.

Photo 289 - Duct-Mount Static Pressure Pickups

Photo 290 - Ceiling or Wall-Mount Space Static Pressure Pickup

Photo 291 - Outdoor Air Reference Static Pressure Pickup

The ADPT should always be used with properly selected static pressure or velocity pressure probes or “pickups” to provide the most accurate and reliable differential pressure readings. The location of the pickups is also critical to the proper operation and performance of the ADPT. Polyethylene tubing (or similar) is typically utilized to connect the ADPTs to the pressure probes (velocity and static). Because of the low pressures involved, the differential pressure readings are very sensitive to the types of connections and fittings used. Poor system connections can lead to erroneous differential pressure readings. It is not uncommon to find polyethylene tubing crudely stuck through a hole in the side of an air-handling unit casing, duct wall, ceiling tile, or exterior wall. While it is possible to get a static pressure reading, it will likely provide an erroneously high or low static pressure reading. Dwyer Instruments provides a complete line of static pressure pickups for most applications.

The ADPT may be mounted in nearly any location that is dry and within its operating temperature and humidity range. Refer to the manufacturer's installation recommendations. Some ADPTs require installation in a specific orientation to function properly. What is most important to the proper function of the ADPT is the location and use of proper static pressure, velocity pressure, and space static pressure probes because they directly affect the accuracy of the differential pressure readings. If the ADPT is installed in or adjacent to the BAS local control panel and the static pressure probe is installed remotely, longer lengths of polyethylene tubing will be required. Excessively long tubing lengths will slow the response of the ADPT to changes in system pressures, so the maximum tubing lengths provided in the following table should be observed. To avoid these issues, the ADPT could be installed close to the static/velocity pressure probes and the signal transmitted through additional wiring which is typically more forgiving of longer distances.

Diameter (Inches)	Maximum Length (Feet)
3/16	0-100
1/4	101-300
3/8	301-900

Table 100 - Setra Pneumatic Tubing Length Recommendations

Some ADPTs cannot be pressurized with a hand-actuated calibration pump. Their differential pressure sensor design utilizes a porous membrane that will not hold or contain the applied test pressure. The high-side pressure sensing line should be equipped with an inline filter to prevent fouling of the pressure-sensing membrane. This type of ADPT will require a small fan that pressurizes a duct or small container with a barbed fitting for hose connections. Test tubing and ¼" tee is then used to connect the manometer, pressure source (pressurization fan), and the ADPT to be calibrated. The fan speed and/or the amount of vented air can be used to change the static pressure applied to the ADPT. In some cases, a more stable reading can be attained if the suction side of the fan is used to a create pressure differential. In this case, the tubing would connect to the negative port of the ADPT.

25.2 Applications

1. **Filter Status Monitoring**: Filter loading is often monitored with ADPTs. When newly installed, filters have a baseline filter differential pressure which should be tested and recorded. With time, the filters will collect dust and debris and will exhibit higher and higher resistance or pressure drop. The positive (or high) port is connected upstream of the filter bank while the negative (or low) port is connected downstream of the filter bank for a positive reading. If the filter differential pressure is below the baseline filter bank pressure differential, this may indicate that ADPT tubing has been disconnected, filter rack inserts are missing, or filters have collapsed. When the filter differential pressure exceeds the filter differential pressure setpoint, its status changes from "Clean" to "Dirty" indicating that the filters should be changed.

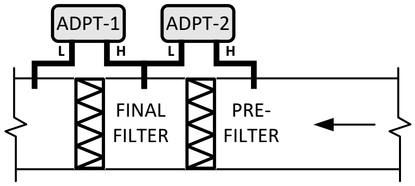

Figure 216 - ADPTs Used to Monitor the Multiple Filters

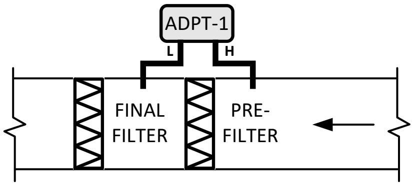

Figure 217 - ADPT Used to Monitor a Single Filter

In many installations, the air-handling unit may have pre-filters as well as a final filter that are monitored by the BAS. The pressure pickup in between the filters is common to both differential pressure transmitters. A tee is typically used to split the pneumatic tubing to allow a connection from both differential pressure transmitters. There is almost always confusion when only a single ADPT is specified, but there are both pre-filters and final filters. Which of the filters should be monitored by the BAS – the pre-filter, the final filter, or both? Typically, the pre-filter condition is monitored as it typically loads up more quickly than the final filters.

2. **Fan Status Monitoring**: Fan operating status is often monitored with ADPTs. This provides a means to detect the failure of either the belt or the motor because the differential pressure produced by the fan will significantly reduce. An ADPT provides a reading of the differential pressure produced by the fan.

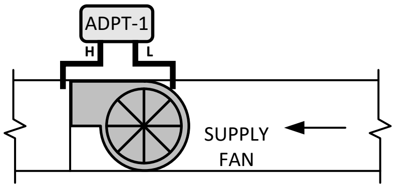

Figure 218 - ADPT Used to Monitor the Supply Fan Status

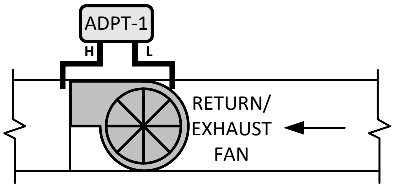

Figure 219 - ADPT Used to Monitor the Return/Exhaust Fan

The BAS controller is typically programmed to indicate that the fan is "On" when the differential pressure is above a predetermined threshold or setpoint. It indicates "Off" when the differential pressure falls below this value. When the fan status does not match the command for a predetermined period (typically 30 to 60 seconds), a fan status alarm is generated. The setpoint should be as high as possible (75% to 90% of the normal operating differential pressure) without causing nuisance trips for constant volume fans. In variable volume systems, the differential pressure setpoint needs to be high enough to positively indicate the operation of the fan while it is operating at minimum flow.

3. **Supply and Return/Exhaust Duct Static Pressure Control**: In variable-air-volume supply, return, and exhaust systems, the duct static pressure is typically maintained at a fixed static pressure. The ADPT should be connected to a static pressure probe or pickup installed 2/3 to 3/4 down the longest duct run. This location typically provides the best indication of the demand for airflow in the duct system. If you were to draw a circle around the majority of VAV terminal units, the static pressure probe should be located at or near the center of that circle. When the ADPT monitors the static pressure at the fan (supply, return, or exhaust), it is not able to sense the airflow demand in real time. By the time that the ADPT senses the change in duct static at the fan, the duct system static pressures may be far from the setpoint. As a result, the reaction to the system demand will lag behind the actual system demand resulting in occupant discomfort.

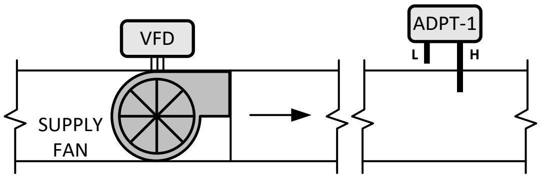

Figure 220 - ADPT Used to Monitor the Supply Fan Status

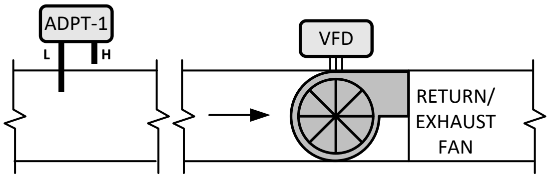

Figure 221 - ADPT Used to Monitor the Return/Exhaust Fan

4. **Space Static Pressure Monitoring and Control**: Sequences of operation often require the monitoring and control of space static pressures. Spaces may be maintained at positive or negative pressurization. Space static pressure monitoring and control is essential for laboratory, industrial, and medical facilities where the direction of airflow and pressure differential are critical. Dirty, contaminated, or humid environments are typically maintained at negative pressurization. Clean rooms and surgical suites require positive pressurization to ensure that contaminants do not enter these spaces. Most spaces in commercial buildings, except restrooms, are maintained at positive pressurization (0.01-0.03 inches W.C.). The controlled leakage of conditioned air out of the building is preferred to uncontrolled leakage of unconditioned air into the building.

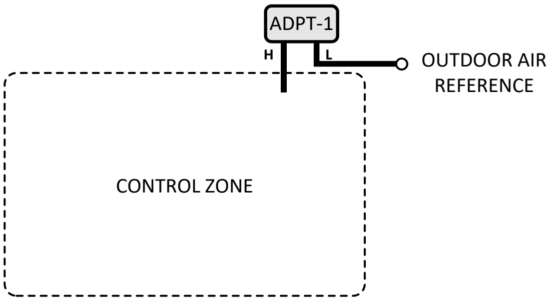

Figure 222 - ADPT Used to Monitor Space Static Pressure

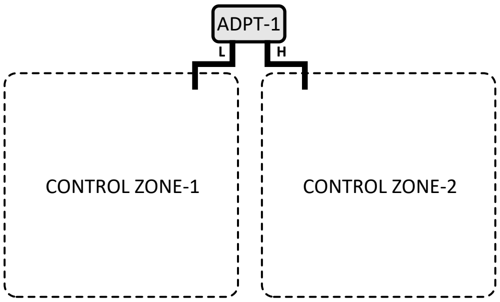

Figure 223 - ADPT Used to Monitor Differential Pressure

The location and the type of static pressure pickup are very important to the performance of ADPTs. If the ADPT is used to monitor the space pressurization in a particular room, then either a wall-mounted or ceiling-mounted space static pressure pickup is connected to the positive port of the ADPT to sample the space pressure. The reference static pressure pickup is installed to sample the outdoor air static pressure and is connected to the negative (low) port of the ADPT. Furthermore, the static pressure pickup should be designed for exterior use and installed following the manufacturer's installation recommendations. The reference port of the ADPT should never reference the ceiling space, especially in plenum return systems.

5. **Mixed-Air Plenum Static Pressure Monitoring & Control**: In certain applications where the flow of ventilation air is critical, mixed-air plenum static pressure may be monitored with an ADPT. The mixed air plenum is where the outdoor air and the return airstreams meet. The mixed-air plenum pressure can provide valuable information that can warn the operator of unwanted situations which include, but are not limited to the following:

    a. Control damper failure
    b. Fire/Smoke damper closure
    c. Lack of outdoor airflow
    d. Worn/failed supply and return fan belts
    e. Filter/Coil loading
    f. Outdoor air inlet blocked (dust, debris, leaves, etc.)
    g. Failure of minimum outdoor airflow control.
    h. Failure of return fan tracking control

In order for outdoor air to enter the air-handling unit, the mixed-air plenum must be negatively pressurized. When the air-handling unit is initially balanced, a baseline or "normal" mixed-air plenum pressure should be documented. At this pressure, the proper flow of outdoor air is provided through the outdoor air duct system. If the mixed-air plenum pressure differs substantially from this baseline value (while all other factors are the same), it typically indicates a change in the system. As the supply fan VFD speed modulates to maintain the supply duct static pressure or space temperature, the return fan must adjust accordingly to maintain the same mixed-air plenum pressurization. If mixed-air plenum pressure is substantially lower (more negative) than the baseline static pressure, it typically indicates one or more of the following: restriction in the outdoor air intake or return duct system, increase in supply fan speed, filter bypass, or a reduction in the return airflow. If the mixed-air plenum pressure is substantially higher (less negative or positive) than the baseline static pressure, this typically indicates one or more of the following: restriction in the supply duct system, increased filter/coil pressure drops, lower supply fan speed, or a higher return fan speed. When the mixed-air plenum pressure is positive, this indicates that the return airflow is higher than the supply airflow and that return air is exhausted from the outdoor air intake. This contributes to negative building pressurization. A Magnehelic® gauge is recommended to provide a visual indication of the mixed-air plenum pressure. This is a simple and definitive way to verify whether the air-handling unit is providing ventilation airflow.

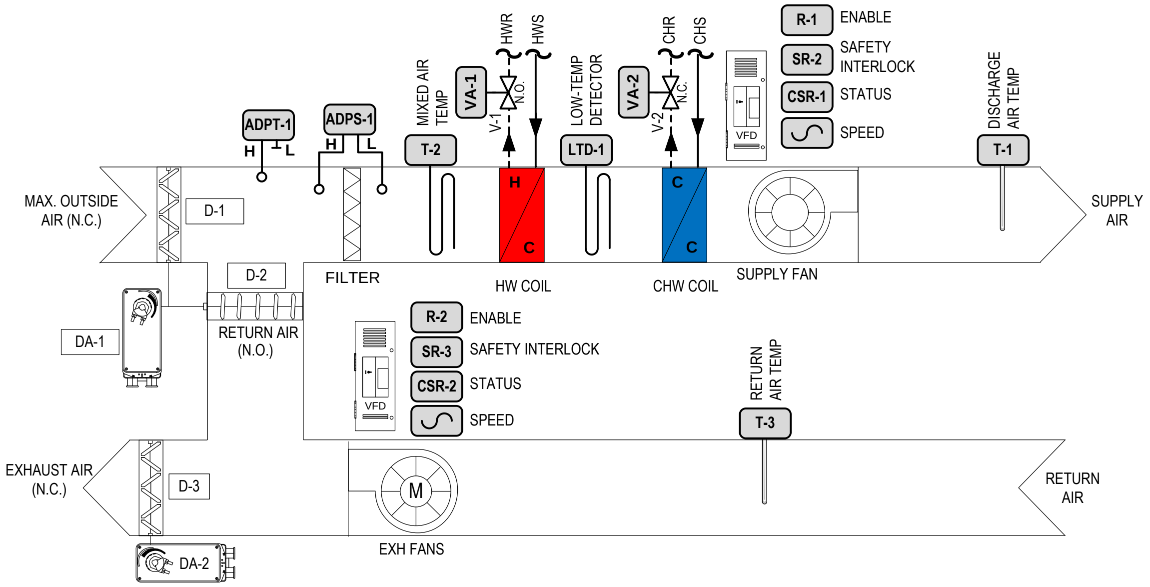

Figure 224 - Schematic of ADPT used for Mixed-Air Plenum Pressure Monitoring

6. **Airflow Measuring Stations**: Airflow Measuring Stations (AFMS) are devices that are used to monitor and control the flow of air. AFMSs based on differential pressures are covered in greater detail in Chapter 27: Duct-Mounted Airflow Measuring Stations-Differential Pressure. Airflow measurement with ADPTs is a mature technology that is commonly used in pressure-independent terminal unit airflow control. The AFMS is composed of a multipoint array that samples multiple total pressure points and multiple static pressure points simultaneously. The Total Pressure (TP) sampling ports are averaged because of their connection to a common plenum which is connected to the high-pressure port of the ADPT. The Static Pressure (SP) ports are likewise constructed and connected to the low pressure port of the ADPT. The differential pressure sampled by the ADPT represents the Velocity Pressure (VP = TP – SP). Once the velocity pressure is known, the air velocity and ultimately airflow can be calculated.

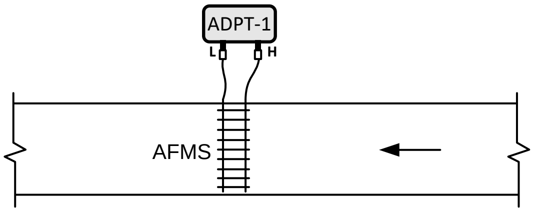

Figure 225 - ADPT for Airflow Measuring Station Monitoring

25.3 Typical Control Wiring

Explanations of the various wiring strategies have been provided in Chapter 3: BAS Inputs and Outputs. To avoid unnecessary repetition of the typical transmitter wiring diagrams, the following table has been provided. Depending on the installation requirements and the preference of the installing Controls Contractor, the wiring strategies implemented can go in several directions.

Analog Input Device Signal	BAS Input Signal	Signal Wiring Configuration
4-20 mA	4-20 mA	Loop-Powered (Two-Wire) Transmitter
4-20 mA	2-10 VDC	Loop-Powered w/ 500 Ohm Resistor
4-20 mA	1-5 VDC	Loop-Powered w/ 250 Ohm Resistor
4-20 mA	4-20 mA	Three-Wire Transmitter
0-10 VDC	0-10 VDC	Three-Wire Transmitter
2-10 VDC	2-10 VDC	Three-Wire Transmitter

Table 101 - Possible Analog Input Wiring Strategies

25.4 Analog Input Testing and Verification

The general test procedures for Air Differential Pressure Transmitters include the following:

1. Verify that the ADPT has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The operating range, mounting, bidirectional/unidirectional, output contacts, wiring, and output signals are some of the features that should be verified.
2. Verify that the ADPT and its static pressure and velocity pressure pickups have been installed at the correct or optimum location.
3. Verify that the ADPT has been installed per the manufacturer's installation recommendations. Verify and document all adjustable dip switch, selector, and jumper settings to ensure the correct signal and range are generated. The final operating range of the ADPT should be consistent with the intended application.
4. As applicable, posture the HVAC system or the required components (damper, control valves, fans, VFD speeds, etc.) to prevent unwanted system changes (modulation, staging, cycling) during the sensor/transmitter calibration.
5. Verify that the ADPT has been correctly wired. The ADPT may have multiple sets of contacts that must be properly landed and coordinated to provide the required signal type and range. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify that the pneumatic tubing/piping and probes are correctly connected and properly located. The high-pressure port should be connected to the higher pressure zone (upstream of the filter, coil, or AFMS) while the low-pressure port is connected to the lower pressure zone (downstream of the filter, coil, or AFMS). It is not uncommon to find errors in the tubing connections. Verify that test tees have been provided to facilitate differential pressure testing and calibration.
7. Verify that the ADPT has been connected to the correct BAS controller analog input. Removing the signal or 24

VAC power wire from the ADPT will cause the data point reading to change. It is a good idea to make a note or take a screenshot of the data point reading that occurs when the analog input device is disconnected.

8. At the same time that the ADPT's electrical contacts are opened, verify and document that the data point bound to the BAS graphics also changes.
9. Verify that the ADPT and its wires at the BAS controller end have been labeled. It is also recommended that any wall- or ceiling-mounted space static pressure pickups be labeled to indicate which system it serves.
10. Verify that the units/facets for the ADPT are correctly displayed. The facets for static pressure are typically Inches Water Column (W.C.).
11. Verify that the precision of the ADPT reading is appropriately set. Duct static pressures and supply duct static setpoints are typically displayed with one or two decimal places depending on the operating duct static or space static pressure level. Space static pressures are typically displayed with three decimal places and their setpoints are typically displayed with two decimal places.
12. Verify that the BAS controller's analog input point has been configured to match the ADPT differential pressure range and output signal. In this example, an ADPT produces an output signal that ranges from 4-20 mA. With the use of a 250 or 500 Ohm resistor across the analog input terminals of the BAS controller, the current signal from the ADPT is converted to a 1-5 VDC or 2-10 VDC voltage signal, respectively.

Reading	**Static Pressure (Inches W.C.)**	**Signal (VDC)**
Minimum	0	2
Maximum	10	10

Table 102 - Initial Analog Input Configuration

If the analog input configuration of the BAS controller is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs. The scale and offset values are used to calculate the differential pressure reading from the voltage signal provided by the ADPT. These values will be updated based on calibration readings as explained in later steps.

Volts (DCV)	Inches (W.C.)
2	0
10	10

Initial Scale= 1.25
Initial Offset= -2.50

Table 103 - Initial Scale-Offset Calculation

13. Verify the accuracy of the ADPT reading by comparison with reference readings from a calibrated digital manometer meter. At each calibration point, record the BAS controller reading, air pressure meter reading, and the signal generated by the ADPT. Low pressures can be field simulated with a calibration pump, fan assembly, or the air-handling unit. If the ADPT does not produce the appropriate output signal or does not report across its full range, then it should be calibrated by modifying its zero and span adjustments. If accurate calibration results cannot be attained, then it should be replaced. Single-point calibrations are not recommended because they will not produce the required information to calibrate transmitter readings. Refer to Chapter 2: BAS Calibration and Chapter 3: BAS Inputs and Outputs for more information.

Reading	**Test/Instrument (Inches W.C.)**	**BAS Data Point (Inches W.C.)**	**Signal (VDC)**
1	0.0	0.01	2.03
2	5.0	4.95	5.98
3	10.0	9.79	9.83

Table 104 - Initial Transmitter/BAS Calibration Check

14. Update the configuration of the analog input of the BAS controller and retest to confirm the calibration of the ADPT. If the static pressure readings still appear to be inaccurate or the ADPT does not provide readings across its full range, then replacement of the ADPT is recommended. Record the final analog input calibration and correction factors.

Reading	**Static Pressure (Inches W.C.)**	**Signal (VDC)**
Minimum	0	2.03
Maximum	10	9.83

Table 105 - Updated BAS Controller Configuration

If scale and offset factors are used to configure the parameters of the BAS controller analog input, update them accordingly using the same methodology explained in Chapter 3: BAS Inputs and Outputs. Confirm the accuracy of the analog input configuration by applying test pressures and compare with the resulting differential pressure readings.

Volts (DCV)	Inches (W.C.)
2.03	0
9.83	10

Updated Scale= 1.28
Updated Offset= -2.60

Table 106 - Updated Scale-Offset Calculations

15. Release all overrides used to posture the system for testing and calibration.
16. Review the trend data to verify that the ADPT reliably and consistently reports to the BAS controller. Numeric interval trend extensions are used to collect trend data at the programmed time intervals. Initial trend data intervals should be short (5 seconds-5 minutes) intervals to allow transient issues (that cannot be identified with longer intervals) to be identified. Once the testing and commissioning stage has concluded, longer time intervals (10-20 minute) can be used to minimize data storage requirements. There should not be any gaps or omissions in the trend data. The trend data should show that the ADPT corresponds with the programmed control logic and schedule.
17. Document the results of all testing. Screenshots of the analog input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the ADPT.

25.5 Review

1. True or False: The tubing connections make no difference in the static pressure readings. Answer: ________
2. True or False: The supply duct static pressure pickup should be installed 2/3 to 3/4 down the longest duct run to monitor the supply air demand. Answer: ________
3. In space pressure monitoring applications, the low pressure port of the ADPT should reference the _________.
   A. Indoor air condition
   B. Outdoor air condition
   C. Ceiling plenum
   D. Return duct
4. If an air-handling unit has a plenum return system and the ADPT is installed in the ceiling, the low-pressure port of the supply duct static pressure transmitter should reference _________.
   A. Indoor air condition
   B. Outdoor air condition
   C. Ceiling plenum
   D. Return duct
5. If an air differential pressure transmitter has a range of 0-6 inches static pressure and an output voltage of 0-10 VDC, the indicated static pressure will be ______________ inches W.C. if the analog input voltage is 3.39 VDC?
6. What facets are typically used with static pressure and air differential pressure? Answer: ________
7. Static pressure _____________ are used to provide a means to connect the ADPT to the system being monitored and maximize the accuracy of the reading.
8. A _______________ mixed-air plenum pressure would indicate that outdoor air is not being drawn into the air-handling unit for ventilation.

25.6 References

1. https://www.dwyer-inst.com/Product/Miscellaneous/Accessories/StaticPressureSensors/StaticPressureTips-Accessories
2. https://www.setra.com/
3. http://www.automatedbuildings.com/news/mar09/articles/ebtron/090224111308ebtron.htm
4. https://www.csemag.com/articles/best-practices-for-infiltration-and-building-pressurization/

Chapter 26 - Hydronic Differential Pressure Transmitters (AI)

26.1 Description

Hydronic Differential Pressure Transmitters (HDPTs) are devices that sample the hydronic fluid in a system and produce an electrical signal that is proportional to the sensed differential pressure. HDPTs are useful in the control and monitoring of hydronic system pressures. They provide indications of the pressure drop across hydronic system components such as heat exchangers and filters. As debris is deposited in these devices, the pressure drop across them increases which decreases the system flow. The HDPT allows real-time monitoring of the pressure drop across heat exchangers and filters so that they may be serviced and maintained when the pressure drop reaches a predetermined threshold. The typical units of measure for pressure drop are Feet Head and Pounds per Square Inch. The HDPT contacts are connected to an analog input of a BAS controller. It is then programmed to interpret the HDPT signal (0-10 VDC, 2-10 VDC, 0-5 VDC, etc.) so that it may be used to control and/or monitor a system pressure or differential pressure. HDPTs come in various operating pressure ranges. To provide accurate and stable control of the differential pressure, it is best to select an HDPT with a differential pressure range that closely matches the normal or expected operating differential pressure.


Photo 292 - HDPT (No Manifold)


Photo 293 - HDPT with Three-Port Manifold


Photo 294 - HDPT with Five-Port Manifold

The HDPT is connected to hydronic systems through sensing lines that are typically constructed of ¼ inch piping (hard or soft) and compression fittings to provide leak-free connections. A ¾" threadolet is typically welded to the pipe. A ¾ inch by ¼ inch bushing is then installed. Finally, a ¼ inch brass or copper compression fitting is then used to connect the ¼ inch copper tubing to the piping system. Isolation valves are typically provided at the piping system connections to facilitate installation, testing, service, and calibration of the HDPT. They also prevent system shutdowns if HDPT replacement or piping modifications are required in the future. These piping system connections are also used to purge air from the HDPT piping. The HDPT may or not be mounted to a manifold. Manifolds typically come in either a 3-valve or 5-valve arrangements (Photographs 293 & 294). The three-valve manifolds have two isolation valves and a bypass valve. The five-valve manifold has the same valves as the three-valve manifold, but also has vent valves on the high and low sides to allow each line to be purged of air. Manifolds make the testing, calibration, and purging of air much easier than HDPTs without them.

The HDPT allows the pressure differential across the supply and return lines to be monitored by the BAS and used for the control of the speed of pumps equipped with variable frequency drives. The HDPT taps should be located where they will provide the best indication of the system demand in real-time. The taps in the supply and return lines are typically located 2/3 to 3/4 down the longest pipe run to ensure that the reading is representative of the system demand or load. If a circle is drawn on a mechanical plan around the largest grouping of two-way control valves that serve their connected equipment, the center of this circle is approximately where the HDPT should be monitoring. Some systems require the installation of multiple HDPTs each of which is located to provide representative differential pressures. The pump would then be controlled to maintain the lowest HDPT reading to setpoint. This concept applies to all hydronic systems (condenser, chilled, hot water, etc.). When the HDPT taps are located at the central plant or closer to the pumps than the center mass of the control valves, it will not sense changes in the load in real time. There will be a time lag. As a result, there will be air-handling units, terminal units, and other hydronic equipment that are unable to reach design flows (and design heating and cooling capacity) until the differential pressure returns to the differential pressure setpoint.

The pump rating indicated on the mechanical equipment schedules is typically used to determine the differential pressure range of the HDPT. The pump's total dynamic head in Feet Head is divided by 2.31 (pressure in FT HD to PSIG conversion factor) to arrive at the maximum possible differential pressure, in PSIG, that the pump can generate. The actual operating differential pressure will be less than this value, but if most of the two-way coil control valves were to close off then it may be possible to see differential pressures approaching the maximum differential pressure produced by the pump. If a pump is rated for 600 GPM at 100 FT HD, this is equivalent to a differential pressure of 43.3 PSIG. Therefore, a differential pressure transmitter rated for 0-50 PSIG would be selected to provide the differential pressure reading for this application. This method of selecting the HDPT is valid, but could potentially result in a differential pressure transmitter with higher ranges than actually required.

A temporary differential pressure setpoint (15 PSIG is often used) is typically selected arbitrarily by the Controls Contractor when they initially program the central plant logic. This value is ultimately determined by the TAB Contractor during the hydronic system balancing. Once the minimum differential pressure (between the supply and return mains) required to provide design water flows to the hydronic coils is known, this value becomes the differential pressure setpoint. The operating range of the HDPT is typically twice the "normal" or differential pressure setpoint. However, this value is typically not known until the TAB contractor completes their hydronic system balancing work. An HDPT with multiple differential pressure ranges could be used for added flexibility. The lowest range that encompasses the final differential pressure setpoint should be selected and the BAS analog input configured accordingly. The final hydronic differential pressure setpoint is often in the 10-20 PSIG range. As a result, HDPTs with a 0-30 PSIG range are often selected.

The manufacturer provides maximum and minimum ambient temperature and humidity limits for the reliable operation of the HDPTs. To ensure that the HDPT's maximum and minimum operating temperatures are not exceeded, thermal traps must be provided. This is especially true of chilled water, hot water, and steam applications. The pressure sensing lines must be long enough to limit the conduction of heat to and from the system being monitored to maintain the HDPT at safe operating temperatures. Connections with high-temperature (>90°F) systems run the risk of overheating the HDPT if the sensing lines are too short. Connections with low-temperature (<50°F) systems run the risk of overcooling, and more importantly, condensation formation, if the sensing lines are too short. Condensation forms not only on the surface of the sensing lines and transmitter, but it can also form inside the transmitter enclosure which can fill with condensate.


Photo 295 - HDPT Initially Installed without a Thermal Trap


Photo 296 - Condensation On and Inside HDPT Enclosure


Photo 297 - Thermal Trap Installed to Prevent Condensation

26.2 Applications

1. **Differential Pressure Monitoring**: In variable flow hydronic applications where the equipment loads are controlled by varying the flow through two-way control valves, the hydronic flow is controlled by either modulating the VFD driving the pump or by opening a bypass control valve to maintain a constant pressure differential between the supply and return mains. The HDPT indicates the system demand by monitoring the pressure differential between the supply and return lines. As the control valves modulate open in response to their respective zone controls, the differential pressure between the supply and return mains reduces. In response, the pump VFD increases speed to maintain the differential pressure at the setpoint. Likewise, when the control valves modulate towards the closed position, the differential pressure increases and the pump VFD speed is reduced to maintain the differential pressure at the setpoint. The differential pressure setpoint is determined during the hydronic system balancing and the BAS controller is programmed to maintain this setting.

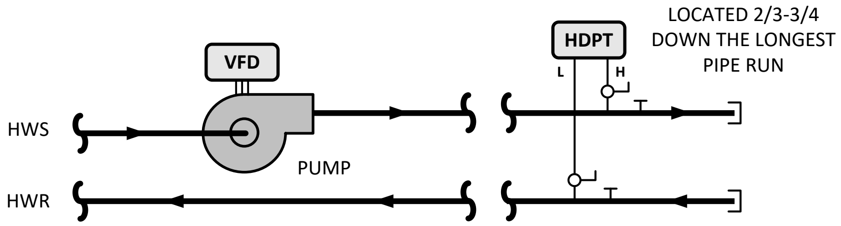

Figure 226 - HDPT for Monitoring Differential Pressure

2. **Heat Exchanger Pressure Drop Monitoring:** By monitoring the differential pressure drop across heat exchangers, such as chiller barrels and plate-and-frame heat exchangers, it is possible to determine when it is necessary to open up them for cleaning. It is helpful to record the initial or baseline pressure drop when the heat exchanger is new or recently cleaned for future reference. Having the current differential pressure is not useful without a reference value to compare it to. It is recommended that the initial differential pressure be provided somewhere on the BAS graphics or noted somewhere on the heat exchanger. When the differential pressure across the piping element reaches the high limit setpoint, then a color change or alarm can be generated to alert the staff that cleaning is required.

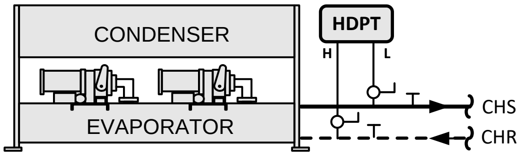

Figure 227 - HDPT for Monitoring Chiller Condenser/Evaporator Pressure Drop

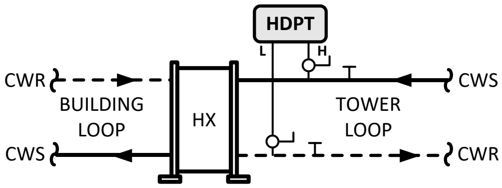

Figure 228 - HDPT for Monitoring Heat Exchanger Pressure Drop

3. **Tank Level Monitoring and Control:** Water level monitoring can also be accomplished with the use of a HDPT. Water exerts a hydrostatic pressure that is proportional to the height of water column. For every foot of water height, the hydrostatic pressure increases by 0.4331 PSIG. Therefore, if the pressure at the bottom of a tank is measured at 43.3 PSIG, this means that the height of the water column is 100 feet in a vented tank. This is the method that the height and volume of many water storage tanks are calculated. It is simple, accurate, and has no moving parts.

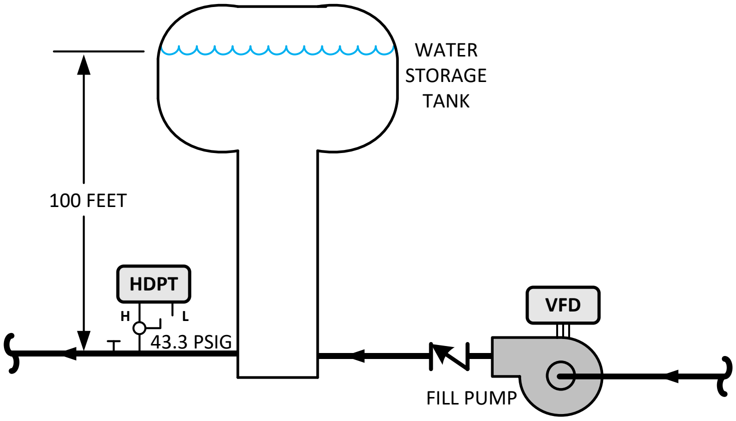

Figure 229 - HDPT for Monitoring Liquid Level in a Storage Tank

4. **Pump status monitoring**: When the high- and low-pressure sensing lines are installed across a pump, it can detect that it is operating when a certain differential pressure has been exceeded. The use of an HDPT for pump status monitoring is not common. CSRs and HDPSs are typically used. The key is to select the HDPT with a range that corresponds to the maximum differential pressure across the pump. Because of the turbulence at the pumps, snubbers are often used to improve measurement accuracy and improve the longevity of the HDPT.

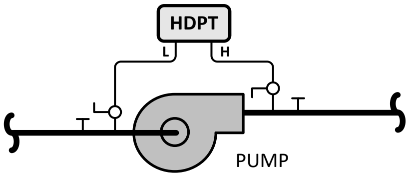

Figure 230 - HDPT for Pump Operating Status Monitoring

26.3 Typical Control Wiring

Explanations of the various wiring strategies have been provided in Chapter 3: BAS Inputs and Outputs. To avoid unnecessary repetition of the typical transmitter wiring diagrams, the following table has been provided. Depending on the installation requirements and the preference of the installing Controls Contractor, the wiring strategies implemented can go in several directions.

Analog Input Device Signal	BAS Input Signal	Signal Wiring Configuration
4-20 mA	4-20 mA	Loop-Powered (Two-Wire) Transmitter
4-20 mA	2-10 VDC	Loop-Powered w/ 500 Ohm Resistor
4-20 mA	1-5 VDC	Loop-Powered w/ 250 Ohm Resistor
4-20 mA	4-20 mA	Three-Wire Transmitter
0-10 VDC	0-10 VDC	Three-Wire Transmitter
2-10 VDC	2-10 VDC	Three-Wire Transmitter

Table 107 - Possible Analog Input Wiring Strategies

26.4 Analog Input Testing and Verification

The general test procedures for Hydronic Differential Pressure Transmitters include the following:

1. Verify that the HDPT has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The operating range, mounting, manifold porting, tubing/piping connections, isolation valves, thermal traps, output contacts, wiring, and output signals are some of the features that should be verified.
2. Verify that the HDPT and its pressure taps have been installed at the correct or optimum location. They should not be located near tees, elbows, or other piping elements that can cause turbulence that could affect the differential pressure reading.
3. Verify that the HDPT has been installed per the manufacturer's installation recommendations. If the HDPT has multiple pressure ranges, verify that the appropriate pressure range has been selected. The lowest pressure range that encompasses the normal operating pressure should be used.
4. As applicable, posture the HVAC system or the required components (damper, control valves, fans, VFD speeds, etc.) to prevent unwanted system changes (modulation, staging, cycling) during the sensor/transmitter calibration.
5. Verify that the HDPT has been correctly wired. The HDPT may have multiple sets of contacts that must be properly landed and coordinated to provide the required signal type and range. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify that the HDPT connections to the system (threadolets, bushings, tubing, piping, tubing, valves, manifold, thermal traps, etc.) are installed correctly. The high-pressure port should be connected to the higher pressure zone (supply main and upstream of heat exchangers and pumps) while the low-pressure port is connected to the lower pressure zone (return main, atmosphere, and downstream of heat exchangers and pumps). If a manifold is used, verify that it is correctly piped and all valves are properly postured. Thermal traps (for chilled and hot water piping) should be provided to prevent the HDPT from exceeding its temperature and moisture limitations.
7. Verify that the HDPT has been connected to the correct BAS controller analog input. Removing the signal or 24 VAC power wire from the transmitter will cause the data point reading to change. Alternatively, if a manifold is used, the isolation valve can be closed and the bypass valve (and purge valve, if equipped) opened to simulate zero differential pressure. It is a good idea to make a note or take a screenshot of the data point reading that occurs when the analog input device is disconnected.
8. At the same time that the HDPT's electrical contacts are opened, verify and document that the data point bound to the BAS graphics also changes.
9. Verify that the HDPT and its wires at the BAS controller end have been labeled.

10. Verify that the units/facets for the HDPT are correctly displayed. The facets for hydronic pressure are typically either feet head, feet Water Gauge (W.G.), feet Water Column (W.C.), or PSIG.
11. Verify that the precision of the HDPT reading is appropriately set. Differential pressures and differential pressure setpoints are typically displayed with one decimal place.
12. Verify the accuracy of the HDPT reading by comparison with reference readings from a calibrated digital manometer meter. At each calibration point, record the BAS controller reading, hydronic pressure meter reading, and the signal generated by the HDPT. Pressures can be field simulated with a calibration pump or the hydronic system at various settings. If the HDPT does not produce the appropriate output signal or does not report across its full range, then it should be calibrated by modifying its zero and span adjustments. If accurate calibration results cannot be attained, then it should be replaced. Single-point calibrations are not recommended because they will not produce the required information to calibrate transmitter readings. Refer to Chapter 2: BAS Calibration and Chapter 3: BAS Inputs and Outputs for more information.

    In this example, an HDPT produces an output signal that ranges from 4-20 mA. However, the BAS controller analog input typically monitors voltage signals in the 0-10 VDC or 2-10 VDC ranges. With the use of a 250 or 500 Ohm resistor across the analog input terminals of the BAS controller, the current signal from the HDPT is converted to a 1-5 VDC or 2-10 VDC voltage signal, respectively.

Reading	Pressure (PSIG)	Volts (VDC)
Minimum	0	2
Maximum	50	10

Table 108 - Initial Analog Input Configuration

If the analog input configuration of the BAS controller is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs. The scale and offset values are used to calculate the differential pressure reading from the voltage signal provided by the HDPT. These values will be updated based on calibration readings as explained in later steps.

Volts (DCV)	PSIG
2	0
10	50

Initial Scale= 6.25
Initial Offset= -12.50

Table 109 - Initial Scale-Offset Calculation

13. Verify the accuracy of the HDPT reading by comparison with reference readings from a calibrated high-pressure hydronic manometer. Pressure is a parameter that is easily simulated with a calibration pump or compressed gas source, so calibration based on multiple readings is easily acquired. At each calibration point, record the BAS controller reading, high-pressure hydronic manometer reading, and the signal generated by the HDPT. If the HDPT does not produce the appropriate output signal or does not report across its full range, then it should be calibrated by modifying its zero and span adjustments. If accurate calibration results cannot be attained, then it should be replaced. Single-point calibrations are not recommended because they will not produce the required information to calibrate transmitter readings. Refer to Chapter 2: BAS Calibration and Chapter 3: BAS Inputs and Outputs for more information.

Reading	Test/Instrument (PSIG)	BAS Data Point (PSIG)	Signal (VDC)
1	0.0	-0.13	1.98
2	25.0	24.88	5.98
3	50.0	49.75	9.96

Table 110 - Initial Transmitter/BAS Calibration Check

14. Update the configuration of the analog input of the BAS controller and retest to confirm the calibration of the HDPT. If the pressure readings still appear to be inaccurate or the HDPT does not provide readings across its full range, then replacement of the HDPT is recommended. The Owner should not have to accept HDPTs that do not perform to the manufacturer's specified accuracy. Record the final analog input calibration and correction factors.

Reading	Pressure (PSIG)	Signal (VDC)
Minimum	0	1.98
Maximum	50	9.96

Table 111 - Updated BAS Controller Configuration

If scale and offset factors are used to configure the parameters of the BAS controller analog input, update them accordingly using the same methodology explained in Chapter 3: BAS Inputs and Outputs. Confirm the accuracy of the analog input configuration by applying test pressures and verifying that the resulting differential pressure readings.

1.98	0
9.96	50

Updated Scale= 6.27
Updated Offset= -12.41

Table 112 - Updated Scale-Offset Calculations

15. Release all overrides used to posture the system for testing and calibration.
16. Review the trend data to verify that the HDPT reliably and consistently reports to the BAS controller. Numeric interval trend extensions are used to collect trend data at the programmed time intervals. Initial trend data intervals should be short (5 seconds-5 minutes) intervals to allow transient issues (that cannot be identified with longer intervals) to be identified. Once the testing and commissioning stage has concluded, longer time intervals (10-20 minute) can be used to minimize data storage requirements. There should not be any gaps or omissions in the trend data. The trend data should show that the HDPT corresponds with the programmed control logic and schedule.
17. Document the results of all testing. Screenshots of the analog input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the analog input device.

26.5 Review

1. True or False: The tubing connections make no difference in the HDPT readings. Answer: ________
2. In a variable-volume hot water system, the high and low pressure ports of the HDPT used should be connected to the system at _________ to provide the best indication of system demand.
   - A. At the chiller
   - B. Central plant
   - C. 2/3 to 3/4 down the longest pipe run
   - D. At the very end of the longest pipe run
3. If an HDPT has a pressure range of 0-50 PSIG static pressure and an output voltage of 2-10 VDC, the indicated static pressure will be ______________ PSIG if the analog input voltage is 6.46 VDC?
4. A thermal trap is typically not required for an HDPT that monitors the differential pressure in a ____________ water system.
5. What is the scale and offset if the HDPT has a pressure range 0-200 PSIG and a corresponding signal range of 2-10 VDC? Answer: Scale=______________ Offset=______________
6. Heat travels between the piping and the HDPT by __________________.
7. Opening the ________________ valve and closing the two system isolation valves of an HDPT manifold results in the differential pressure dropping to a zero (0) reading.
8. How high (Feet Head) is the water level if the static pressure at the bottom of a vented storage tank is 216.55 PSIG? Answer: __________________.

26.6 References

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3. https://realpars.com/differential-pressure-transmitter/
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5. https://assets.kele.com/product-assets/ashcroft-inc/skus/cx4f014210iw/related/datasheet_245_cx4f014210iw.pdf
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Chapter 27 - Duct-Mounted Airflow Measuring Stations - Differential Pressure (AI)

27.1 DESCRIPTION

An Airflow Measuring Station (AFMS) is a device that samples the velocity pressure at the point of measurement so that the velocity and airflow may be calculated. AFMSs are typically installed in ducts (supply, return, exhaust, etc.), fan inlets, and at outdoor air openings to quantify the airflow rate. The AFMS works on the same principle as a Pitot tube. It samples the upstream (or Total) pressures and downstream (or Static) pressures at multiple locations which are equally spaced to provide a representative average velocity over the measured cross-section. The upstream sampling points are open to a common plenum which averages the upstream Total Pressure readings. The downstream static pressure sampling points are similarly configured to provide an average Static Pressure.

Photo 298 - Duct-Mounted AFMS Installation

Photo 299 - Outdoor AFMS Installation in a Rooftop Unit

Photo 300 - Typical AFMS ADPT Installation

Per Equation 95, the Velocity Pressure is equal to the Total Pressure minus the Static Pressure. The upstream side of the velocity pressure pickup provides the Total Pressure reading and is connected to the high port of the ADPT with pneumatic tubing. The downstream side of the velocity pressure pickup provides the Static Pressure reading and is connected to the low-pressure port of the ADPT. The ADPT directly measures the average velocity pressure acquired by the velocity pickup and transmits a direct current voltage (0/2-10 VDC) signal to the BAS controller that is proportional to the velocity pressure. From the velocity pressure reading (provided by the ADPT), the BAS controller calculates the velocity and finally the airflow rate. AFMSs are used when the control and monitoring of airflows are required. This chapter focuses on duct-mounted AFMSs whose operation is based on velocity pressure readings acquired by ADPTs. This type of AFMS consists of a multi-point velocity pressure pick-up array, an ADPT, and a BAS controller.

Using Equation 99 (Assuming standard conditions), the air velocity is calculated from the measured velocity pressure. Airflow (CFM) is then calculated by multiplying the calculated velocity by the cross-sectional area of the duct (Equation 100) where the AFMS is installed. The variable represented by CF is the Correction Factor which is initially one and is updated to calibrate the BAS airflow reading to the reference calibration airflow reading.

(Equation 95) $TP = SP + VP$

(Equation 96) $VP = TP - SP$

(Equation 97) $V = 1096.7\sqrt{\frac{V_P}{\rho}}$ (Non-Standard Conditions)

(Equation 98) $\rho_{Local} = \frac{P_B}{(T_F+460)}$ (Non-Standard Conditions)

(Equation 99) $V = 4{,}005\sqrt{VP}$ (Standard Conditions of 70°F and 29.92 inches Mercury)

(Equation 100) $$Flow = A * V = FT^2 * \frac{Feet}{Minute} = \frac{FT^3}{Minute}$$

(Equation 101) $$Flow = A * 4005 * \sqrt{VP} * CF$$

The duct configuration where the AFMS is installed has a major impact on the resulting velocity/airflow reading. Any field condition that causes turbulence can negatively affect the airflow reading because its operation is based on pressure measurements. For the AFMS reading to be useful, it must be stable. This only occurs when the velocity profile is smooth and uniform. The manufacturer-recommended minimum lengths of straight duct upstream and downstream of the AFMS are required to provide the optimal conditions for accurate and stable airflow readings. These distances provide time for the airstream to stabilize and acquire a uniform velocity profile before being measured by the velocity pickup and ADPT. An AFMS should never be installed downstream of any duct fitting, louver, damper, or transition that causes turbulence without the minimum lengths of straight duct. Mechanical duct designs often do not provide adequate space to allow the proper installation of AFMSs. Site conditions often dictate that the AFMS be installed in the available space which may not satisfy the manufacturer's installation recommendations. If this is the case, it is unlikely that the AFMS will function properly and provide accurate airflow indications. Turbulence can render AFMSs useless if the airflow readings are so erratic and unstable that they cannot be relied upon to provide a stable reading for airflow control or monitoring. AFMSs based on thermal dispersion technology are quickly gaining favor in the HVAC control industry because they are less susceptible to turbulence caused by less than ideal duct configurations.

Photo 301 - Fan Inlet AFMS Installation

Photo 302 - Test Tees at Filter ADPT

Photo 303 - Typical AFMS Velocity Array and Tubing Close-Up

AFMS installed in outdoor air intakes and ducts present unique challenges. The incoming outdoor air can carry moisture, dust, and debris which are deposited on the upstream side of the multi-point velocity pressure array. As the debris continues to accumulate and block the sampling ports, the indicated airflow drops because it is unable to sense the actual Total Pressure. As a result, the indicated air velocity and airflow gradually reduces. If the air-handling unit is programmed to maintain a minimum outdoor airflow rate, the outdoor air and return air dampers will modulate to maintain the outdoor airflow at setpoint. If the multi-point sampling array is not cleaned, the indicated outdoor airflow will continue to reduce and the control logic will continue to close off the return air damper and open the outdoor air damper to maintain the outdoor airflow rate at setpoint. Eventually, the outdoor air damper will be fully open and the return air damper will be fully closed. If an air-handling unit appears to be economizing when it should not, the AFMS should be visually inspected and tested.

The AFMS requires periodic cleaning and inspection to ensure that the air sampling ports remain open and free of obstructions and that all pneumatic tubing connections are intact. Ideally, a filter rack sized for a low velocity (150-300 FPM) should be installed upstream of the AFMS to prevent debris accumulation on the AFMS or its flow straightener. A flow straightener may be installed upstream of the AFMS to smooth its velocity profile and reduce the air turbulence before the velocity pressure is measured by the ADPT. Access doors should be provided upstream of the multi-point velocity pressure array and upstream of the airflow straightener to allow inspection and cleaning. Airflow straighteners and AFMSs in outdoor air streams accumulate debris quickly and should be inspected and cleaned at least quarterly to ensure that the sampling ports of the multi-point velocity pressure array are clean and the airflow indication remains accurate.

The size of the AFMS relative to the airflow to be measured is another important aspect to consider. Air-handling units often have AFMS installed in the outdoor air intake for the control of the minimum ventilation airflow. If the outdoor intake opening were 48 Inches by 36 Inches, the AFMS is typically configured to sample this opening. The air-handling unit in this scenario has a minimum outdoor airflow of 500 CFM and maximum supply airflow of 3,000 CFM. The AFMS is typically installed to monitor and control the minimum ventilation airflow rate. The resulting air velocity at the minimum ventilation airflow rate is only 41.67 Feet Per Minute (FPM) at standard conditions. This air velocity results in a velocity pressure of 0.000108 Inches W.C. This velocity pressure is extremely low and will result in poor control because the smallest damper movement will continually overshoot and undershoot the airflow setpoint. It is evident that the resulting velocity pressure is very low and would change constantly under the best of duct conditions. If we also consider the close proximity of size transitions, duct fittings, louvers, and dampers, the turbulence they generate will overshadow the velocity pressure signal we seek to capture. Turbulence creates pressure waves that are detected by the ADPT in the form of signal noise. It impossible to monitor and control airflow when the noise signal generated by turbulence (of nearby duct components) is greater than the velocity pressure signal.

(Equation 102) $$V = \frac{Flow}{A} = \frac{500}{(4*3)} = 41.67\frac{Ft}{Minute}$$

(Equation 103) $$VP = \left(\frac{V}{4{,}005}\right)^2 = \left(\frac{41.67}{4{,}005}\right)^2 = 0.000108\ Inches\ W.C.$$

A better solution is to install both minimum and maximum outdoor air ducts to monitor and control the outdoor airflow. The minimum outdoor air duct and damper should be sized to provide an air velocity of 250-1000 FPM at the design minimum outdoor airflow rate. The maximum outdoor air damper only has to open during the economizer (or free-cooling), demand-controlled ventilation, or purge/flush cycles. Higher air velocities generate higher velocity pressures, but this has to be balanced against the noise, pressure drop, and the level of negative-pressurization available in the mixed-air plenum. In some cases, there may not be enough negative pressurization to induce sufficient airflow through the minimum outdoor air duct that is sized for 500 FPM velocity. A minimum outdoor air duct that is 12 inches by 12 inches ($1FT^2$) would provide the velocity pressure 0.01559 inches W.C. which is 144 times (0.0156/0.000108) higher and much easier for the BAS controller to measure and control. Inline fans may be utilized to deliver the minimum-required ventilation air through a minimum outdoor air duct. A speed controller is used to set the speed that delivers the required ventilation airflow or a VFD modulates the fans speed to maintain the outdoor airflow at setpoint. This duct should be equipped with a filter bank to prevent duct debris build-up on the AFMS.

(Equation 104) $$Flow = A * V = FT^2 * \frac{Feet}{Minute} = \frac{FT^3}{Minute}$$

(Equation 105) $$A = \frac{Flow}{\mathrm{V}} = \frac{500}{500} = 1.0FT^2$$

(Equation 106) $$VP = \left(\frac{V}{4{,}005}\right)^2 = \left(\frac{500}{4{,}005}\right)^2 = 0.0156\ Inches\ W.C.$$

27.1.1 AFMS Calibration

Calibration of AFMSs based on differential pressure is a two-step process. First, the ADPT must be calibrated to ensure that it functions properly and provides an accurate differential pressure reading across its full range. This is important because the calculated velocity and airflow are based on the measured velocity pressure. Test pressures are applied to the ADPT to verify that it accurately reports the differential pressure. The configuration of the analog input is then updated based on the calibration data points so that it accurately reports the differential (velocity) pressure indicated by the ADPT.

Secondly, the velocity and airflow indications are calculated from the measured velocity pressure and must be calibrated. Only the parameters (area, correction factor, etc.) that affect the calculated velocity and airflow are updated. Calibrating the velocity and airflow indications requires reference readings from calibrated instruments using industry-accepted procedures. AFMS flow indications are typically calibrated by TAB Contractors when they perform the testing, adjusting, and balancing of the air distribution systems. However, any person with calibrated instruments and proper usage can perform airflow measurements for calibration purposes. Calibrating duct-mounted AFMS readings typically requires an update of the flow area and/or correction factor to make the BAS-indicated airflow rate match the airflow indications from the calibrated reference instruments.

27.2 Applications

1. **Airflow Monitoring and Control**. AFMSs may be installed anywhere where monitoring of an airstream is required. AFMS are often utilized to monitor and control the flow of outdoor air to air-handling units. In this application, the

AFMS is used to quantify the flow of ventilation or "fresh" air introduced to the space through air-handling units. The air-handling unit is typically programmed to modulate the outdoor air, return air, and relief air dampers to maintain a certain minimum outdoor airflow rate. It may also modulate a dedicated outdoor air fan to maintain the outdoor airflow at setpoint.

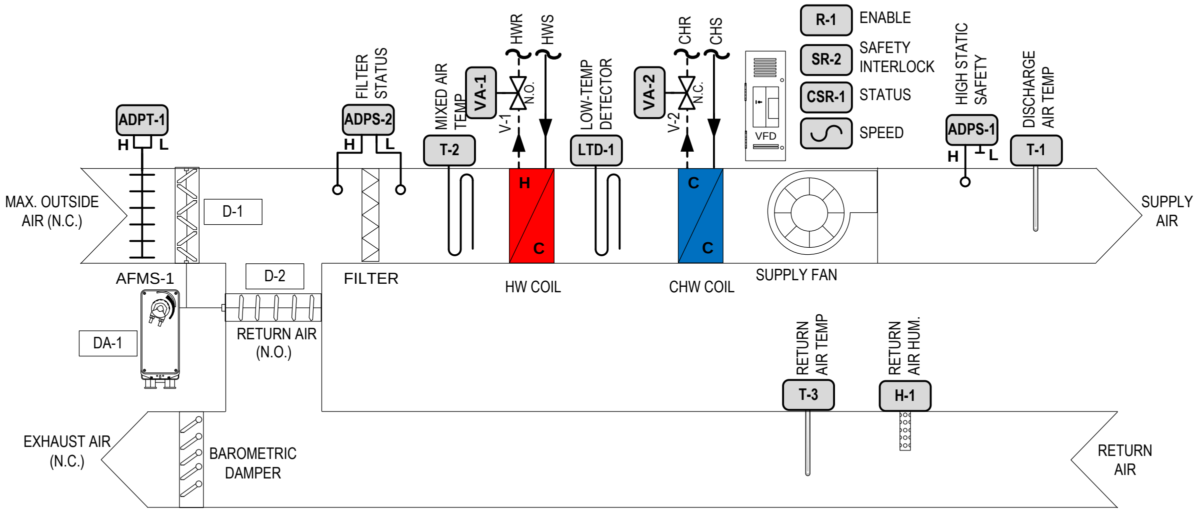

Figure 231 - Minimum Outdoor Air Fan and AFMS Installation

2. **Airflow Tracking**. When an air-handling unit has both supply and return fans, AFMSs are often used to control the speed of the return fan. The supply fan speed is typically modulated to maintain a certain static pressure in the supply duct. An AFMS quantifies the supply airflow and may either be located in the supply duct downstream of the air-handling unit or it may be located at the inlet of the supply fan. The return airflow is likewise quantified with a separate AFMS.

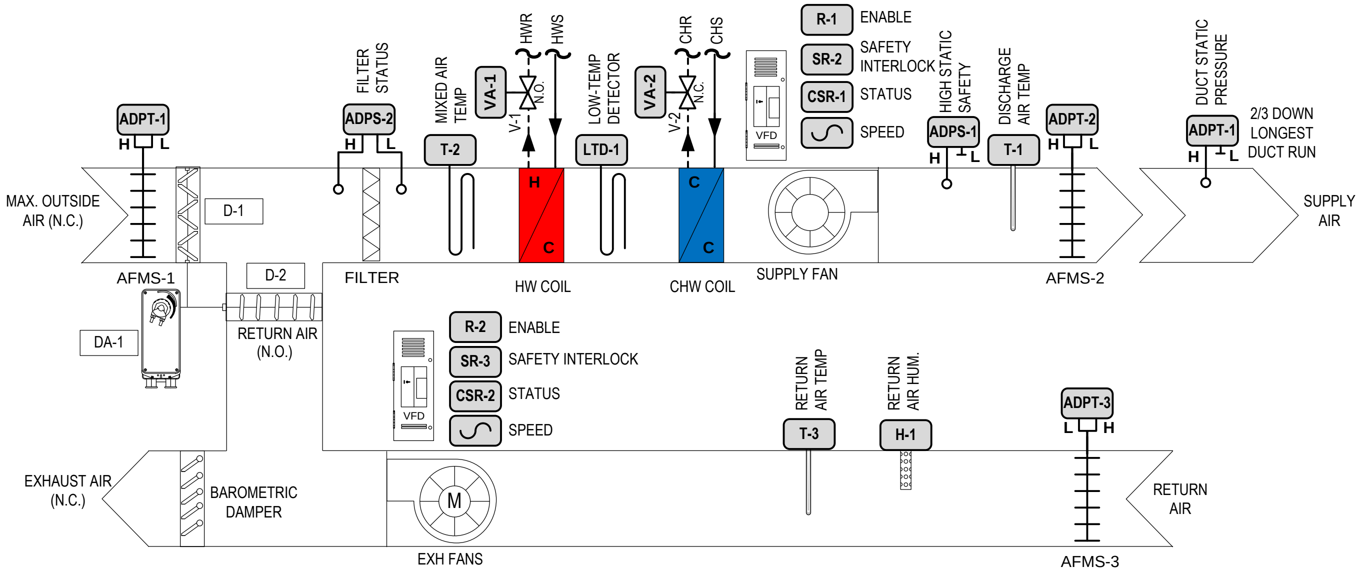

Figure 232 - Air-Handling Unit with Multiple Airflow Measuring Stations

An airflow offset is designated that typically coincides with the minimum required outdoor airflow requirement. If the design minimum outdoor airflow is 2,000 CFM, then the return fan's VFD speed is modulated to maintain the return fan airflow rate at 2,000 CFM less than the supply fan flow rate. The outdoor airflow measuring station is used to make adjustments to the outdoor air damper position to control the outdoor airflow to setpoint.

% Full Flow	Supply Fan Flow (CFM)	Airflow Differential (CFM)	Return Fan Flow (CFM) Setpoint
20	4,000	-2,000	2,000
40	8,000	-2,000	6,000
60	12,000	-2,000	10,000
80	16,000	-2,000	14,000
100	20,000	-2,000	18,000

Table 113 - Supply and Return Fan Flows

27.3 Analog Input Testing and Verification

There are two typical configurations for AFMSs whose operation is based on differential pressure measurement. The first type of AFMS is equipped with circuitry that processes the integral ADPT reading and performs the airflow calculations. It typically includes a user interface panel that allows entry of the duct dimensions and calibration factors. The AFMS provides a standard signal (0/2-10 VDC) to the BAS that is proportional to the calculated airflow rate. The second type of airflow measurement system is composed of individual components and the BAS calculates the airflow rate (not the AFMS). The AFMS has no circuitry and is treated as a typical velocity pressure probe. The AFMS is connected to the ADPT with polyethylene tubing and the ADPT is connected to the BAS with wiring. This test procedure assumes that the BAS measures the velocity pressure from the AFMS through the ADPT and calculates the resulting airflow. Depending on the AFMS configuration, some of the steps in this procedure may not be required:

1. Verify that the AFMS/ADPT has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The operating range, mounting, bidirectional/unidirectional, output contacts, wiring, and output signals are some of the features that should be verified.

2. Verify that the AFMS/ADPT has been installed at the correct or optimum location. If the ADPT is utilized with an AFMS, verify that the minimum upstream and downstream duct diameters recommended by the manufacturer have been provided.

3. Verify that the AFMS/ADPT has been installed per the manufacturer's installation recommendations. Verify and document all adjustable dip switch, selector, and jumper settings to ensure the correct signal and range are generated. The final operating range of the AFMS/ADPT should be consistent with the intended application. If the AFMS/ADPT has no location that satisfies the manufacturer's recommended location requirements, document the criteria that are not satisfied with measurements.

4. As applicable, posture the HVAC system or the required components (damper, control valves, fans, VFD speeds, etc.) to prevent unwanted system changes (modulation, staging, cycling) during the sensor/transmitter calibration.

5. Verify that the ADPT has been correctly wired. The ADPT may have multiple sets of contacts that must be properly landed and coordinated to provide the required signal type and range. Drawings or sketches are typically best for documenting the wiring strategies used.

6. Verify that the pneumatic tubing/piping and probes are correctly connected and properly located. The high-pressure port should be connected to the higher pressure zone (upstream of filter, coil, or AFMS) while the low-pressure port is connected to the lower pressure zone (downstream of filter, coil, or AFMS). It is not uncommon to find errors in the tubing connections. Verify that test tees have been provided to facilitate differential pressure testing and calibration.

7. Verify that the ADPT has been connected to the correct BAS controller analog input. Removing the signal or 24 VAC power wire from the transmitter will cause the data point reading to change. It is a good idea to make a note or take a screenshot of the data point reading that occurs when the analog input device is disconnected.

8. At the same time that the ADPT's electrical contacts are opened, verify and document that the data point bound to the BAS graphics also changes.

9. Verify that the ADPT and its wires at the BAS controller end have been labeled.

10. Verify that the units/facets for the AFMS/ADPT are correctly displayed. The facets for velocity pressure, velocity, and airflow are typically Inches Water Column (W.C.), Feet per Minute (FPM), and Cubic Feet per Minute (CFM), respectively.

11. Verify that the precision of the AFMS/ADPT reading is appropriately set. Velocity pressures are typically displayed

with three decimal places because these values are typically very small. Velocity and flow readings and setpoints of the same are typically displayed with whole numbers (no decimals).

12. Verify that the BAS controller's analog input point has been properly configured to match the ADPT differential pressure range and output signal. BAS controllers are manufactured in other parts of the world, so it is not uncommon for the pressures to be initially in Metric units and converted to English units. With the use of a 250 or 500 Ohm resistor across the analog input terminals of the BAS controller, a current signal from the ADPT may be converted to a 1-5 VDC or 2-10 VDC voltage signal, respectively.

Reading	Static Pressure (Inches W.C.)	Signal (VDC)
Minimum	0	2
Maximum	1.5	10

Table 114 - Initial Analog Input Configuration

If the analog input configuration of the BAS controller is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs. The scale and offset values are used to calculate the differential pressure reading from the voltage signal provided by the ADPT. These values will be updated based on calibration readings as explained in later steps.

Volts (DCV)	Inches (W.C.)
2	0
10	1.5

Calculated Scale= 0.188
Calculated Offset= -0.375

Table 115 - Initial Scale-Offset Calculation

13. Verify the accuracy of the ADPT reading by comparison with reference readings from a calibrated digital manometer meter. At each calibration point, record the BAS controller reading, hydronic pressure meter reading, and the signal generated by the ADPT. Low pressures can be field simulated with a calibration pump or fan assembly at various settings. If the ADPT does not produce the appropriate output signal or does not report across its full range, then it should be calibrated by modifying its zero and span adjustments. If accurate calibration results cannot be attained, then it should be replaced. Single-point calibrations are not recommended because they will not produce the required information to calibrate transmitter readings. Refer to Chapter 2: BAS Calibration and Chapter 3: BAS Inputs and Outputs for more information.

Reading	Test/Instrument (Inches W.C.)	BAS Data Point (Inches W.C.)	Signal (VDC)
1	0.0	0.01	1.91
2	0.75	0.74	5.98
3	1.5	1.55	10.03

Table 116 - Initial Transmitter/BAS Calibration Check

14. Update the configuration of the analog input of the BAS controller with the test data from the previous step, so that it accurately reports the static pressure. Retest to confirm proper functioning of the ADPT. If the differential pressure readings still appear to be inaccurate or the ADPT does not provide readings across its full range, then replacement of the ADPT is recommended. The owner should not have to accept ADPTs that do not perform to the manufacturer's specified accuracy. Record the final analog input calibration and correction factors.

Reading	Test/Instrument (Inches W.C.)	Signal (VDC)
Minimum	0	1.91
Maximum	1.5	10.03

Table 117 - Updated BAS Controller Configuration

If scale and offset factors are used to configure the parameters of the BAS controller analog input, update them accordingly using the same methodology explained in Chapter 3: BAS Inputs and Outputs. Confirm the accuracy of the analog input configuration by applying test pressures and verifying that the resulting differential pressure readings.

Volts (DCV)	Inches (W.C.)
1.91	0
10.03	1.5

Updated Calculated Scale= 0.185
Updated Calculated Offset= -0.353

Table 118 - Updated Scale-Offset Calculations

15. Verify that the accuracy of the airflow reading by comparison with reference readings from calibrated instruments. The reference airflow reading will be performed by either performing a duct traverse or by the summation of DRG hood readings.

Reading	Test/Instrument (CFM)	AFMS (CFM)	Error (% RD)
Minimum	1525	1575	3.3
Maximum	6576	6473	1.6

Table 119 - Updated BAS Controller Configuration

16. Update the variables used in the calculation of the airflow reading. Do not update any variables (scale and offset) having to do with the ADPT reading as it has already been calibrated. Update the Area and Correction Factor, Gain, or equivalent to calibrate the BAS airflow indication to the reference airflow readings and retest to confirm accuracy compliance.
17. Release all overrides used to posture the system for testing and calibration.
18. Review the trend data to verify that the airflow meter reliably and consistently reports to the BAS controller. Numeric interval trend extensions are used to collect trend data at the programmed time intervals. Initial trend data intervals should be short (5 seconds-5 minutes) intervals to allow transient issues (that cannot be identified with longer intervals) to be identified. Once the testing and commissioning stage has concluded, longer time intervals (10-20 minute) can be used to minimize data storage requirements. There should not be any gaps or omissions in the trend data. The trend data should show that the airflow meter corresponds with the programmed control logic and schedule.
19. Document the results of all testing. Screenshots of the analog input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the analog input device. Record the damper position and the duct static pressure at the time of flow calibration. This provides valuable data for future reference.

27.4 Review

1. At standard conditions, a velocity pressure of 1 inch W.C. is produced by standard air at a velocity of ________ FPM.
2. True or False: Missing test tee caps on the pneumatic lines of a VAV terminal unit pose no issue for airflow measurements with an AFMS. Answer: _________
3. True or False: An AFMS based on velocity pressure performs the same no matter how the velocity pickup tubing connections are configured. Answer: _________
4. Duct fittings and transitions cause ________________________ which negatively impacts AFMSs based on velocity pressure readings.
5. Some AFMSs have airflow ________________________ installed upstream of them to smooth the air and reduce turbulence before measuring the velocity pressure.

27.5 References

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2. https://www.krueger-hvac.com/files/white%20papers/white_paper_airflow_measurements.pdf

Chapter 28 - Terminal Unit Airflow Measuring Stations - Differential Pressure (AI)

28.1 DESCRIPTION

Pressure-independent terminal units are the components of an air distribution that control the flow of air to or from a conditioned zone. Some applications require a constant flow of air and are referred to as Constant-Air-Volume (CAV) terminal units. Other applications allow the airflow rates to vary between pre-defined minimum and maximum airflow rates and are typically referred to as Variable-Air-Volume (VAV) terminal units. For example, medical, industrial, and laboratory spaces may require constant airflow control to maintain the space pressurization to specific conditions (positive or negative) based on the use of the space. Other facilities are able to take advantage of the efficiency improvements provided by variable airflow systems.

Photo 304 - Terminal Unit Controller Example #1

Photo 305 - Terminal Unit Controller Example #2

Photo 306 - Terminal Unit Controller Example #3

In either case, they control the airflow by utilizing Airflow Measuring Stations (AFMS) which allow the measurement and control of the airflow. This is very important to understand because air distribution systems are very dynamic and may be composed of tens to hundreds of terminal units each conditioning their respective zones. As they vary their airflow rates throughout the day, the duct static pressure changes. The air-handling unit controller typically modulates the fan speed to maintain the duct static pressure at setpoint. The terminal unit controllers utilize the AFMSs based on differential pressure to determine the airflow rate and modulate the primary air damper to maintain the local airflow rate at the calculated setpoint.

Photo 307 - Typical Single-Duct Terminal Unit with Hot Water Heat Coil

Photo 308 - Typical Single-Duct Terminal Unit with No Heat Coil

Photo 309 - Typical Single-Duct Terminal Unit with Electric Heat

Many terminal unit controllers are designed with an integral ADPT which is connected by pneumatic tubing to the airflow pickup. Manufacturers of the terminal unit flow pickups have developed, through extensive laboratory testing, K-factors for various inlet duct diameters. The K-factor is defined as the airflow across the airflow pickup that results in a 1 inch W.C. pressure differential. K-factors are developed for each terminal unit inlet diameter. It is very much akin to the flow coefficient or C_V of a control valve. Titus is a prominent manufacturer of DRGs, VAV terminal units, and the Aerocross airflow pickups.

Duct Size (In.)	Flow Range (CFM)	Area (FT^2)	Circumference (In.)	K-factor
4	0-225	0.087	12.6	273
5	0-350	0.136	15.7	360
6	0-500	0.196	18.8	448
7	0-650	0.267	22.0	667
8	0-900	0.349	25.1	904
9	0-1050	0.442	28.3	1,167
10	0-1400	0.545	31.4	1,436
12	0-2000	0.785	37.7	1,891
14	0-3000	1.069	44.0	3,015
16	0-4000	1.396	50.3	3,839

Table 120 - Terminal Unit AeroCross K-factors (Titus/Aerocross)

Many Controls Contractors use the Titus K-factors regardless of terminal unit manufacturer. They provide a good starting point for all terminal units when initially programming and configuring the BAS controllers. This gets the airflow indication of the BAS controllers in the "ball park," but calibration of the airflow reading against reference airflow instruments is still absolutely required. If a terminal unit BAS controller is installed or replaced, the airflow reading should always be calibrated to verify its performance and ensure optimal efficiency. This is the only way to ensure the 500 CFM indicated flow is equal to 500 CFM of actual flow. Per the following equation, Honeywell® Spyder® controllers (and others) calculate airflow through VAV terminal units.

(Equation 107) $$Flow = K * \sqrt{DP} = X \frac{FT^3}{Minute}$$

The airflow pickups used in pressure-independent terminal units use a multi-point velocity sampling array which may be in the form of either a cross, ring, or diamond. The design of the airflow pickup amplifies the differential pressure measured across it, so it does not measure true Total Pressure (TP) and Static Pressure (SP) as does a typical duct-mounted AFMS or Pitot tube. This signal amplification provides accurate and stable control of the airflow even at low airflow rates consistent with operation at minimum airflow setpoints. It is easier to think of terminal unit airflow pickup pressures as simply High and Low pressures. The High pressure is determined from the sampling points on the upstream side of the airflow pickup. They are open to a common plenum or chamber which pneumatically averages the sensed pressures. The Low pressure is determined from the downstream sampling points which are similarly configured. The difference between the High and Low pressures is directly measured by the ADPT by its direct connections to the airflow pickup. Based on the size of the airflow pickup and its measured differential pressure, the AFMS airflow is calculated.

Photo 310 - Diamond Velocity Pickups

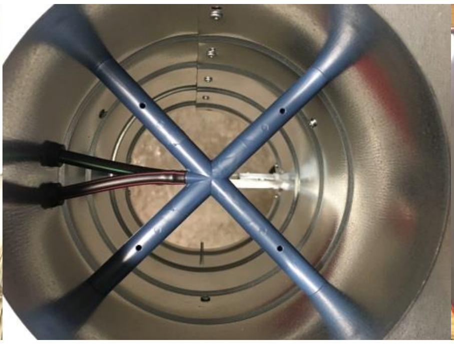


Photo 311 - Plastic Velocity Pickups

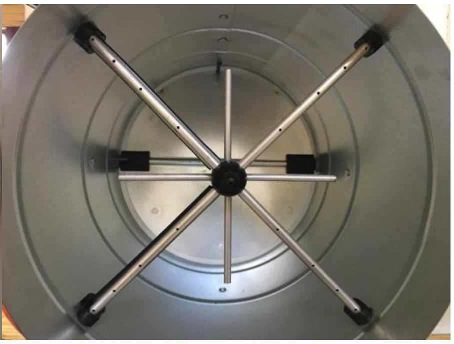


Photo 312 - Stainless Steel Velocity Pickups

The control damper is used to modulate the flow of primary air through the terminal unit. It is located after the airflow pickup so that the turbulence it generates as it throttles the primary air does not affect the airflow indication. Its shaft extends to the outside of the inlet duct and into the control cabinet (if equipped). The electric or pneumatic actuator is secured to the damper shaft and terminal unit enclosure or mounting plate. The terminal unit controller may have an integral actuator or it may control a separate actuator. Depending on the terminal unit manufacturer, there may be a mechanical stop. Photograph 314 shows a 3/8 inch long pin at the bottom of the inlet duct which stops the damper blade from rotating past the fully closed position. If no stop exists, properly securing the actuator to the damper shaft is critical. When the actuator is mounted to the damper, it must be at the same position (either fully open or fully closed) to function correctly. Most actuators have a manual drive release button or crank that allows the actuator to be set to one extreme position or the other. The end of the damper shaft typically has an arrow or line that indicates the radial position of the damper blade. When the arrow is parallel to the duct, it is fully open. When it is perpendicular to the duct, it is fully closed.


Photo 313 - VAV Terminal Unit Test Tees with Caps


Photo 314 - Damper Blade Mechanical Stop (Bottom)


Photo 315 - VAV Terminal Unit Butterfly Damper

Most terminal units have a very short duct collar (4-8 inches) where the adjoining ductwork connects to the terminal unit inlet. Therefore, the airflow indication is highly dependent on the construction of the terminal unit's inlet ductwork. Duct fittings and directional changes cause air turbulence which negatively impacts the indicated airflow and its stability. When they are installed too close to the AFMS they create turbulence which creates a constantly changing differential pressure and airflow indications. This makes airflow calibration difficult because we are trying to calibrate to a target that is constantly moving. The airflow reading selected to compare to the reference airflow reading provided by calibrated instruments may be higher or lower than the actual flow. This could result in the airflow accuracy improving or worsening with each calibration attempt. As a result, more calibration iterations are required.

In many installations, the terminal units are connected to the supply ductwork with insulated flexible ducts. Even a perfectly straight flexible duct generates turbulence because of its rough and irregular internal surface. When flexible ducts terminate at the terminal unit duct collar with acute angles it imparts even higher levels of turbulence in the supply airstream just as it is measured by the AFMS. This has a significant effect on the accuracy and stability of the differential pressure measured by the ADPT which subsequently impacts the calculated velocity and airflow indication. In some situations, airflow control is impossible because the indicated airflow constantly changes. This, in turn, causes the damper position to constantly adjust which will significantly shorten the actuator's life.

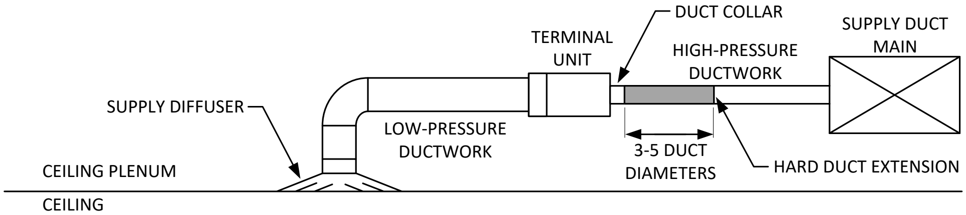


Figure 233 - Terminal Unit Hard Duct Extension

For optimum accuracy and stability of airflow readings, a hard duct extension of at least 3-5 duct diameters (minimum 18 inches) constructed of straight sheet metal is recommended at the terminal unit duct collar. This length of straight duct provides room for the supply air velocity profile to stabilize before measurement. In addition, the angle of the hard or flexible duct connection to the duct extension should not be any larger than 30 degrees. This will result in a stable airstream which will significantly improve the accuracy and stability of the velocity and airflow indications. In addition, it will also improve the effectiveness of the calibration process because the airflow indications will not be fluctuating erratically. Fewer iterations will be required to calibrate the BAS airflow indication to the reference airflow readings if sufficient straight duct is provided at terminal unit inlets.

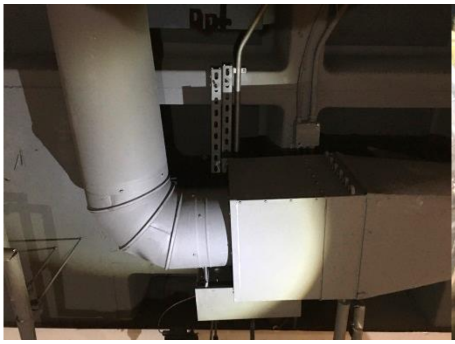


Photo 316 - 90-Degree Elbow at Terminal Unit Inlet

Photo 317 - Size Transition at Terminal Unit Inlet

Photo 318 - Straight Duct at Terminal Unit Inlet

Loose pneumatic tubing connections and missing test tee caps can negatively impact the differential pressure readings acquired by the ADPT. The tubing connections between the BAS controller and the airflow pickup should be checked to verify that they are fully seated and tightly sealed. Most terminal unit have test tees with caps which provide a convenient place to compare the differential pressure reported by the BAS controller to readings measured by a calibrated manometer. It is not uncommon to find caps missing, cracked, split, or dry-rotted in existing systems. If any of these conditions exist, they should be replaced with new caps. Missing or leaky caps will drastically affect the differential pressure reading which will negatively impact the calculated velocity and airflow. If the high side test tee cap is missing, the sensed differential pressure will be lower than actual resulting in a low airflow indication and potentially a fully open primary air damper. If the low side test tee cap is missing, the sensed differential pressure will be higher than actual resulting in a high airflow indication and potentially a fully closed primary air damper.

The size of the airflow pickup relative to the airflow to be measured is a very important aspect to consider. Terminal units sized for current and future airflow loads can be problematic, especially when the future load never materializes. Oversizing of the terminal units is never recommended and should only be implemented with Constant-Air-Volume (CAV) terminal units. If the design flow is 400 CFM, then a terminal unit with a 6 inch diameter inlet would be better suited than one with an 8 inch diameter inlet per Table 120. Oversized terminal units often experience problems when operating at minimum airflows because small changes in damper position create large changes in airflow rate. Each terminal unit has a minimum airflow threshold for stable airflow control and it varies with each terminal unit installation. Flow control issues are typically encountered when the airflow rates fall below this minimum threshold. The velocity pressure and airflow indications can go to zero and quickly overshoot the airflow setpoint when the required damper position approaches the fully closed position. This occurs when the minimum airflow setpoint is too low and/or when the terminal unit is oversized. When low-flow hunting is discovered in a terminal unit, its minimum airflow rate must be increased until the terminal unit controller can maintain control of the airflow in a stable manner. Alternatively, the damper position can be locked to a constant percentage open. Low-flow hunting generates a distinct sound as the control damper fully closes and opens repeatedly. The best solution is to right-size the terminal unit for the current load and plan for a terminal unit change when the future expansion occurs.

28.2 AFMS Calibration

Calibration of terminal unit AFMSs based on differential pressure requires a two-step process. The ADPT must first be calibrated to ensure that it functions properly and provides an accurate air differential pressure reading because the calculated airflow is based on this value. Test pressures are applied to the ADPT to verify that it accurately reports the differential pressure across its full range. The configuration of the analog input is then updated based on the calibration data points so that it accurately reports the differential pressure. If it cannot be calibrated, the ADPT or entire terminal unit controller must be replaced.

Calibration of the ADPT in terminal unit controllers is a gray area for typical commissioning projects. It is recognized that calibration of the airflow indication is required, but little attention is paid to the calibration of the differential pressure reading provided by the terminal unit ADPT. Terminal unit ADPT pressure differential readings are typically only tested and calibrated when there is an issue with the airflow indication. Verifying the ADPT pressure reading takes time which is typically limited. The TAB Contractor does not do it because sensor and transmitter calibration is typically viewed as a controls function that should be performed by the Controls Contractor. Some specifications require the TAB Contractor to provide sensor calibration readings, but they typically do not have access to the control system or the required training to make the required corrections. Consequently, they must work with the Controls Contractor to calibrate the BAS input and output device readings. It is typically assumed that the Controls Contractor has calibrated the differential pressure reading provided by the ADPT, but this rarely occurs based on my experience. There is a high reliance on the fact that the ADPTs are new and should function correctly and accurately. Ideally, the ADPT differential pressure readings are calibrated before the airflow indications are calibrated.

After the ADPT differential pressure reading has been calibrated, the airflow indications must then be calibrated. Calibration of airflow indications requires reference airflow readings from calibrated instruments using industry-accepted procedures. Terminal unit AFMSs are typically calibrated by the TAB Contractors when they perform the testing, adjusting, and balancing of the pressure-independent terminal units and their connected air devices. To calibrate the airflow reading, the airflow rate is measured with calibrated instruments, compared to the BAS-indicated airflow, and the K-factor (or similar correction factor) is updated. This calibration process corrects the BAS airflow indication so that it matches the instrument airflow reading within the calibration tolerance. Updating the K-factor is performed in one of two ways. Either the new K-factor is calculated manually and entered into the BAS controller configuration or the actual airflow reading is entered and the BAS controller automatically calculates the new K-factor. The K-factor is typically updated using the following equation:

(Equation 108) $$Kfactor_{NEW} = Kfactor_{OLD} * \frac{Flow_{Measured}}{Flow_{BAS}}$$

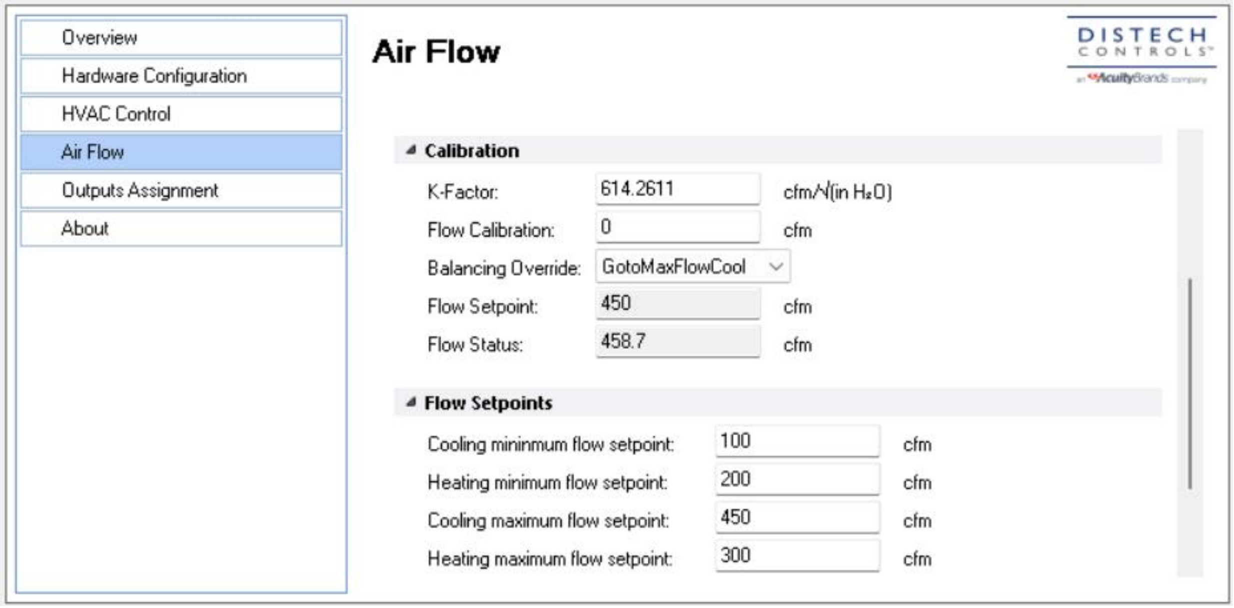
Before and after calibrating the airflow indication of terminal units it is very important to document four things: K-factor, terminal unit damper position, airflow pickup pressure, and duct static pressure. These items provide concrete evidence that the airflow calibration process occurred, the conditions at the time, and its results. In addition, they provide solid baseline performance data to use when changes to the system operating characteristics are evaluated or the results are questioned. BAS screenshots are an efficient way to document the before and after data.

If the airflow indicated by the BAS is higher than the actual airflow, the updated K-factor will decrease per Equation 108. When the K-factor is updated with the new value, the airflow reading will immediately drop to a lower value that is close to the measured airflow. The control damper will begin to modulate to a more open damper position as it attempts to increase the airflow rate to setpoint. If the airflow indicated by the BAS is lower than the actual airflow, the updated K-factor will increase per Equation 108. When the K-factor is updated with the new value, the airflow reading will immediately increase to a value close to the measured airflow. The control damper will begin to modulate to a more closed damper position as it attempts to reduce the airflow rate to setpoint.

Before taking more hood readings or duct traverses, the airflow should be given time to stabilize and provide a fairly steady airflow indication. This is especially true if there was a large difference between the measured and indicated airflow rates. Measuring too quickly could reduce the accuracy of the airflow indication and/or increase the number of iterations required to calibrate the airflow reading. If all goes well, the verification reading should be within the calibration tolerance. If it is not, perform another K-factor update and retest. If the K-factor corrections go up and down, verify that the supply duct static pressure is not changing and verify the inlet conditions at the terminal unit duct collar. It is also helpful to monitor the differential pressure with a digital manometer or Magnehelic® gauge using the test tees on the pneumatic lines. This pressure differential reading should be stable. If it is not, look for poor terminal unit inlet conditions (elbows, flexible duct, short duct length, etc.) that cause inlet turbulence and take corrective actions.

A terminal unit summary screen (Figure 8) that details the terminal unit data (primary air damper position, airflow, airflow setpoint, etc.) of all terminal units is very useful because it allows you to view the performance of several terminal units simultaneously. The duct static pressure, VFD speed, and discharge air temperature readings should also be part of the terminal unit summary screen. After all terminal unit airflows have been calibrated, the summary screen is also used to determine the final duct static pressure setpoint that leaves one or two "critical" terminal units with their primary air damper fully open while simulating full cooling conditions (maximum airflow). Screenshots of the summary screens also serve as evidence of the system performance at the time of the balancing.

The following diagram shows the terminal unit balancing module for the Distech line of terminal unit BAS controllers. This module allows the terminal unit flow parameters (maximum flow, minimum flow, inlet diameter, initial K-factor, damper actuator stroke time, etc.) to be entered and updated. It provides the ability to enter the measured airflow rate. Once it is entered, the new K-factor (or K-factor offset depending on the manufacturer) is automatically updated to calibrate the BAS-indicated airflow rate to the airflow rate provided by calibrated reference instruments.



Air Flow

Calibration

K-Factor: 614.2611 cfm/$\sqrt{\text{(in }H_2O)}$

Flow Calibration: 0 cfm

Balancing Override: GotoMaxFlowCool

Flow Setpoint: 450 cfm

Flow Status: 458.7 cfm

Flow Setpoints

Cooling mininmum flow setpoint: 100 cfm

Heating minimum flow setpoint: 200 cfm

Cooling maximum flow setpoint: 450 cfm

Heating maximum flow setpoint: 300 cfm

Figure 234 - Terminal Unit Airflow Calibration Module

28.3 Innovation

Distech Controls has a line of terminal unit controllers that utilize Ethernet communication. This innovation eliminates the time that is typically expended establishing equipment communications, identifying communication issues, troubleshooting the communication issues, and correcting the communication issues. The Eclypse Connected VAV controllers (ECY-VAV Series) can provide pre-loaded software to reduce deployment, start-up, and checkout time. Ethernet cables with completed RJ45 connectors are installed between terminal unit controllers to form the daisy chain communication trunk. This innovative controller has a polarity insensitive differential pressure transmitter which eliminates pneumatic tubing errors and the time associated with identifying and correcting them. If any single controller in the communication chain should fail, the Ethernet communication bus continues to operate unaffected. This controller is also capable of communicating with its Allure EC Smart Vue space temperature sensor over Ethernet wiring. Conventional two-wire temperature sensors can also be utilized. Its small form factor makes it very easy to install in even the smallest terminal unit control cabinets. Its design has addressed the shortcomings of the typical terminal unit controller resulting in lower installation, start-up, maintenance, and operating costs. Perhaps the best feature of this controller is its embedded web server that allows access to its graphical user interface through a conventional web browser. From this interface you can also enable the EC-gfx software and view the Envision graphics. Therefore, before it is ever connected to the building automation system, you can set its IP address, configure its operation, set airflow rates, and even calibrate airflow.


Photo 319 - Actuator/Damper Shaft Connection


Photo 320 - Pneumatic Velocity Pressure Tubing Connections

Photo 321 - Ethernet Communications Daisy-Chain Wiring

28.4 Applications

Airflow measuring stations have many applications which include, but are not limited to, the following:

1. **Pressure-Independent Terminal Units**. Pressure-independent Terminal Units (TUs) or VAV boxes maintain space temperature by modulating the supply airflow rate from its minimum to its maximum flow setpoint. The airflow pickups are typically integral to the terminal units. The BAS controller is either installed on site or may be sent to the terminal unit manufacturer for factory installation.

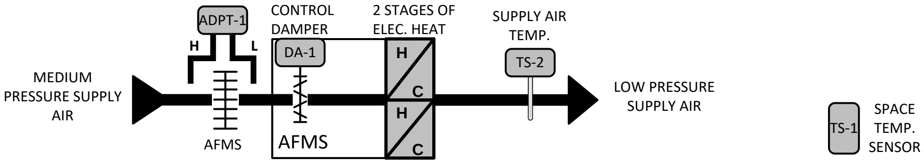


Figure 235 - VAV Terminal Unit Airflow Measuring Station Diagram

2. **Airflow Tracking**. Airflow tracking is often employed in medical, process, manufacturing, and laboratory settings to maintain pressure differentials among spaces. Areas that are to remain sterile are positively pressurized to keep contaminants out and areas that contain dangerous chemicals or odors are negatively pressurized for containment. For instance, if a laboratory is to be maintained at negative pressurization and it has variable supply airflow for cooling, the variable exhaust air terminal unit will be controlled to maintain an exhaust airflow that is higher than the supply airflow by an offset value. Therefore, as the supply airflow rate changes with changing cooling requirements, the exhaust flow rate modulates to maintain a flow rate that is 200 CFM greater than the supply airflow rate.

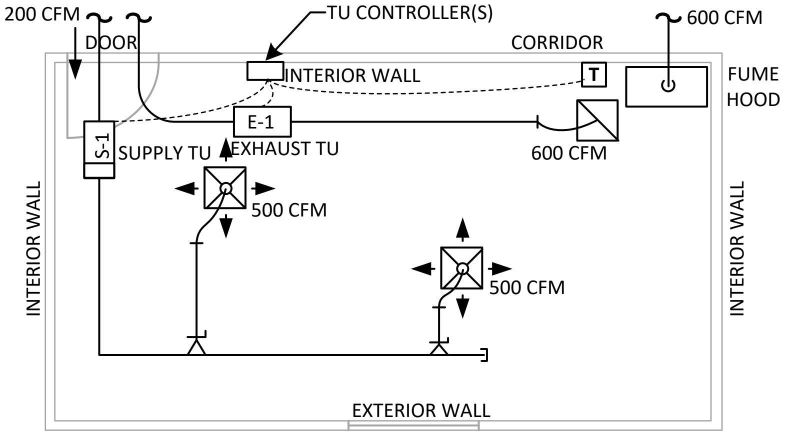


Figure 236 - Typical Laboratory Pressure Control Using Terminal Unit AFMS

The following table illustrates the values that would typically be observed in a laboratory space with two variable-flow terminal units that are controlled to maintain negative pressurization by maintaining 200 CFM more exhaust air than supply air. The supply air terminal modulates its control damper to provide an airflow that maintains the space at its cooling setpoint. The exhaust terminal unit modulates to maintain the calculated exhaust airflow setpoint which is 400 CFM less than the supply airflow because the 600 CFM is exhausted by the fume hood. Therefore, the exhaust airflow tracks 200 CFM higher than the supply airflow rate to maintain the negative space pressure. The same strategy is employed for spaces that must be maintained at positive pressurization.

% Full Flow	Supply TU Flow (CFM)	Hood Exhaust Flow (CFM)	Exhaust TU Flow (CFM) Setpoint
20	800	-600	-400
40	1,200	-600	-800
60	1,600	-600	-1,200
80	2,000	-600	-1,600
100	2,400	-600	-2,000

Table 121 - Supply and Exhaust Terminal Unit Flows

28.5 Typical Control Wiring

Terminal unit controllers are a unique type of BAS controller that typically includes an integral floating actuator (for damper modulation) and differential pressure transmitter (for airflow calculation). The Eclypse ECY-VAV controller has four universal inputs and can support up to two modulating actuators and/or two floating actuators making it very flexible. It also has CAT5 subnet that can support Allure EC Smart Vue Series communicating sensors that can incorporate occupancy, humidity, carbon dioxide, and various combinations thereof without requiring hard-wired inputs. A typical terminal unit wiring example would include 24 VAC power, space temperature sensor (communicating or hard-wired), discharge air temperature sensor, and wiring for a reheat coil (electric or hot-water), if required. It is common for a VAV terminal unit controller to also monitor and control an exhaust fan or two. The following wiring diagram is typical of Distech ECY terminal unit controllers.

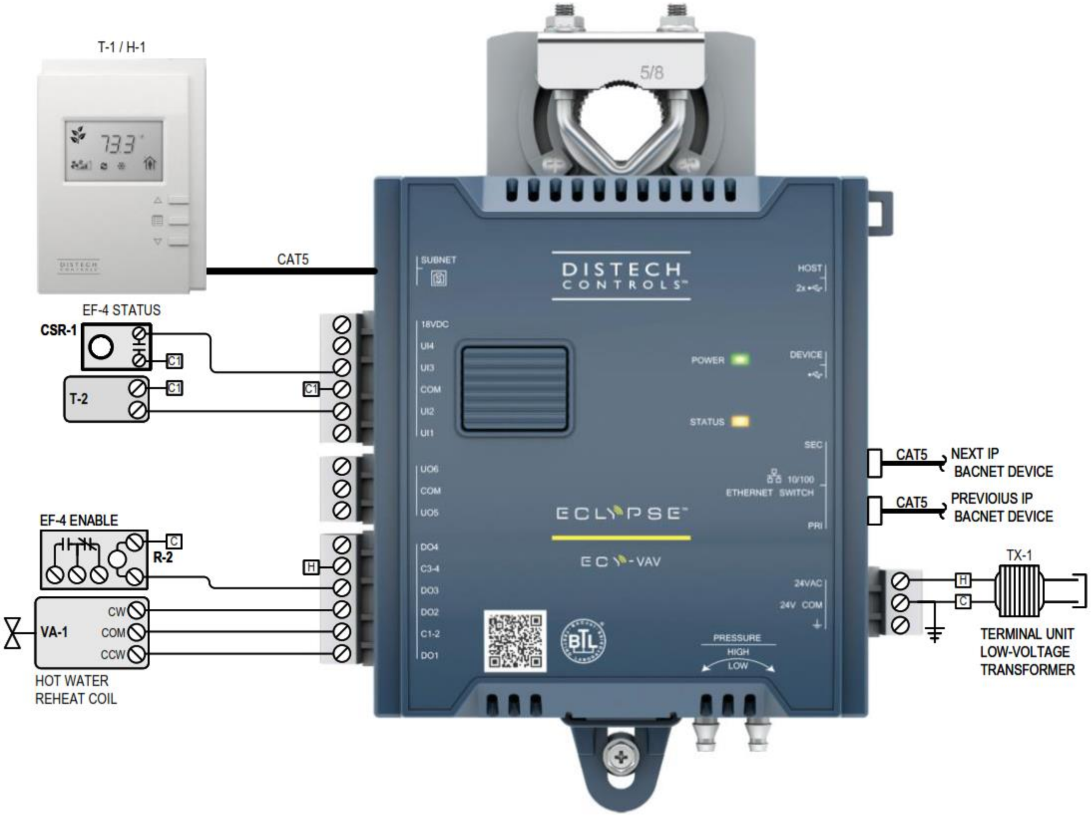


Figure 237 - Typical Terminal Unit Wiring

If the ADPT and actuator are integral to the BAS controller, then there will be no wiring to verify. If the ADPT is separate from the BAS controller, then it will be reviewed and tested to verify that it is properly wired. Explanations of the various wiring strategies have been provided in Chapter 3: BAS Inputs and Outputs. To avoid unnecessary repetition of the typical transmitter wiring diagrams, the following table has been provided. Depending on the installation requirements and the preference of the installing Controls Contractor, the wiring strategies implemented can go in several directions.

Analog Input Device Signal	BAS Input Signal	Signal Wiring Configuration
4-20 mA	4-20 mA	Loop-Powered (Two-Wire) Transmitter
4-20 mA	2-10 VDC	Loop-Powered w/ 500 Ohm Resistor
4-20 mA	1-5 VDC	Loop-Powered w/ 250 Ohm Resistor
4-20 mA	4-20 mA	Three-Wire Transmitter
0-10 VDC	0-10 VDC	Three-Wire Transmitter
2-10 VDC	2-10 VDC	Three-Wire Transmitter

Table 122 - Possible Analog Input Wiring Strategies

28.6 Analog Input Testing and Verification

Terminal unit controllers whose velocity is based on differential (velocity) pressure readings are typically equipped with an integral ADPT. Whether integral or separate, most of the testing and verification steps will apply. The velocity pickup is typically part of the terminal unit and its size is dependent on the airflow requirements.

1. Verify that the TU, AFMS, and BAS controller (with integral ADPT) have the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The operating range, communication protocol, mounting, size, inlet duct design, output contacts, wiring, and output signals are some of the features that should be verified.
2. Verify that the TU, AFMS, and BAS controller have been installed at the correct or optimum location.
3. Verify that the TU, AFMS, and BAS controller have been installed per the manufacturer's installation recommendations for each component. Verify and document all adjustable dip switch, selector, and jumper settings to ensure the correct signal and range are generated. The final operating range of the ADPT should be consistent with the intended application. Note any instances where the supply ductwork or flexible ductwork connects to the terminal unit duct collar at acute angles as this will cause turbulence which affects the stability of the velocity pressure reading. Press the damper clutch and verify that the zero position of the actuator and damper are correctly aligned.
4. As applicable, posture the HVAC system or the required components (damper, control valves, fans, VFD speeds, etc.) to prevent unwanted system changes (modulation, staging, cycling) during the sensor/transmitter calibration. Verify the operating parameters of the air-handling unit or fan providing the airflow and whether it can maintain it in a stable manner. Note the VFD speed, amperage, and the duct static pressure setpoint. A duct static pressure measurement is recommended to verify the local duct static pressure.
5. Verify the control action of the terminal unit primary air damper by space temperature setpoint changes. Command the damper to 0% open then 100% open to verify that is strokes in the correct direction. If it does not stroke in the correct direction, you can either change the binary output assignments or switch the binary output wire terminations.
6. Document the currently programmed inlet diameter, K-factor, and primary air damper position that provides the design airflow rate. The damper position provides indicates the terminal unit's ability to provide the required airflow. Observe the airflow indication to assess its stability and whether the terminal unit can reach the design airflow rate.
7. If the ADPT is integral to the BAS controller, remove the pneumatic tubes from the velocity pressure ports of the BAS controller. This will cause the velocity pressure to drop to zero if it reads correctly. Consequently, the calculated velocity and airflow indications should also go to zero. If the ADPT is separate from the BAS controller, verify that the ADPT has been connected to the correct BAS controller analog input by removing the signal or 24 VAC power wire from the transmitter. This will cause the data point reading to change. It is a good idea to make a note or take a screenshot of the data point reading that occurs when the analog input device is disconnected.
8. If the ADPT is integral to the BAS controller, skip to step #10. At the same time that the ADPT is disabled, verify and document that the data point bound to the BAS graphics also changes.
9. Verify that the ADPT has been correctly wired. The ADPT may have multiple sets of contacts that must be properly landed and coordinated to provide the required signal type and range. Drawings or sketches are typically best for documenting the wiring strategies used. Wiring for other miscellaneous connected points (space temperature, humidity, setpoint adjustment, fan status, fan enable, etc.) will be covered under the appropriate chapters.
10. Verify that the pneumatic tubing/piping and probes between the airflow pickup and the ADPT are correctly located and tightly fitting. The high-pressure port of the ADPT should be connected to the upstream side of the airflow pickup. The low-pressure port of the ADPT should be connected to the downstream side of the airflow pickup. It is not uncommon to find errors in the tubing connections. Also, verify that the test tees have tightly fitting caps. In existing systems, verify that the test tees are not dry-rotted, cracked, or split.
11. While at the terminal unit, verify the size (typically diameter) of the inlet duct collar. The manufacturer's nameplate typically provides this data or it may be measured. Because the airflow is directly determined by the K-factor flow equation (Equation 107), the velocity is calculated by dividing the calculated airflow by the inlet area (in square feet).
12. Verify that the ADPT and its wires at the BAS controller end have been labeled. In addition, provide a label that indicates the terminal unit identity and it corresponding MAC address/IP address.
13. Verify that the units/facets for the ADPT pressure, calculated velocity, and calculated airflow are correctly displayed. The facets for velocity pressure, velocity, and airflow are typically Inches Water Column (W.C.), Feet per Minute (FPM), and Cubic Feet per Minute (CFM), respectively.
14. Verify that the precision of the ADPT reading is appropriately set. Differential pressures are typically displayed with three decimal places because these values are typically very small. Air velocity and flow readings and setpoints of the same are typically displayed with whole numbers (no decimals).

15. Verify that the BAS controller's analog input point has been configured to match the ADPT differential pressure sensor range and output signal. A signal generator may be also be used to validate whether the analog input has been correctly configured. Ramp the simulated voltage or current signal up and down to verify that the BAS controller properly interprets the analog input signal.

Reading	Static Pressure (Inches W.C.)	Signal (VDC)
Minimum	0	2
Maximum	1.5	10

Table 123 - Initial Analog Input Configuration

If the analog input configuration of the BAS controller is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs. The scale and offset values are used to calculate the differential pressure reading from the voltage signal provided by the ADPT. These values will be updated based on calibration readings as explained in later steps.

Volts (DCV)	Inches (W.C.)
2	0
10	1.5

Calculated Scale= 0.188

Calculated Offset= -0.375

Table 124 - Initial Scale-Offset Calculation

16. Verify the accuracy of the ADPT readings by comparison with reference readings from a calibrated digital manometer. At each calibration point, record the BAS controller reading, digital manometer reading, and the signal generated by the ADPT. Low pressures can be field simulated with a calibration pump, fan assembly, or the air-handling unit. If the ADPT does not produce the appropriate output signal or does not report across its full range, then it should be calibrated by modifying its zero and span adjustments. If accurate calibration results cannot be attained, then it should be replaced. Single-point calibrations are not recommended because they will not produce the required information to calibrate transmitter readings. Refer to Chapter 2: BAS Calibration and Chapter 3: BAS Inputs and Outputs for more information.

Reading	Test/Instrument (Inches W.C.)	BAS Data Point (Inches W.C.)	Signal (VDC)
1	0.0	-0.02	1.91
2	0.75	0.75	5.98
3	1.5	1.49	9.92

Table 125 - Initial Transmitter/BAS Calibration Check

17. Update the configuration of the analog input of the BAS controller until the BAS controller accurately reports the differential pressure. Retest to confirm proper functioning of the ADPT. If the differential pressure readings still appear to be inaccurate or the ADPT does not provide readings across its full range, then replacement of the ADPT is recommended. Record the final analog input calibration and correction factors.

Reading	Test/Instrument (Inches W.C.)	Signal (VDC)
Minimum	0	1.91
Maximum	1.5	9.92

Table 126 - Updated BAS Controller Configuration

If scale and offset factors are used to configure the parameters of the BAS controller analog input, update them accordingly using the same methodology explained in Chapter 3: BAS Inputs and Outputs.

Volts (DCV)	Inches (W.C.)
1.91	0
10.03	1.5

Updated Calculated Scale= 0.185

Updated Calculated Offset= -0.353

Table 127 - Updated Scale-Offset Calculations

18. Posture the terminal unit for maximum design airflow which also verifies that it is capable of providing design airflow given the duct construction and duct static pressure. Be sure to give the terminal unit airflow PID loop time to adjust to the new airflow setpoint and stabilize. Simulating the maximum required airflow demand may be done by several

methods. A common method for supply air terminal units is to set the terminal unit space temperature setpoint to a low value (10°F -15°F below current space temperature). Alternatively, a balancing module or program setting may be used to set the supply airflow rate to its maximum flow setpoint. Some people set the minimum airflow setpoint equal to the maximum airflow setpoint. High space temperatures may be simulated with a resistance decade box or variable resistor. A space heater may also be used to simulate high space temperatures as it could result in damage to the temperature sensor.

19. Verify the accuracy of the airflow readings by comparison with airflow readings determined by either duct traverse or summation of airflow readings by flow hood measurements. The BAS controller software modules may have the ability to perform two point airflow calibrations. In general, airflow rates are calibrated with a single airflow reading at the maximum airflow setpoint. The instruments used should be calibrated to NIST standards.

Reading	Test/Instrument (CFM)	AFMS (CFM)	Error (% RD)
Minimum	672	600	12.0
Maximum	1376	1203	11.4

Table 128 - Initial Airflow Comparison

20. Update the K-factor or equivalent factor used to calculate the airflow rate so that it agrees sufficiently with the airflow rate provided by calibrated reference instruments.

(Equation 109) $$\text{Kfactor}_{\text{NEW}} = \text{Kfactor}_{\text{OLD}} * \frac{\text{Flow}_{\text{Measured}}}{\text{Flow}_{\text{BAS}}} = 1436 * \frac{1376}{1203} = 1642$$

Do not update any ADPT variables (scale and offset) that affect the velocity pressure reading. If the K-factors seem too high or low, verify that the K-factor is appropriate for the inlet diameter.

Reading	Test/Instrument (CFM)	AFMS (CFM)	Error (%)
Minimum	612	600	2.0
Maximum	1435	1400	2.5

Table 129 - Final Airflow Comparison

21. Perform additional iterations of airflow calibrations, if required, by returning to step #19. If the number of iterations exceeds 3, a review of the conditions upstream of the terminal unit is required. Also, verify that the size of the terminal unit is appropriate for the flow requirements. The terminal unit inlet conditions should be free of size change transitions, directional changes, and any other duct condition that could generate air turbulence. The supply duct static pressure should be consistent and stable. A constantly changing duct static pressure will make calibration of airflow readings difficult.
22. Document the final K-factor, primary air damper position, and duct static pressure that provides the design airflow rate. Observe the airflow indication to assess its stability and whether the terminal unit can reach the design airflow rate.
23. Set the terminal unit for its minimum airflow setpoint and evaluate the stability of the airflow indication at low flow conditions. Operation at low airflow rates is often a problem for terminal units particularly when the airflow setpoint is aggressively low or the terminal unit size is too large for the flow. If low-flow hunting is observed, increase the low flow setpoint until stable control of the airflow is established.
24. Release all setpoint changes and overrides used to posture the system (air-handling unit and terminal units) for testing and calibration.
25. Review the trend data to verify that the terminal unit airflow reading reliably and consistently functions. Numeric interval trend extensions are used to collect trend data at the programmed time intervals. Initial trend data intervals should be short (5 seconds-5 minutes) intervals to allow transient issues (that cannot be identified with longer intervals) to be identified. Once the testing and commissioning stage has concluded, longer time intervals (10-20 minute) can be used to minimize data storage requirements. There should not be any gaps or omissions in the trend data. The trend data should show that the airflow meter corresponds with the programmed control logic and schedule.
26. Document the results of all testing. Screenshots of the analog input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the analog input device. Record the terminal unit damper position and the duct static pressure at the time of flow calibration. This provides valuable data for future reference. If the

flow was calibrated at 100% damper position, there is no more room for an increase at the current duct static pressure. If the damper position was 50% open, then the flow can easily be increased, if needed. The supply duct static pressure directly impacts the terminal unit flow capability. If the static pressure setpoint was lowered, the VAV terminal unit would operate at a more open damper position to achieve the flow setpoint. It would operate at a lower damper position if the supply duct static pressure setpoint were increased.

28.7 Review

1. The ____________________ is the term that expresses the airflow across the velocity pickup that results in a 1 inch W.C. pressure drop.
2. True or False: Missing test tee caps on the pneumatic lines of a VAV terminal unit pose no issue for airflow measurements with an AFMS. Answer: ________
3. ________________________ describes the inability of the terminal unit to maintain stable control of the airflow while operating at the minimum airflow setpoint.
4. True or False: An AFMS based on velocity pressure performs the same no matter how the velocity pickup tubing connections are configured. Answer: ________
5. True or False: Before the airflow indication is calibrated, the ADPT should be calibrated to ensure that it accurately reports the sensed differential pressure. Answer: ________
6. A/An ________________________ should be installed at the inlet of the terminal unit to allow the air to stabilize before it is measured by the AFMS.
    A. Flow straightener
    B. Hard Duct Extension
    C. Flexible Duct
    D. 90 degree elbow
7. All AFMSs based on differential pressure are susceptible to the negative impacts of ______________.
    A. Discoloration
    B. Turbulence
    C. Magnetic Flux
    D. Voltage Fluctuations

28.8 References

1. https://www.krueger-hvac.com/files/white%20papers/white_paper_airflow_measurements.pdf
2. https://www.ruskintitus.com/wp-content/uploads/2016/03/AeroCross-Flow-Sensor-Application-Guide.pdf

Chapter 29 - Airflow Measuring Stations - Thermal Dispersion (AI)

29.1 Description

Airflow Measuring Stations (AFMS) based on Thermal Dispersion (TD) are used when control and monitoring of airflows are required. Thermal dispersion technology has been in use in the process industry for many years. This method of velocity measurement is based on temperature rather than on pressure which is highly susceptible to the effects of turbulence. Its operation is based on the use of two temperature sensors, typically RTDs and thermistors. The first temperature sensor provides the reference temperature indication. The second temperature sensor is heated by an electric resistance heating element to provide a predetermined temperature differential between it and the reference temperature sensor reading. The two temperature sensors are typically situated within a circular opening in the shaft of a sampling probe. These openings provide a standardized area through which the sampled airstream flows and are oriented parallel to the path of travel. Several sets of thermal dispersion sensors may be situated along the probe length. Several probes may be required to provide the minimum coverage or sampling depending on the size of the cross-section to be sampled. The sampling probes typically have a whip (length of wire) and a connector that terminates at the TD AFMS panel.

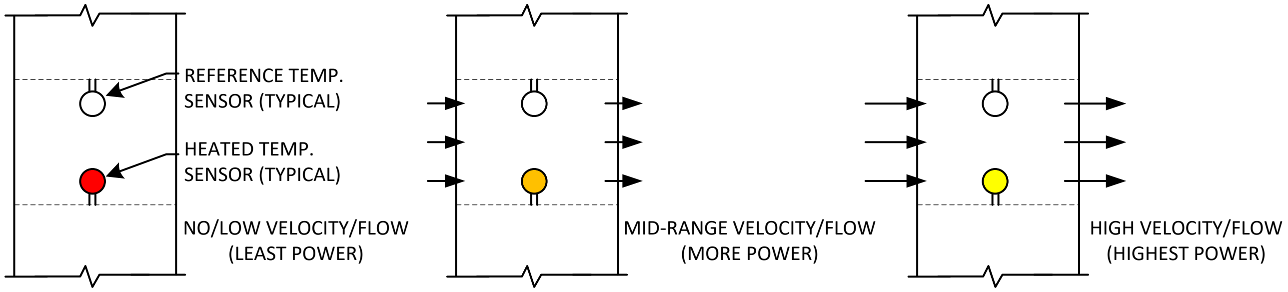


Figure 238 - Thermal Dispersion Concept

When there is low or no airflow, the power required to maintain the prescribed temperature differential between the two temperature probes is low because there is minimal to no airflow to absorb or "disperse" the heat of the second temperature sensor. The highly accurate temperature sensors allow velocity measurements even at very low flows. As the air velocity increases, more electrical power is required to maintain the temperature differential between the two temperature sensors because of the convective cooling effect of the air passing over the heated temperature sensor. The air velocity is determined by correlating the electrical power required to maintain the target temperature differential to the velocity of the air. This method of air velocity measurement does not depend on the measurement of velocity pressure which is easily affected by turbulence in the airstream.

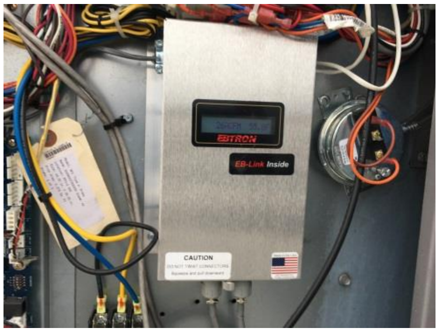


Photo 322 - Ebtron Thermal Dispersion Control Panel

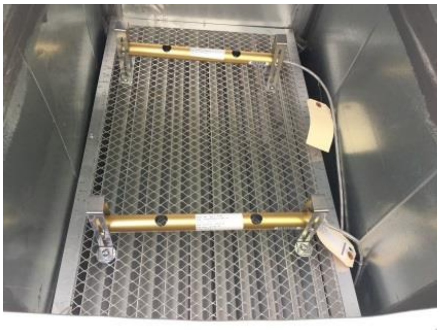


Photo 323 - Ebtron Thermal Dispersion Probes (Outdoor Air Grill)

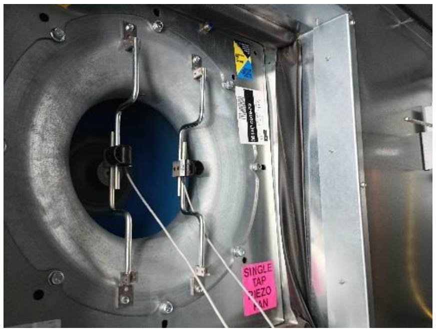


Photo 324 - Ebtron Thermal Dispersion Probes (Fan Inlet)

The TD temperature sensors are encased in a glass or other material that protects them from physical contact. These sensors are very small and very fragile and the slightest touch can easily break them. This undoubtedly is why they are typically protected by placing them in small openings drilled along a robust sampling probe. This configuration provides protection and allows the sampling probe to be mounted at the point of measurement with a variety of securements. The sampling probe openings provide standardized conditions for the measurement of air velocity. This feature also allows the same sampling probes to be installed in air-handling units and ducts of any configuration or aspect and still measure velocity through the standard openings. It's akin to bringing laboratory conditions to the field.

The duct configuration where the thermal dispersion AFMS is installed can still have a significant impact on the resulting airflow reading. To minimize their effect on the velocity measurements, AFMS manufacturers specify minimum distances of free duct upstream and downstream of the thermal dispersion AFMS which minimize the effects of turbulence and provides time for the velocity profile to stabilize before the air velocity measurement. Air velocity measurement with thermal dispersion technology is much less susceptible to turbulence caused by duct configuration irregularities or proximity to duct fittings because its operation is based on temperature rather than pressure. Thus, they are also more forgiving of less-than-ideal duct installations. In addition, the use of thermal dispersion AFMS provides a high turndown ratio which provides accurate velocity readings even at low air velocities. As the use and acceptance increases, their cost becomes more and more competitive with AFMSs based on differential pressure. It is for these reasons that they are quickly gaining favor in the HVAC industry.

(Equation 110) $$Flow = A * V = FT^2 * \frac{Feet}{Minute} = \frac{FT^3}{Minute}$$

(Equation 111) $$Flow = A * V * \text{Gain}$$

With increasing frequency, mechanical designs are allowing and/or prescribing thermal dispersion AFMSs that communicate their flow data rather than use analog voltage/current signals from the flow meter to a local BAS controller. As a result, it is much more common to see thermal dispersion AFMSs using BACnet or Modbus that communicate over MS/TP or IP wiring. Depending on the manufacturer, the communication terminals may be integral to the thermal dispersion AFMSs or included in an interface panel which accepts the voltage/current signal from the flow meter and communicates this data to the BAS. Ebron is a leading provider of thermal dispersion AFMSs that utilize an intermediate panel to provide the communication capability. Communicating thermal dispersion AFMSs communicate their airflow data directly to the JACE (or other supervisory controller) instead of being wired to a local field controller and then communicated to the supervisory controller.

The choice of whether to use communicating or analog flow signals depends first on whether the airflow data is for monitoring purposes or for active airflow control. When the airflow rate is only monitored, the way the airflow rate is acquired is not critical. When the airflow meter data is used for active flow control, we should consider where the flow control logic resides. For example, large central air-handling units are often managed by control logic that resides in the JACE (or other supervisory controller) because of their higher point capability. Airflow meters that communicate their airflow data are a viable option because they communicate directly with the supervisory controller which is controlling the airflow rate. In addition, these communication trunks are generally shorter and include fewer devices, so they are more reliable.

When the airflow control logic resides in the field controller, direct connection of the thermal dispersion AFMSs via analog signal is generally more desirable because it eliminates the latency that is created when a thermal dispersion AFMS is integrated to the JACE (or other supervisory controller) and then the airflow rate is communicated to the field controller. In addition, the airflow data is at a higher risk of failure because it passes through two control devices (flow meter/panel and supervisory controller) before arriving at the field controller. This would be acceptable for monitoring purposes, but would not be ideal for active airflow control. If a communication trunk is damaged or the JACE (or other supervisory controller) is down, rebooting, or otherwise incapacitated, the airflow data will not be available and these are important issues to consider when determining whether to connect the thermal dispersion AFMSs by analog or communication wiring. If the airflow control logic resides in the field controller, it is generally more reliable and efficient for the airflow meter to be directly connected (to the field controller) via an analog signal (0-10 VDC/4-20 mA). This eliminates the risks of latency issues, communication failures, and maximizes the system reliability.

29.1.1 AFMS Calibration

Thermal dispersion AFMSs are an integrated system that typically come with an electronic enclosure with a user interface (Photograph 322) to which all of the velocity probes are connected. The airflow calculations are typically performed by this AFMS controller which processes the temperature data from the probes, power demands (of the heated temperature sensor), dimensions of the measured opening, number of sampling points at the point of measurement. Once the air velocity and resulting airflow are calculated, an output signal (0-10 VDC, 2-10 VDC, or 4-20 mA) is produced that is proportional to the calculated airflow. The BAS controller's analog input is configured to correctly interpret this thermal dispersion AFMS signal. The final step in the installation and setup of a thermal dispersion AFMS is the calibration of its airflow reading. Reference airflow readings with calibrated instruments are compared to the thermal dispersion AFMS readings. The Gain or CF (Correction Factor) of the thermal dispersion AFMS is updated so that its airflow indication matches reference reading and is rechecked to verify accuracy.

Photo 325 - Ebtron Thermal Dispersion Area Configuration

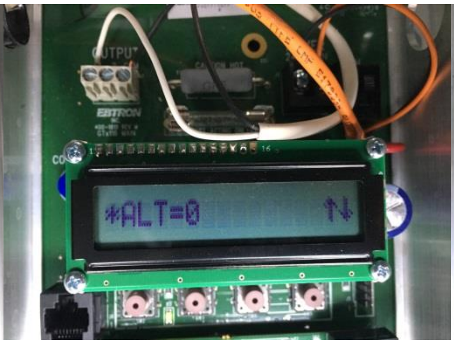


Photo 326 - Ebtron Thermal Dispersion Altitude Configuration

Photo 327 - Ebtron Thermal Dispersion Gain Configuration

Ebtron control enclosures have a removable cover where the buttons, switches and wiring connections are accessed. It also has a small user interface screen that displays operating data (typically flow and air temperature) and the configuration data. The Controls Contractor configures an analog input which is initially based on the TD AFMS velocity range and the dimensions of the opening where it will be installed. For example, if a TD AFMS has a velocity range of 0-3,000 FPM and it is installed in a 12 inch by 12 inch (1 FT^2) minimum outdoor air duct, this results in a flow range of 0-3,000 CFM. These units often arrive pre-configured from the factory.

Reading	Airflow (CFM)	Signal (VDC)
Minimum	0	0
Maximum	3000	10

Table 130 - TD AFMS Analog Input Configuration

The Ebtron TD AFMS provides a user interface where the zero and span of the velocity transmitter can be adjusted based on either a single-point or a two point calibration. In most cases, the TAB Contractor performs a single-point calibration adjusting only the Gain factor. This method of airflow calibration allows the correction of the transmitter output signal which is different from the normal calibration process where the configuration of the analog input of the BAS controller is adjusted to match the sensor transmitter performance.

The TAB Contractor reviews the settings to verify that they agree with the installed location and conditions. They posture the system in preparation of airflow measurements to ensure that the system remains in the desired operating mode for the duration of the test. The airflow rate is measured by duct traverse or summation of flow hood readings and compared to the airflow displayed by the TD AFMS. They access the TD panel and adjust the Gain so that the indicated airflow agrees with the measured airflow. Initially, the Gain is 1.0. Depending on the reference airflow readings, the Gain setting may be adjusted up or down to match the reference airflow readings. If a large change in Gain is required, confirm the programmed area setting.

(Equation 112) $$Flow_{Measured} = Flow_{TD\ AFMS} * \text{Gain}$$

(Equation 113) $$Velocity_{Measured} = Velocity_{TD\ AFMS} * \text{Gain}$$

(Equation 114) $$\text{Gain} = \frac{Velocity_{Measured}}{Velocity_{TD\ AFMS}} = \frac{Flow_{Measured}}{Flow_{TD\ AFMS}}$$

29.2 Applications

1. **Airflow tracking**. When an air-handling unit is equipped with both supply and return fans, the thermal dispersion AFMSs may be used to control the speed of the return fan through airflow tracking. The supply fan speed is typically controlled to maintain a certain supply duct static pressure. A supply AFMS quantifies the supply airflow and may either be located in the supply duct downstream of the air-handling unit or it may be located at the inlet of the centrifugal fan or fans. The return airflow is likewise quantified with a separate AFMS.

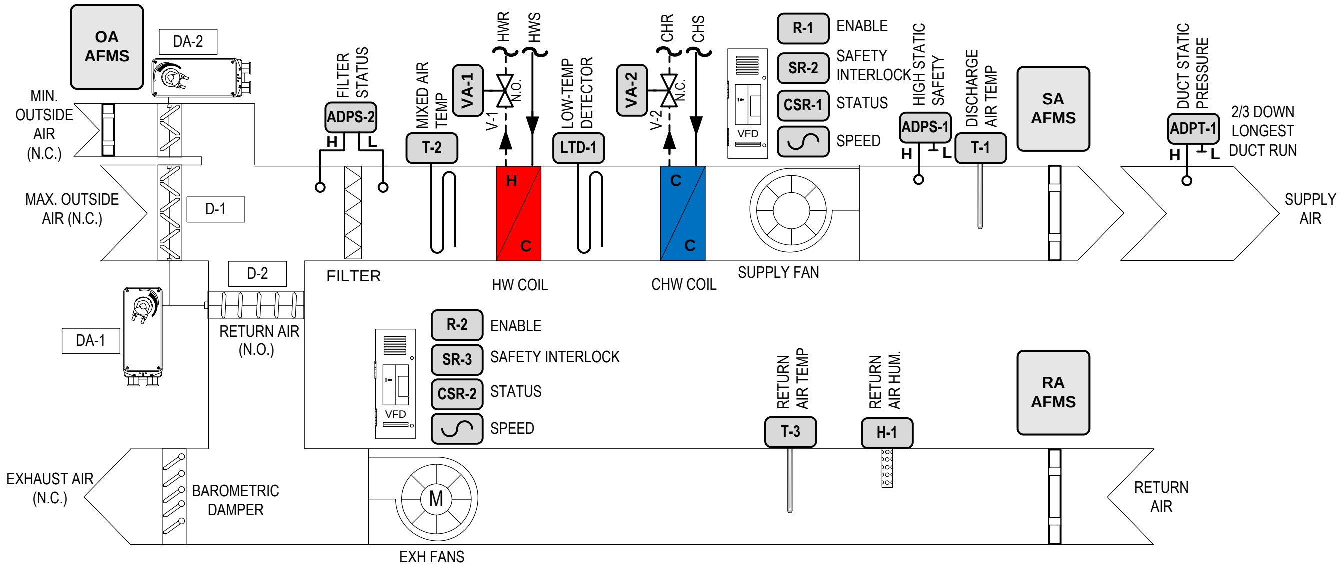


Figure 239 - Air-Handling Unit with Airflow Measuring Stations

An offset or differential between the supply and return airflow is programmed which typically coincides with the minimum required outdoor airflow requirement for this air-handling unit. If the design minimum outdoor airflow is 5,000 CFM, then the return fan's VFD speed is modulated to maintain the return airflow rate that at 5,000 CFM less than the supply airflow rate. The following table illustrates the airflow values that would typically be observed in an air-handling unit utilizing airflow tracking.

% Full Flow	Supply Fan Flow (CFM)	Airflow Offset (CFM)	Return Airflow (CFM) Setpoint
20	10,000	-5,000	5,000
40	20,000	-5,000	15,000
60	30,000	-5,000	25,000
80	40,000	-5,000	35,000
100	50,000	-5,000	45,000

Table 131 - Airflow Tracking of Supply and Return Fans

2. **Airflow Monitoring and Control**. AFMSs based on thermal dispersion technology may be installed anywhere where monitoring and/or control of airflow is required. It is often necessary to control the flow of minimum outdoor air to air-handling units. Thermal dispersion AFMSs may also be used to control the flow of supply, exhaust, or return air to or from a specific zone or space.

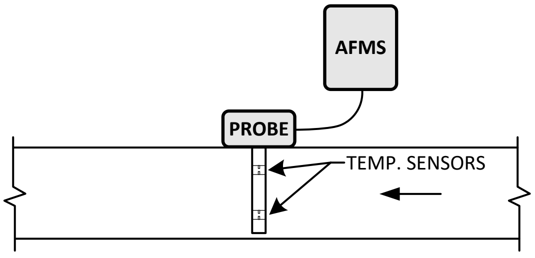


Figure 240 - Duct-Mounted AFMS

3. **Terminal Unit Airflow Control**. Typically, it is cost prohibitive to use thermal dispersion AFMSs for the control of airflow in pressure-independent terminal units. AFMSs based on air differential pressures are typically used for this application because it is a mature technology with lower equipment costs. TD AFMSs are becoming more and more price competitive and they are used with increasing frequency in medical, laboratory, industrial, and even commercial applications. They are also used where the control of space pressurization is the primary design objective and where the increased accuracy, reliability, turndown, and cost are warranted. Siemens has a terminal unit controller that incorporates two ADPTs allowing it to control two separate terminal units (supply and exhaust). Most controls manufacturers require two separate VAV controllers each with an ADPT to calculate the supply and exhaust/return

airflows. The flow signal from one of the controllers is supplied to the other.

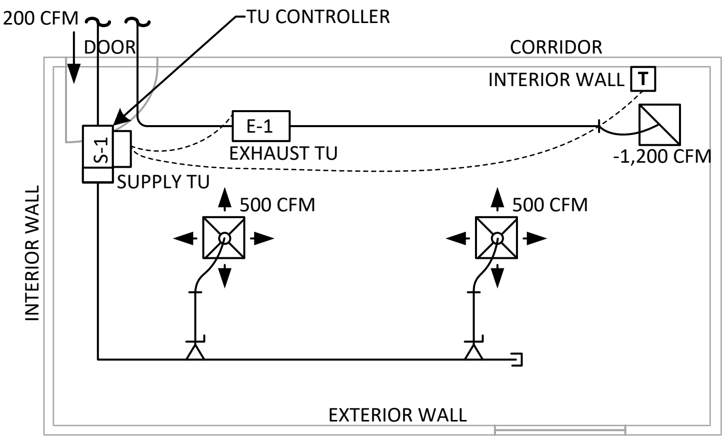


Figure 241 - Typical Laboratory Pressure Control Using Terminal Unit AFMS

The supply air terminal unit controllers based on velocity pressure typically have a spare analog input to accept the velocity signal from the second AFMS and an extra analog output to modulate the control damper of the second VAV terminal unit. This allows the material, installation, and programming cost of the second controller to be subtracted from the cost of the controls. This also eliminates the need to communicate the flow data from one controller to the other which increases reliability and stability. Ebtron® manufacturers a single probe TD AFMS that is compact, highly accurate, and economical. The EF-x1000-T TD AFMS can be mounted in the inlet duct of terminal units or inserted in smaller ducts to provide accurate velocity and airflow indications. It is also perfect for minimum outdoor air inlet ducts of air-handling units. The use of thermal dispersion AFMS can reduce (or negate the additional cost of the thermal dispersion AFMS) the controls costs in some applications by allowing a single BAS controller to control both the supply and exhaust/return terminal units.

Photo 328 - Close-Up of Ebtron EF-x1000-T TD AFMS

Photo 329 - Ebtron EF-x1000-T TD AFMS

Photo 330 - Close-up View of
Photo 331 - Thermal Dispersion Probes

29.3 Typical Control Wiring

Thermal dispersion AFMSs typically do not come with a power supply. The power supply is typically provided by the Controls Contractor and is located in the BAS local control panel. Separate conduits may be required to convey the power and signal wires from the AFMS control panel to the BAS local control panel. DIP switches, special terminals, and user interface settings may need to be set to choose the feedback signal. Refer to the manufacturer-provided installation literature.

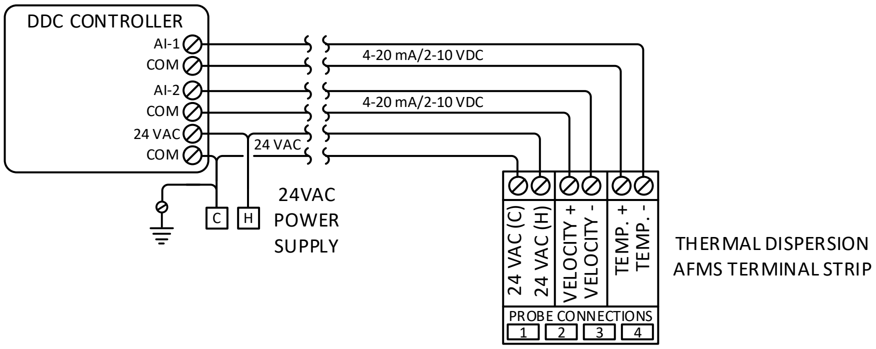


Figure 242 - Thermal Dispersion Airflow Measuring Station and Field Controller Wiring Example

Thermal dispersion AFMSs have the option of BACnet integration through MS/TP (RS-485) wiring which simplifies the wiring considerably because the data is communicated instead of being transmitted by individual pairs of wires for each data point. In general, Controls Contractors prefer to group devices by manufacturer and baud rate to avoid communication issues. Combining devices of differing manufacturers is only done when experience has proven that they can coexist on the same MS/TP trunk without issues. The designer should consider the possibility of a failure in the communication bus and how this loss affects the control logic.

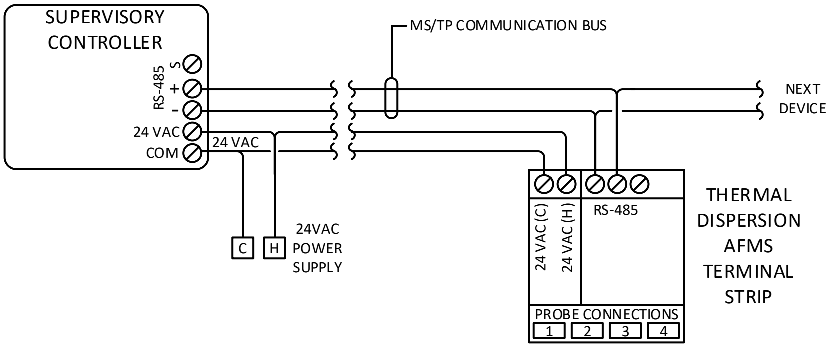


Figure 243 - Thermal Dispersion Airflow Measuring Station with RS-485 Wiring Example

Thermal dispersion AFMSs also have the option of BACnet integration through Ethernet wiring which further simplifies the wiring because all available data points are communicated simultaneously. It has been my experience that Ethernet controllers are more stable, reliable, and more resistant to EMI and grounding issues.

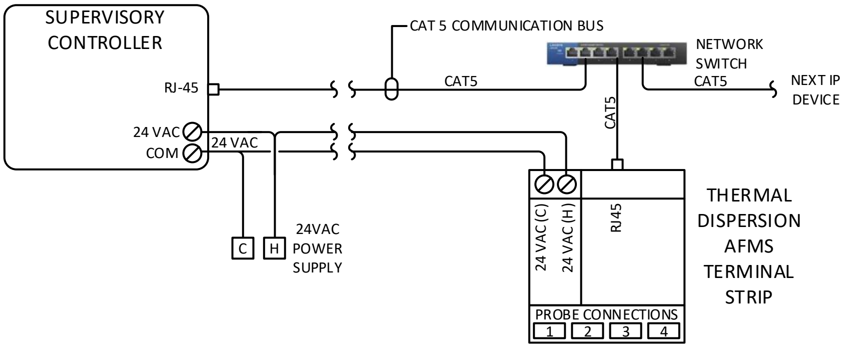


Figure 244 - Thermal Dispersion Airflow Measuring Station with Ethernet Wiring Example

29.4 Analog Input Testing and Verification

1. Verify that the TD AFMS has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The operating range, mounting, communication protocol, output contacts, wiring, power requirements, and output signals are some of the features that should be verified.

2. Verify that the TD AFMS has been installed at the correct or optimum location paying particular attention to whether the minimum upstream and downstream distances recommended by the manufacturer have been provided. TD

AFMSs based on thermal dispersion are more forgiving of less than ideal duct conditions.

3. Verify that the TD AFMS has been installed per the manufacturer's installation recommendations. Verify and document all adjustable dip switch, selector, and jumper settings to ensure the correct signal and range are generated. The final operating range and number of velocity sampling points of the TD AFMS should be consistent with the intended application and manufacturer's installation recommendations. In addition, the direction of the probes should be parallel to the direction of the airflow to provide the most airflow indication.
4. Posture the HVAC system or the required components (damper, control valves, fans, VFD speeds, etc.) to prevent unwanted system changes (speed modulation, damper/valve modulation, compressor staging, heat staging, etc.) during the sensor/transmitter calibration. Use setpoint changes and/or overrides of damper position and fan speed commands to ensure that the operating conditions do not change during the testing and calibration.
5. Verify that the TD AFMS has been connected to the correct BAS controller analog input. Removing the signal wire or disabling the 24 VAC power to the TD AFMS will cause this data point reading to change. It is a good idea to make a note or take a screenshot of the data point reading that occurs when the analog input device is disconnected.
6. At the same time that the TD AFMS's electrical contacts are opened, verify and document that the data point bound to the BAS graphics also changes.
7. Verify that the TD AFMS has been correctly wired. The TD AFMS may have multiple sets of contacts that must be properly landed and coordinated to provide the required signal type and range. Drawings or sketches are best for documenting the wiring configuration. AFMSs based on thermal dispersion technology typically produce direct current voltage signals (0-10VDC, 2-10VDC, 0-5VDC, etc.) and current signals (4-20 mA). TD AFMSs are particularly susceptible to permanent failure if 24 VAC power is connected to the signal contacts of the terminal board. A fixed output voltage that does not vary as the airflow varies is a typical failure mode of the TD AFMS.
8. Verify that the TD AFMS and its wires at the BAS controller end have been labeled.
9. Verify that the units/facets for the TD AFMS are correctly displayed. The facets for velocity and airflow are typically Feet per Minute (FPM), and Cubic Feet per Minute (CFM), respectively.
10. Verify that the precision of the TD AFMS velocity and airflow readings are appropriately set. Velocity and airflows are typically displayed with no decimal places because these values are typically large. Velocity and airflow setpoints are also typically displayed with whole numbers.
11. Verify that the BAS controller's analog input point has been properly configured to match the TD AFMS velocity range and output signal. A signal generator may be also be used to validate whether the analog input has been correctly configured. Ramp the simulated voltage or current signal up and down to verify that the BAS controller properly interprets the analog input signal.

Thermal dispersion AFMSs provide an inferred air velocity measurement based on temperature sensor readings and power requirements of the heated temperature sensor. Once the velocity is determined, the BAS controller calculates the airflow by multiplying the velocity by the cross-sectional area of the duct or opening. The analog input of the BAS controller may be initially configured to interpret the voltage signal from the TD AFMS as follows:

Reading	Velocity (FPM)	Signal (VDC)
Minimum	0	0
Maximum	3,000	10

Table 132 - Initial Analog Input Configuration

If the analog input configuration of the BAS controller is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs. The scale and offset values are used to calculate the velocity reading from the voltage signal provided by the AFMS. These values will be updated based on calibration readings as explained in later steps.

Volts (DCV)	Velocity (FPM)
0	0
10	3,000

Calculated Scale= 300.0
Calculated Offset= 0.0

Table 133 - Initial Scale-Offset Calculation

The TD AFMS may be equipped with a user interface panel that allows direct entry of the duct or opening cross-sectional area. This allows the TD AFMS to calculate the airflow rate and provide a proportional output signal. Assuming the flow area to be 3 square feet (3 FT^2), the analog input of the BAS controller may be initially configured to interpret the DC signal from the TD AFMS as follows:

Reading	Flow (CFM)	Signal (VDC)
Minimum	0	0
Maximum	9,000	10

Table 134 - Initial Analog Input Configuration

If the analog input configuration of the BAS controller is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs. The scale and offset values are used to calculate the airflow reading from the voltage signal provided by the AFMS. These values will be updated based on calibration readings as explained in later steps.

Volts (DCV)	Flow (CFM)
0	0
10	9,000

Calculated Scale= 900.0
Calculated Offset= 0.0

Table 135 - Initial Scale-Offset Calculation

12. Verify the accuracy of the TD AFMS reading by comparison with reference readings acquired by either duct traverse or summation of airflow readings by flow hood measurements. The instruments used should be calibrated to NIST-traceable standards. The reference velocity or airflow measurements should be made where it ensures maximum accuracy. At each calibration point, record the BAS controller reading, measured velocity/airflow reading, and the signal generated by the TD AFMS. The air handling unit or control damper is typically postured to provide calibration readings. If the TD AFMS does not produce the appropriate output signal or does not report across its full range, then it should be calibrated by modifying its zero (Gain) and span (Offset) adjustments. If accurate calibration results cannot be attained, then it should be replaced. Single-point calibrations are not recommended because they will not produce the required information to calibrate transmitter readings. Refer to Chapter 2: BAS Calibration and Chapter 3: BAS Inputs and Outputs for more information.

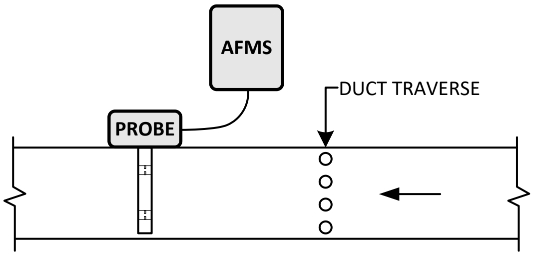


Figure 245 - Duct Traverse Upstream of Thermal Dispersion Airflow Measuring Station

If the TD AFMS provides a velocity reading, then the calibration readings may resemble the following:

Reading	Test/Instrument (FPM)	BAS Data Point (FPM)	Signal (VDC)
1	0.0	9	0.03
2	1,062	996	3.32
3	2,074	2,123	7.08

Table 136 - Initial Transmitter/BAS Calibration Check

If the TD AFMS provides an airflow reading, then the calibration readings would resemble the following:

Reading	Test/Instrument (CFM)	BAS Data Point (CFM)	Signal (VDC)
1	0	27	0.03
2	3,186	2,988	3.32
3	6,222	6,369	7.08

Table 137 - Initial Transmitter/BAS Calibration Check

13. Update the configuration of the analog input of the BAS controller and retest to confirm the calibration of the TD

AFMS. If the TD AFMS readings still appear to be inaccurate or it does not provide readings across its full range, then replacement is recommended. Record the final analog input calibration and correction factors.

Reading	Test/Instrument (FPM)	Volts (VDC)
Minimum	0	0.03 VDC
Maximum	2,074	7.08 VDC

Table 138 - Updated BAS Controller Configuration

If scale and offset factors are used to configure the parameters of the BAS controller analog input, update them accordingly using the same methodology explained in Chapter 3: BAS Inputs and Outputs. In most cases, the actual velocity will not reach the maximum possible value originally defined. Update the scale and offset values with the maximum velocity values obtained during the calibration readings.

Volts (DCV)	Velocity (FPM)
0.03	0
7.08	2,074

Updated Calculated Scale= 294.2
Updated Calculated Offset= -8.8

Table 139 - Updated Scale-Offset Calculations

If the TD AFMS provides an airflow indication, then update the analog input configuration of the BAS controller as follows:

Reading	Airflow (CFM)	Volts (VDC)
Minimum	0	0.03
Maximum	6,222	8.07

Table 140 - Initial Analog Input Configuration

If scale and offset factors are used to configure the parameters of the BAS controller analog input, update them accordingly using the same methodology explained in Chapter 3: BAS Inputs and Outputs. Update the scale and offset values with the calibration readings.

Volts (DCV)	Flow (CFM)
0.03	0
7.08	6,222

Updated Calculated Scale= 882.6
Updated Calculated Offset= -26.5

Table 141 - Updated Scale-Offset Calculations

14. Retest to confirm the level of accuracy. Adjust the calibration factors as necessary to calibrate the velocity and airflow readings to the reference values. Record the final analog input calibration Gain and Offset values programmed in the TD AFMS (if applicable).
15. Release all overrides used to posture the system for testing and calibration.
16. Review the trend data to verify that the airflow meter reliably and consistently reports to the BAS controller. Numeric interval trend extensions are used to collect trend data at the programmed time intervals. Initial trend data intervals should be short (5 seconds-5 minutes) intervals to allow transient issues (that cannot be identified with longer intervals) to be identified. Once the testing and commissioning stage has concluded, longer time intervals (10-20 minute) can be used to minimize data storage requirements. There should not be any gaps or omissions in the trend data. The trend data should show that the airflow meter corresponds with the programmed control logic and schedule.
17. Document the results of all testing. Screenshots of the analog input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the analog input device.

29.5 Review

1. The Ebtron thermal dispersion control panel provides the ability to correct the airflow indication by adjusting the ______________ and ______________ values.
2. The basis of operation of thermal dispersion AFMS is __________________ differential between a standard temperature sensor and one that is heated.
3. True or False: Thermal dispersion AFMS are less forgiving of turbulence caused by poor duct construction. Answer: _________
4. Thermal dispersion AFMS are utilized in which applications: Answer: ______________.

   A. CAV/VAV Terminal Units
   B. Outdoor Air Intake
   C. Supply, Return, Exhaust Ducts
   D. All of the Above

5. The airflow measuring station circuitry used the electrical ____________________ required to maintain a temperature differential to determine the air velocity and flow rate.
6. If the airflow direction were reversed, the thermal dispersion AFMSs would provide an airflow indication that is ________________ than the airflow indication of the air in the correct direction.

   A. Greater Than
   B. Equal to
   C. Less than

29.6 References

1. https://ebtron.com/product-category/airflow-temperature-measurement-devices-amd-atmd/
2. https://www.airmonitor.com/hvac/product-category/thermal-dispersion-measurement/

Chapter 30 - Hydronic Flow Meters (AI)

30.1 Description

This chapter focuses on hydronic flow meters that provide a flow reading via an analog signal to the BAS controller. Hydronic flow meters are used to indicate the instantaneous flow rate through the piping system being monitored and produces a linear signal (0-10 VDC or 4-20 mA) that is proportional to the flow rate. There are several different flow meter technologies available on the market. Some of these include, but are not limited to, the following:

1. Turbine Flow Meters
2. Magnetic Flow Meter
3. Vortex Flow Meters
4. Ultrasonic Flow Meter
5. Orifice Flow Meters

In my experience, the majority of the commercial HVAC applications utilize either the turbine or the magnetic flow meters. The flow measurement technologies vary and each has its own manufacturer's installation, operational requirements, as well as limitations. An explanation of each will not be provided, but they all provide a fluid flow measurement by first measuring the velocity of the fluid and then calculating the flow based on the inner pipe diameter. It is important to understand the operating principles of the installed flow meter to be able to know that it is operating correctly and to correctly troubleshoot, if necessary.

Photo 332 - Onicon Turbine Insertion Flow Meter

Photo 333 - Onicon Magnetic Insertion Flow Meter

Photo 334 - Onicon Magnetic Inline Flow Meter

Flow meters with moving parts (turbine and impeller blades) are especially susceptible to dirt, debris, and other construction debris that may be introduced to the piping system. Solid pieces of debris can break blades off of the impellers or impede their rotation. Over time, smaller piece of debris can abrade the blades of the impeller significantly affecting their accuracy. Strands of plastic, wire, Teflon tape, or strings can get wrapped around the turbine blades and their shafts reducing the apparent velocity and ultimately the flow reading. It is highly recommended that the piping system be thoroughly cleaned and flushed before installing the flow meters. Magnetic flow meters are quickly gaining favor because they have no internal parts to impede flow or catch debris. Magnetic flow meters are very durable, accurate, and reliable. The manufacturer's installation recommendations, especially with regard to grounding, must be followed for all flow meters.

Hydronic flow meters provide two main types of outputs – pulsed and analog. Flow meters with analog output provide a continuous indication of flow as represented by a 0-10 VDC or a 4-20 mA signal. For example, a chilled water flow meter rated for 0-600 GPM may output an analog signal that ranges between 2 VDC and 10 VDC. An output signal of 6.19 VDC would represent a flow rate of 314.3 GPM. Most hydronic HVAC systems operate constantly while occupied or may operate all of the time. Flow meters that provide an analog output signal are typically used to monitor chilled water, hot water, and condenser water system flows. These values are used more for monitoring, control purposes, and system performance evaluations.

Flow meters with pulsed outputs are typically used to quantify the total volume passed through the flow meter. A pulse is generated each time a certain amount of fluid has passed through the flow meter. Flow meters that provide pulsed outputs are typically smaller in size, monitor lower flow rates, are more accurate, and have a higher turndown ratio making them ideal for sub-metering and billing purposes. There are multiple pulsed flow meter designs, but the underlying principle is based on the use of a magnet and either reed switches or Hall Effect sensors to provide the measurement of hydronic flow. The flow drives an internal gear drive which totalizes the water volume. A magnet is placed on one of the gears and each time the magnet passes a reference position a pulse is detected. The pulses are connected to a binary input of a BAS controller which totalizes the pulses received to determine the total flow volume. The frequency of the pulses is proportional to the flow rate. Meters with a pulsed output tend to be positive displacement type and are used when the measured quantity is billed to an end-user or purchaser. Pulse water and gas meters are excellent examples of utility meters used for billing purposes. In water flow meters, each pulse may represent 100 cubic feet of water (or 748 Gallons) of water. If 34 pulses are recorded in a billing cycle, then the client will be billed for 25,432 gallons of water. It is important to realize that pulse meters produce the pulse after the volume associated with each pulse has passed through it. If the flow stops, so will the pulses. They do not indicate the instantaneous flow rate.

With increasing frequency, mechanical designs are allowing and/or prescribing hydronic flow meters that communicate their flow data rather than use analog voltage/current signals from the flow meter to a local BAS controller. As a result, it is much more common to see hydronic flow meters using BACnet or Modbus that communicate over MS/TP or IP wiring. Depending on the manufacturer, the communication terminals may be integral to the flow meter or included in an interface panel which accepts the voltage/current signal from the flow meter and communicates this data to the BAS. Onicon is a leading provider of mass flow meters that utilize an intermediate panel (System 10, System 20, System 40, or System-1000 BTU meter panel) to provide the communication capability. Communicating hydronic flow meters transmit their flow data directly to the JACE (or other supervisory controller) instead of being wired to a local field controller and then communicated to the supervisory controller.

The choice of whether to use communicating or analog flow signals depends first on whether the flow data is for monitoring purposes or for flow control. When the flow rate is only monitored, the way the flow rate is acquired is not critical. When the flow meter data is used for active flow control, we should consider where the flow control logic resides. For example, central plants are often managed by control logic that resides in the JACE (or other supervisory controller) because of their high point capability. Flow meters that communicate their flow data are a viable option because they communicate directly with the supervisory controller which is controlling the flow rate. In addition, these communication trunks are generally shorter and include fewer devices, so they are more reliable.

When the flow control logic resides in the field controller, direct connection of the flow meter via analog signal is generally more desirable because it eliminates the latency that is created when a flow meter is integrated to the JACE (or other supervisory controller) and then the flow rate is communicated to the field controller. In addition, the flow data is at a higher risk of failure because it passes through two control devices (flow meter/panel and supervisory controller) before arriving at the field controller. This would be fine for monitoring purposes, but would not be ideal for minimum chilled water flow control through chillers and/or boilers. If a communication trunk is damaged or the JACE (or other supervisory controller) is down, rebooting, or otherwise incapacitated, the flow data will not be available and these are important issues to consider when determining whether to connect the hydronic flow meters by analog or communication wiring. If the flow control logic resides in the field controller, it is generally more reliable and efficient for the flow meter to be directly connected (to the field controller) via an analog signal (0-10 VDC/4-20 mA). This eliminates the risks of latency issues, communication failures, and maximizes the system reliability.

30.2 Applications

1. **Minimum Flow Control**. Air-cooled and water-cooled chillers are capable of variable primary chilled water flow. However, they have a limit as to how far the chilled water flow can be reduced. Hydronic flow meters monitor the chiller flow rate while the chilled water pump VFD modulates to maintain the differential pressure at setpoint. When the connected chilled water flow requirements approach the minimum flow threshold of the chiller(s), the bypass control valve V-1 modulates open to maintain the flow above the minimum flow setpoint. Turbine and magnetic flow meters are often chosen for this application. It has been my experience that magnetic flow meters are a superior choice as long as it is properly installed and grounded. Turbine flow meters are highly susceptible to damage and impairment by debris in the system.

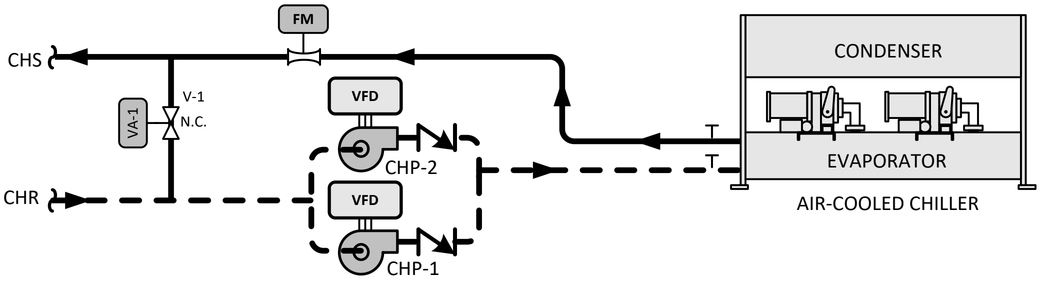


Figure 246 - Air-Cooled Chilled Water System with a Flow Meter

2. **Condenser Water Make-up Totalizing**. Cooling towers remove the chiller's condenser heat by evaporation. As a result, it requires constant replenishing of domestic water to maintain the cooling tower basin(s) at its normal operating level. Since the cooling tower water is evaporating, it is not returning to the water utility for treatment. Water utilities typically charge for the water used plus an additional charge for water treatment (sewage) when the water returns to their waste water treatment plants for processing. A deduct meter is typically installed on the cooling tower make-up water line to quantify the domestic water usage, so that the water treatment charges for this quantity of domestic water is deducted from the water bill. The same can be done for hose-bibbs and irrigation lines because this domestic water does not return to the water utility through the sewage system for treatment.

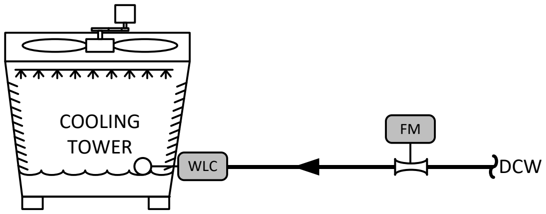


Figure 247 - Cooling Tower Make-up Water Line with Flow Meter

3. **Chiller Staging.** Many chilled water plants are configured for constant volume primary flow and variable secondary flow. The secondary pumps modulate their speed to maintain the differential pressure at a setpoint determined by the Balancing Contractor. The chilled water flow through each chiller is constant and is also known from the TAB Contractor's field testing and balancing. The chilled water flows through the primary loop has two steps which are determined by the number of chillers that are enabled. The flows through each chiller can be estimated at 2.4 GPM per Ton (assuming a 10°F temperature drop) of cooling capacity. Control of the central chilled water system typically depends on maintaining a higher flow in the primary loop than the secondary loop. If the primary loop flow exceeds the secondary loop flow, the chilled water return water will short-circuit to the plant through the primary-secondary bridge piping. Flow meters are utilized to monitor the flow of each loop to determine when the second chiller is required. When the secondary chilled water flow approaches primary loop flow, an additional chiller is enabled. In this example, chiller staging is more a matter of flow control to maintain chilled water temperature control.

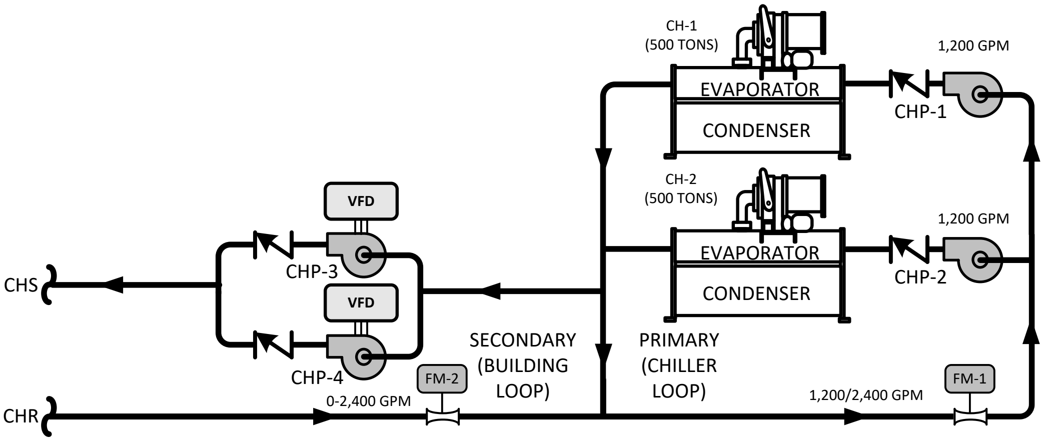


Figure 248 - Primary-Secondary Chilled Water Plant With Flow Meters

4. **Leakage Monitoring**. Make-up water assemblies are typically used to maintain the closed loop hydronic systems (hot water, chilled water, condenser water, etc.) at a certain pressure. During normal operation, there is no leakage in a closed hydronic system. If a leak were to occur (coil, set of flanges, valve packing, or pump casing), then the hydronic system would lose water resulting in a pressure reduction. When the hydronic system pressure drops below the pressure reducing valve's setpoint, it opens to restore the hydronic system to its pressure setpoint. A flow meter placed on the make-up water line can be used by the BAS to detect system leakage and line breaks. Once detected, the operator could immediately be notified or an automated isolation valve could close to minimize or eliminate the potential for water damage.

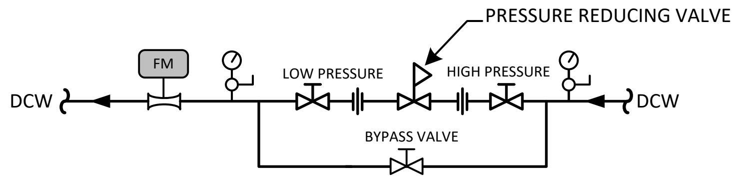


Figure 249 - Make-up Water Assembly with Flow Meter

5. **Sub-metering of Chilled/Hot/Condenser Water Usage**. Central plants that serve large campuses consisting of multiple buildings often use flow meters to divide the operating and maintenance costs of the central plant among its building or departments based on their usage of various utilities. In this application, a flow meter will be required for each utility that is to be measured and submetered. These flow meters are typically accompanied by supply and return temperature sensors to allow the energy or heat flow to be calculated and recorded by the BAS. Chilled and hot water meters are typically the type that provides an instantaneous reading while domestic water use is typically quantified by meters with pulsed outputs.

30.3 Typical Control Wiring

Hydronic flow meters typically do not come with a low-voltage transformer. It is typically provided by the Controls Contractor and is located in the BAS local control panel. Separate conduits may be required to convey the power and signal wires from the AFMS control panel to the BAS local control panel. DIP switches, special terminals, and user interface settings may need to be set to choose the feedback signal. Refer to the manufacturer-provided installation literature. Depending on the manufacturer, the flow meter may provide the flow rate directly or you may have to calculate it from the known inner pipe diameter and the fluid velocity provided by the meter.

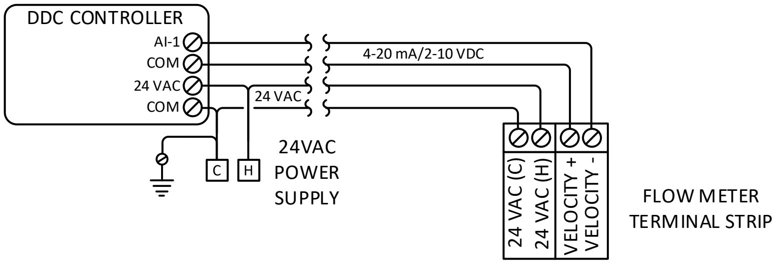


Figure 250 - Hydronic Flow Meter and Field Controller Wiring Example

Hydronic flow meters have the option of BACnet integration through MS/TP (RS-485) wiring which simplifies the wiring considerably because the data is communicated instead of being transmitted by individual pairs of wires for each data point. In general, Controls Contractors prefer to group devices by manufacturer and baud rate to avoid communication issues. Combining devices of differing manufacturers is only done when experience has proven that they can coexist on the same MS/TP trunk without issues. The designer should consider the possibility of a failure in the communication bus and how with this loss affects the control logic. Depending on the criticality of the process, direct wiring of the hydronic flow signal may be desired or required.

The criticality of the process often dictates the hydronic flow meter type that is utilized. Flow meters that provide the flow indication in the form of a 0-10 VDC/1-20 mA signal are typically considered more reliable, so they are used in applications of a critical nature (i.e. minimum chiller/boiler flow control). Integrated hydronic flow meters are typically used in applications when the flow rate is monitored (not controlled) because the loss of communication will not drastically affect the process.

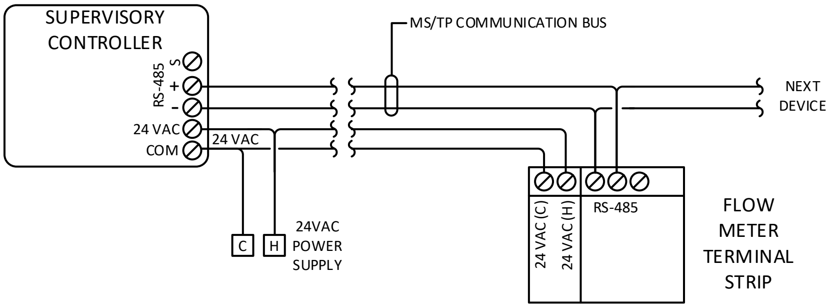


Figure 251 - Hydronic Flow Meter with RS-485 Wiring Example

Flow meters also have the option of BACnet integration through Ethernet wiring which further simplifies the wiring because all available data are communicated simultaneously. It has been my experience that Ethernet communications are more stable, reliable, and more resistant to EMI and grounding issues.

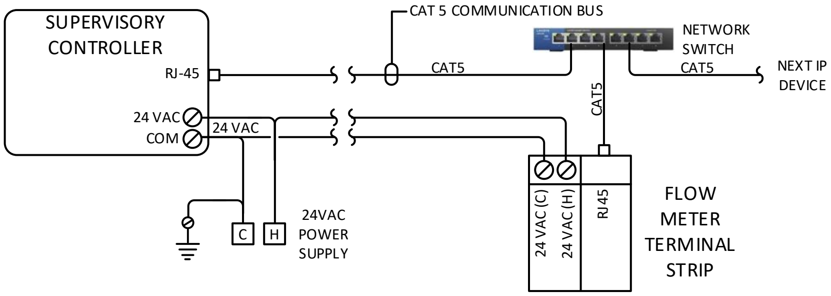


Figure 252 - Hydronic Flow Meter with Ethernet Wiring Example

30.4 Analog Input Testing and Verification

1. Verify that the hydronic flow meter has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The operating range, mounting, bidirectional/unidirectional, orientation, output contacts, communication protocol, wiring, and output signals are some of the features that should be verified.
2. Verify that the hydronic flow meter has been installed at the correct or optimum location paying particular attention to whether the minimum upstream and downstream distances recommended by the manufacturer have been provided.
3. Verify that the hydronic flow meter has been installed per the manufacturer's installation recommendations. Verify and document all adjustable dip switch, selector, and jumper settings to ensure the correct signal and range is generated. The final operating range of the hydronic flow meter should be consistent with the intended application. Verify that the hydronic flow meter has been installed in the correct orientation and depth. If flow is reversed, the indicated flow reading may not be calculated correctly or may not report at all. If electromagnetic flow meters are utilized, verify that the power, signal, and grounding wires have been properly installed as this type of meter is especially susceptible to grounding issues.
4. As applicable, posture the HVAC system or the required components (damper, control valves, fans, VFD speeds, etc.) to prevent unwanted system changes (modulation, staging, cycling) during the sensor/transmitter calibration.
5. Verify that the hydronic flow meter has been correctly wired. The hydronic flow meter may have multiple sets of contacts that must be properly landed and coordinated to provide the required signal type and range. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify that the HDPT connections to the system (threadolets, bushings, tubing, piping, tubing, valves, manifold, thermal traps, etc.) are installed correctly. The high-pressure port should be connected to the higher pressure zone (supply main and upstream of heat exchangers and pumps) while the low-pressure port is connected to the lower pressure zone (return main, atmosphere, and downstream of heat exchangers and pumps). If a manifold is used, verify that it is correctly piped and all valves are properly postured.
7. Verify that the hydronic flowmeter has been connected to the correct BAS controller analog input. Removing the signal or 24 VAC power wire from the transmitter will cause the data point reading to change. It is a good idea to make a note or take a screenshot of the data point reading that occurs when the analog input device is disconnected.

8. At the same time that the hydronic flowmeter's electrical contacts are opened, verify and document that the data point bound to the BAS graphics also changes.
9. Verify that the hydronic flow meter and its wires at the BAS controller end have been labeled. If multiple flow meters are included on a project, flow meter identifiers and their BAS MAC/IP address should also be included on the label.
10. Verify that the units/facets for the hydronic flow meter are correctly displayed. The facets for hydronic velocity and flow are typically Feet per Second (FPS) and Gallons per Minute (GPM), respectively. Hydronic flow meters typically provide a flow reading instead of a velocity reading
11. Verify that the precision of the hydronic flow meter reading is appropriately set. Hydronic flows are typically displayed with whole numbers or a maximum of one decimal place. Velocity and flow readings and setpoints of the same are typically displayed with whole numbers (no decimals).
12. Verify that the BAS controller's analog input point has been properly configured to match the velocity/flow range of the installed hydronic flow meter and the output sign. Most hydronic flow meters come with a laminated card that details its operating range and output signal. It is critical that the configuration of the analog input of the BAS controller exactly match the hydronic flow meter output signal.

    Hydronic flow meters provide the measurement of the fluid velocity. Hydronic flow meters are typically equipped with a user interface panel that allows direct entry of the fluid and pipe diameter. This allows the hydronic flow meter to calculate the hydronic flow and provide an output signal that is proportional to the flow rate. Flow meters come with a tag that provides the flow parameters (flow and signal ranges) and this data is used to configure the analog input of the BAS controller. The analog input of the BAS controller may be initially configured to interpret the DC signal from the hydronic flow meter as follows:

Reading	Flow (GPM)	Volts (VDC)
Minimum	0	2
Maximum	500	10

Table 142 - Initial Analog Input Configuration

    If the analog input configuration of the BAS controller is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs. The scale and offset values are used to calculate the fluid flow reading from the voltage signal provided by the hydronic flow meter. These values will be updated based on calibration readings as explained in later steps.

Volts (DCV)	Flow (GPM)
2	0
10	500

Updated Calculated Scale= 62.5
Updated Calculated Offset= -125.0

Table 143 - Initial Scale-Offset Calculation

13. Verify the accuracy of the hydronic flow meter reading by comparison with reference readings from calibrated instruments. Reference flow measurement should be taken in the same pipe circuit as the flow meter. At each calibration point, record the BAS controller reading, hydronic flow meter reading, and the signal generated by the hydronic flow meter. Flow is a parameter that cannot be easily field simulated (like pressure), but two calibration points are typically possible – Normal operating current and the off or de-energized state. If the pump is driven by a variable frequency drive or has valve control, then multiple calibration points are possible. If the flow meter does not produce the appropriate output signal or does not report across its full range, then it should be calibrated by modifying its zero and span adjustments. If accurate calibration results cannot be attained, then it should be replaced. Single-point calibrations are not recommended because they will not produce the required information to calibrate transmitter readings. Refer to Chapter 2: BAS Calibration and Chapter 3: BAS Inputs and Outputs for more information. Calibration by hydronic flow measurements may resemble the following table.

Reading	Test/Instrument (GPM)	BAS Data Point (GPM)	Transmitter Signal (VDC)
1	0.0	1.87	2.03
2	216.8	220	5.52
3	454.5	442.5	9.08

Table 144 - Initial Transmitter/BAS Calibration Check

14. Update the configuration of the analog input of the BAS controller and retest to confirm the calibration of the

hydronic flow meter. If the hydronic flow readings still appear to be inaccurate or the hydronic flow meter does not provide readings across its full range, then replacement of the hydronic flow meter is recommended. Record the final analog input calibration and correction factors.

Reading	Test/Instrument	Volts (VDC)
Minimum	0	2.03
Maximum	454.5	9.08

Table 145 - Updated BAS Controller Configuration

If scale and offset factors are used to configure the parameters of the BAS controller analog input, update them accordingly using the same methodology explained in Chapter 3: BAS Inputs and Outputs. In most cases, the actual velocity will not reach the maximum possible value originally defined. Update the scale and offset values with the maximum velocity values obtained during the calibration readings. Confirm the accuracy of the analog input configuration change by comparing new reference flows to the hydronic flow indicated by the BAS.

Volts (DCV)	Flow (GPM)
2.03	0
9.08	454.5

Updated Calculated Scale= 64.5
Updated Calculated Offset= -130.9

Table 146 - Updated Scale-Offset Calculations

15. Release all overrides used to posture the system for testing and calibration.
16. Review the trend data to verify that the hydronic flow meter reliably and consistently reports to the BAS controller. Numeric interval trend extensions are used to collect trend data at the programmed time intervals. Initial trend data intervals should be short (5 seconds-5 minutes) intervals to allow transient issues (that cannot be identified with longer intervals) to be identified. Once the testing and commissioning stage has concluded, longer time intervals (10-20 minute) can be used to minimize data storage requirements. There should not be any gaps or omissions in the trend data. The trend data should show that the hydronic flow meter corresponds with the programmed control logic and schedule.
17. Document the results of all testing. Screenshots of the analog input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the analog input device.

30.5 Review

1. True or False: The BAS controller input configuration does not have to match the flow meter output parameters. Answer: _________
2. True or False: Magnetic flow meters are typically not affected by debris in the pipeline. Answer. ______________
3. A __________________ flow meter output signal is typically used when the totalized flow is to be billed?
4. Which type of flow meter is especially susceptible to debris in the system? Answer. ______________
    A. Magnetic
    B. Turbine
    C. Orifice
    D. Ultrasonic
5. A ______________ meter is used to eliminate the water treatment costs of domestic water that does not return to the water utility.
6. An ______________ meter is used to quantify the amount of energy each tenant of a building uses to bill them for the amount of energy their suite requires for space conditioning.

30.6 References

1. https://www.onicon.com
2. https://www.neptunetg.com/products/watermeters/

Chapter 31 - Electric Actuator Position Feedback (AI)

31.1 Description

Some control applications require the monitoring of the actual valve and/or damper positions. Having this data allows the confirmation that the valve and/or damper command was followed and provides the ability to detect the failure of the actuator. Modulating electric damper/valve actuators are typically controlled by an analog output signal generated by a control program PID loop to maintain the process variable at setpoint. Position feedback signals (0/2-10 VDC) are an option of most DCA electric actuators, so they are typically integral to the actuator. Position feedback devices produce a low-voltage signal that is proportional to the actuator position. Voltage signals (0/2-10 VDC) are typically used, but other signals (current, resistance, etc.) and ranges are possible depending on the manufacturer and feedback device. The BAS interprets this feedback signal following the parameters defined by the analog input configuration. If the position feedback signal is a 2-10 VDC signal as the actuator position varies between 0 and 100% open, then the BAS controller analog input should be programmed with the same parameters.

Photo 335 - Exhaust Damper Actuator with Position Feedback

Photo 336 - Chilled Water Byass Valve with Position Feedback

Photo 337 - Steam Globe Valve with Position Feedback

Should the commanded position and the feedback position feedback indication differ by more than a maximum threshold (typically 5%-10%), this would be interpreted as a failure of the damper/valve actuator. A sure sign that a position feedback signal has not been calibrated is when the position indication of the damper or valve does not match the commanded position. At 0%, 50%, and 100% open, the commanded and position indications should be fairly equal. Position feedback is not generally a point included with most control system designs because it requires an additional analog input for each monitored damper or valve. This can quickly drive up the cost of the controls package. Position feedback points are typically specified for critical HVAC systems or process applications that cannot tolerate excursions from pre-defined temperature and humidity limits. Position feedback of actuators can provide immediate notification of actuator failures rather than waiting until the environmental conditions or process parameters are out of tolerance.

Valve/Damper Position (% Open)	Feedback Signal (VDC)	Position Feedback (% Open)
0	2	0
25	4	25
50	6	50
75	8	75
100	10	100

Table 147 - Position Feedback Summary

When a single electric actuator does not provide sufficient motive force to drive a large valve, multiple actuators are utilized. The actuators actuate simultaneously multiplying the required torque/force applied to the driven valve or damper. To control multiple actuators with a single analog output signal, two methods may be employed. The first method is implemented by connecting the analog output signal from the BAS controller to multiple actuator input terminals. The second method utilizes the analog position feedback signal of the primary or master actuator to control the slave actuator. If additional actuators require control, the feedback signal of the previous slaved actuator is supplied to the control signal terminals of the next slaved actuator. The analog output signal from the BAS controller is supplied to the master actuator and the actuator feedback signals supply the actuator commands to all subsequent actuators.

31.2 Applications

1. **Damper/Valve Position Monitoring**: In some applications, an indication of the actual damper/valve position is required - not just the commanded position. When the commanded position and the position feedback signals do not match, the operator knows that there is an issue with the valve or damper.
2. **Damper/Valve Slaving**: When a single valve or damper actuator does not provide the required torque, an extra actuator may be utilized and the two operate in tandem. Some actuator manufacturers require that the feedback signal of the lead or primary actuator be used to drive the secondary actuator.

31.3 Typical Control Wiring

The following diagram shows the wiring strategy typically encountered when the position feedback signal is monitored by the BAS controller.

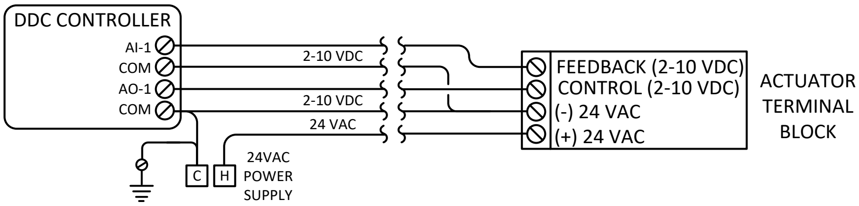


Figure 253 - Typical Actuator Voltage Control with Position Feedback Wiring Diagram

The following diagram shows an example of the wiring for a master-slave arrangement of electric actuators powered by the same 24 VAC power supply. With this arrangement, the BAS does not monitor the valve position. The feedback signal of the master actuator serves as the control signal of the slaved actuator. This arrangement can continue for as many additional actuators as necessary. It is typically used when multiple actuators are mounted to the same damper or valve. Alternatively, the analog output of the BAS controller can be wired directly to the control signal input of both actuators.

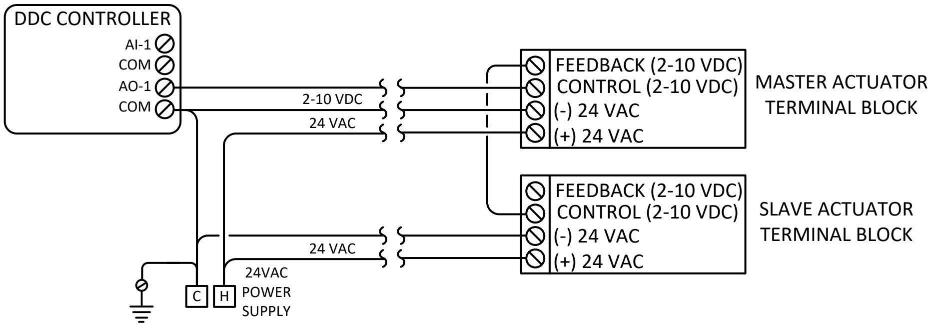


Figure 254 - Typical Master-Slave Actuator Wiring Diagram

31.4 Analog Input Testing and Verification

The general test procedures for Electric Actuator Position Feedback include the following:

1. Verify that the actuator position feedback device has the capabilities and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The operating range, mounting, output contacts, wiring, and output signals are some of the features that should be verified.
2. Verify that the actuator position feedback device has been installed at the correct or optimum location.
3. Verify that the actuator position feedback device has been installed per the manufacturer's installation recommendations. The actuator feedback signal is often generated by circuits that are integral to the actuator.
4. Posture the HVAC system or the required components (damper, control valves, fans, VFD speeds, etc.) to prevent unwanted system changes (modulation, staging, cycling) during the sensor/transmitter calibration. Position overrides commands are typically used.
5. Verify that the actuator position feedback device has been connected to the correct BAS controller analog input. Removing the signal or 24 VAC power wire from the actuator/transmitter will cause the position reading to change. It is a good idea to make a note or take a screenshot of the data point reading that occurs when the analog input device is disconnected.

6. At the same time that the actuator position feedback device's electrical contacts are opened, verify and document that the data point bound to the BAS graphics also changes.
7. Verify that the actuator position feedback device has been correctly wired. The actuator position feedback device may have multiple sets of contacts that must be properly landed and coordinated to provide the required signal type and range. Drawings or sketches are typically best for documenting the wiring strategies used.
8. Verify that the actuator position feedback device and its wires at the BAS controller end have been labeled.
9. Verify that the units/facets for the actuator position feedback device are correctly displayed. The facets for the actuator position are typically percent open (% Open).
10. Verify that the precision of the actuator position reading is appropriately set. Actuator positions are typically displayed with a maximum of one decimal place. Actuator position setpoints are typically displayed with whole numbers (no decimal places).
11. Verify that the BAS controller's analog input point has been configured to match the actuator position feedback device range and output signal. The analog input of the BAS controller may be initially configured to interpret the voltage signal from the actuator position feedback device as follows:

Reading	Actuator Position (% Open)	Actuator Signal (VDC)
Minimum	0	2
Maximum	100	10

Table 148 - Initial Analog Input Configuration

If the analog input configuration of the BAS controller is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs. The scale and offset values are used to calculate the actuator position from the voltage signal provided by the actuator. These values will be updated based on calibration readings as explained in later steps.

Volts (DCV)	Position (%)
2	0
10	100

Calculated Scale=	12.50
Calculated Offset=	-25.00

Table 149 - Initial Scale-Offset Calculation

12. Verify the accuracy of the position feedback reading by comparison with reference field observations. At each calibration point record the BAS damper/valve position command, feedback position observation, and the signal generated by the position feedback transmitter. Calibration of the actuator position feedback device is typically performed by comparing the actual actuator position (and/or commanded position) to the reported actuator position. However, others prefer to calibrate the feedback reading to the commanded position. When the device command and actual position are displayed next to one another, it is annoying to see differences between the readings. This method requires that the analog output that controls the actuator be calibrated before calibrating the position monitoring point. If accurate calibration results cannot be attained, then it should be replaced. Single-point calibrations are not recommended because they will not produce the required information to calibrate transmitter readings. Refer to Chapter 2: BAS Calibration and Chapter 3: BAS Inputs and Outputs for more information. Calibration of the actuator position feedback signal may resemble the following table.

Reading	Test/Instrument (% Open)	BAS Data Point (% Open)	Signal (VDC)
1	0	3.0	2.24
2	50	50.63	6.05
3	100	98.25	9.86

Table 150 - Initial Transmitter/BAS Calibration Check

13. Verify that the output signal generated or transmitted by the position feedback is appropriate for the sensor reading. This step verifies that the sensor transmitter produces or transmits the correct output signal which will be monitored by an analog input of the BAS controller. If the sensor transmitter does not produce the appropriate output signal or does not report across its full range, then it should be replaced.

Reading	Test/Instrument (% Open)	Transmitter Signal (VDC)	Calculated Output (% Open)
1	0	2.24	3.0
2	100	9.86	98.25

Table 151 - Transmitter Output Signal Verification

14. Update the configuration of the analog input of the BAS controller and retest to confirm the calibration of the actuator position feedback device. At the fully closed position, the indicated position reading should be 0.0% or very close to it. Likewise, at the fully open position, the indicated position should be 100% open or close to it. If the actuator position feedback device readings still appear to be inaccurate or the actuator position feedback device does not provide readings across its full range, then replacement of the actuator position feedback device is recommended. Record the final analog input calibration and correction factors.

Reading	Test/Instrument (% Open)	Volts (VDC)
Minimum	0%	2.24
Maximum	100%	9.86

Table 152 - Updated BAS Controller Configuration

If scale and offset factors are used to configure the parameters of the BAS controller analog input, update them accordingly using the same methodology explained in Chapter 3: BAS Inputs and Outputs. Confirm the accuracy of the analog input configuration change by comparing new actuator feedback signal to the hydronic flow indicated by the BAS.

Volts (DCV)	Position (%)
2.24	0
9.86	100

Updated Calculated Scale= 13.12

Updated Calculated Offset= -29.40

Table 153 - Updated Scale-Offset Calculations

15. Release all overrides used to posture the system for testing and calibration.
16. Review the trend data to verify that the actuator position feedback device reliably and consistently reports to the BAS controller. Numeric interval trend extensions are used to collect trend data at the programmed time intervals. Initial trend data intervals should be short (5 seconds-5 minutes) intervals to allow transient issues (that cannot be identified with longer intervals) to be identified. Once the testing and commissioning stage has concluded, longer time intervals (10-20 minute) can be used to minimize data storage requirements. There should not be any gaps or omissions in the trend data. The trend data should show that the actuator position feedback device corresponds with the programmed control logic and schedule.
17. Document the results of all testing. Screenshots of the analog input point data as well as the BAS graphics are useful for documenting the ability of the BAS to monitor the analog input device.

31.5 Review

1. If a damper position feedback device has a 2-10 VDC signal between fully closed and fully open and is indicating a signal of 4.85 VDC, what position should be indicated in the BAS? Answer. ______________
2. If the damper position feedback indicated on the BAS graphics is 20% open when the damper has been commanded fully closed, what most likely has occurred? Answer: _________
    - A. The actuator produces a 0-10 VDC control signal and the analog input for the position feedback signal has been configured for 2-10 VDC.
    - B. The actuator produces a 2-10 VDC control signal and the analog input for the position feedback signal has been configured for 0-10 VDC.
    - C. Damper efficiency has improved by 20%
    - D. None of the above

Section 4: Binary Output (BO) Devices

Chapter 32 - Equipment Remote Enable (BO)

32.1 Description

Building automation systems routinely interface with and provide supervisory control of HVAC equipment (chiller, boilers, humidifiers, VFDs, packaged air-handling units, etc.) equipped with their internal controllers. Chillers (both water-cooled and air-cooled), for example, have a manufacturer-provided controller that has been programmed to control and monitor its various processes to ensure safe, reliable, and efficient operation. They can operate autonomously with or without a BAS. However, for energy efficiency and the reduction of unnecessary wear and tear, their operation is typically limited through the BAS. The BAS provides a run-permissive signal through an isolation relay which provides electrical isolation between the BAS controller and the controlled equipment. The BAS enables the controlled equipment based on programmed logic, operating schedule, or manual override.

Most equipment capable of enabling by remote signal will have terminal board contacts. These contacts may include remote enable/disable, operating status, alarm/fault status, and output/setpoint adjustment signals. This chapter focuses on the remote enable contacts that allow an external binary signal to control when the equipment operates. Typically, when the remote enable contacts are connected or made electrically continuous, the equipment will energize and operate as long as its internal safeties are in their normal state. It is common to see a jumper wire installed across these contacts when temporary operation is required (before BAS control is established). The equipment enable contacts are typically wired to the normally-open switched contacts of an isolation relay that is controlled, either directly or indirectly, by a binary output of a BAS controller. When the operation of the controlled equipment is no longer required, the binary output of the BAS controller is disabled. This de-energizes the coil of the isolation relay thereby causing the switched relay contacts to revert to their de-energized state (normally open) which opens the remote enable circuit and disables the controlled equipment.

Photo 338 - RIBU1S Isolation Relay for Chiller Enable

Photo 339 - RIBU1C Isolation Relay for Boiler Enable

Photo 340 - RIBU1C Isolation Relay for Return Fan VFD Enable

The obvious sign that a piece of equipment is under BAS control is the presence of an isolation relay mounted to its control enclosure or nearby junction box. This isolation relay is typically either connected directly to a binary output of a BAS controller or is indirectly connected to it through an intermediate isolation relay mounted in the BAS local control panel. Recall from Chapter 3: BAS Inputs and Outputs that it is very common to have two isolation relays for every binary output when the controlled equipment is not within sight of the BAS control panel. The most frequently observed isolation relay used for equipment enabling is the Functional Devices, Inc. model RIBU1C. Most isolation relays used in HVAC applications have an LED that illuminates when its coil is energized. This provides a visual indication of the relay's commanded state.

It is not uncommon for Owners, Operators, or Designers to require that the controlled equipment be allowed to operate if there was ever a failure of the BAS or its power. This is fairly typical for central plant equipment like boilers, air-cooled chillers, cooling towers, and their pumps. This is typically accomplished by connecting the remote enable contacts of the controlled equipment to the normally-closed contacts rather than the normally-open contacts of the isolation relay. Therefore, if the BAS controller or its power were to fail, then the equipment's remote enable terminals would continue to be electrically continuous because they are connected to the normally-closed switched relay contacts. The chiller can be manually operated as if the BAS did not exist. With this wiring strategy, we have to keep in mind that the isolation relay coil (RIBU1C, RIBU1S, or similar) must be enabled or powered by the BAS controller binary output to disable the controlled equipment. In addition, modifications to the control logic are also required. As a result, the isolation relay's status LED will be lit when it is disabled and off when it is enabled. This can be confusing for all because this is opposite the normal relay enable strategy where the binary output is energized to power the isolation relay coil which enables the connected equipment.

Remote enable relays are often used as the dividing line between the BAS and the HVAC equipment (typically rooftop, boilers, chillers, etc.) with packaged controls whether or not they have been integrated to the BAS. Through the JACE, integrated equipment with packaged controls is enabled through isolation relays and operating and control data is acquired through the communication protocol. Delivering the run or enable command through BACnet or other communication protocols can be problematic if the communication trunk is less than 100% reliable. Most Controls Contractors prefer to enable equipment through an isolation relay controlled by a nearby BAS controller rather through the communication protocol. The isolation relay provides visual evidence of the start command that can be easily verified. If the equipment does not operate or operates incorrectly then the equipment manufacturer or their local representatives can be called to troubleshoot. Without a functional communication trunk, the enable signal will not reach the integrated equipment or the BAS controller that delivers this command. It is for this reason that the normally-closed contacts of the isolation relay are often used to enable the integrated equipment. Therefore, if the communication trunk fails, the integrated equipment will still operate. This wiring strategy keeps the integrated equipment (typically rooftop units) operational and occupants comfortable until the communication trunk is restored.

Occasionally, older equipment without remote enable contacts will be encountered. To control these pieces of equipment it is necessary to find a control circuit or power circuit where the remotely controlled relay contacts can be installed. For example, the burner controllers of older boilers do not have remote enable contacts. Review the burner's wiring diagrams to determine the best place to install the isolation relay. The enabling isolation relay is typically connected in series with the boiler's burner control circuit which essentially removes the signal that tells the burner to fire. Some may install the enabling isolation relay in series with the burner On/Off switch. The enabling isolation relay should never be installed in a safety circuit. None of the safety functions should be compromised by the installation of the remote enable isolation relay. Consult the equipment manufacturer or their literature to verify that the proposed location for the control relay is acceptable.

32.2 Applications

1. **Equipment Enable/Disable**. HVAC equipment with their manufacturer-provided controllers can be enabled and disabled by the BAS through one or more isolation relays.

32.3 Typical Control Wiring

The following example shows the binary output of a BAS controller being used to control a remote isolation relay that is mounted at or near the controlled equipment (boiler, chiller, humidifier, etc.). The switched contacts of the isolation relay are connected to the equipment's remote enable contacts and provide either an Enable command with closed contacts or a Disable command if the contacts are open. In this wiring example, the controlled equipment will only energize when the binary output is enabled. The normally-closed contacts could also be wired to the remote enable contacts to allow the equipment to operate should a failure in the BAS controller or its communications ever occurs.

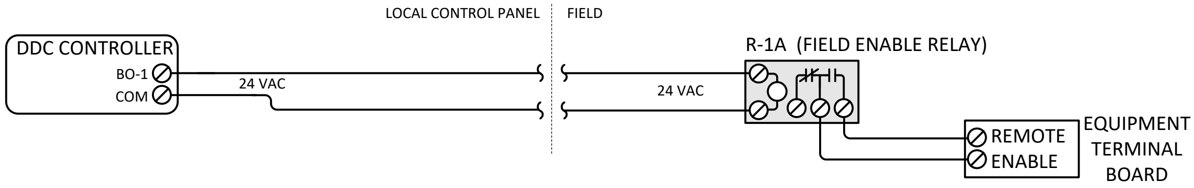


Figure 255 - Equipment Remote Enable Wiring

The following wiring example shows the same wiring above, but it has an additional isolation relay that is mounted in the local control panel whose switched relay contacts control the coil of the remote isolation relay. In essence, the panel-mounted isolation relay controls the field-mounted isolation relay. This wiring strategy is typically used when the controlled equipment is not within sight of the BAS controller. The panel-mounted relay provides local electrical isolation and visual indication of the binary output status which drastically reduces troubleshooting time. The IDEC RH series of relays are typically used in the local control panel because of its small size and DIN rail or surface mounting capabilities. Its switched contacts are used to control the coil of the remotely mounted isolation relay which is typically a Functional

Devices RIBU1C relay or similar.

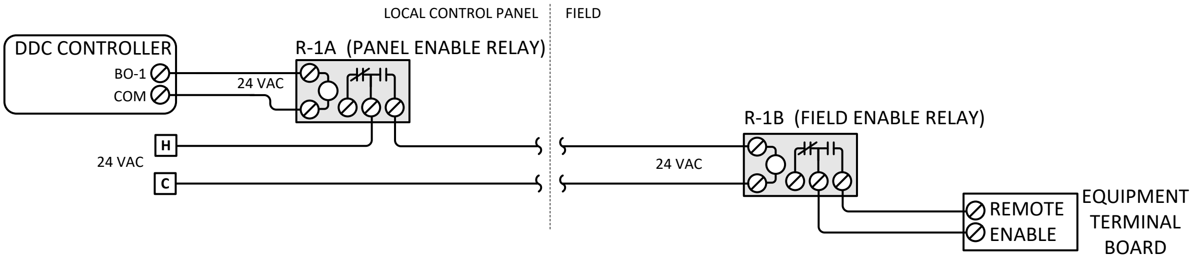


Figure 256 - Equipment Remote Enable Wiring

32.4 Binary Output Testing and Verification

Testing and verification of Equipment Remote Enable may pose an electrical hazard because of the potential exposure to high-voltage (120 VAC and higher) electrical conductors. De-energize the electrical power whenever possible. Use the appropriate personal protective equipment to ensure your safety and those around you when access to live electrical enclosures is required. The general test procedures for Equipment Remote Enable include the following:

1. Verify that the isolation relays have the capabilities, capacity, and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The mounting, weather-rating, coil voltage, status indicating LEDs, manual override, contact ratings, number of poles, switched contact ratings, and wiring requirements are some of the features that should be verified.
2. Review the sequences of operation to verify whether the controlled equipment should fail safe to the enabled or disabled state. It is not uncommon for enable contacts of chillers, boilers, and pumps to be connected to the normally-closed switched contacts of the enabling isolation relay.
3. Verify with the equipment wiring diagram and equipment literature whether the closure of the remote enable contacts enables or disables the equipment. This will help avoid any surprises and help facilitate the required control strategy necessary to comply with the sequences of operation.
4. Verify that the isolation relay has been installed in the correct or optimum location. Isolation relays should be securely mounted adjacent to the terminal block of the controlled equipment. They are typically mounted in a knockout or hole drilled in the enclosure of the control cabinet, junction box, or wire trough. Isolation relays should not be inside these enclosures hanging by the wires. It is good practice to mount the isolation relay at the controlled equipment so that its status LED is visible without opening an electrical enclosure (boiler, chiller, VFD, etc.). This provides a very useful visual indication of whether this piece of equipment has been enabled (or is disabled) by the BAS.
5. Verify that the isolation relays have been installed per the manufacturer's installation recommendations.
6. Verify that the isolation relays have been correctly wired. Review the ladder logic diagrams typically included in the control submittal. Drawings or sketches are typically best for documenting the wiring strategies used. The switch contacts of the isolation relay should terminate at a pair of remote enable terminals dedicated to enabling the controlled equipment. Some equipment may not have dedicated remote enable terminals. In these cases, the capacity control circuit that enables its operation (enabling, staging, cycling, etc.) must be identified and the switched contacts of the isolation relay are wired so that they are part of that circuit. Therefore, the controlled equipment can only operate when the switched contacts of the BAS isolation relay are closed and when its own capacity control circuit calls for its operation. Be sure to confirm that the switched contacts of the BAS isolation relay were not connected to any safety circuits of the controlled equipment.
7. Verify that the isolation relay is connected to the correct BAS controller binary output. In general, Controls Contractors use isolation relays to provide electrical isolation between the BAS controller and the controlled equipment (boiler, chiller, packaged equipment controller, or VFD). Using the binary output data point (not the BAS graphics), cycle the enable command to verify that it energizes and de-energizes on command. Electrical measurements can also be made at the terminals of the controlled equipment to verify control.
8. As the BAS controller binary output is overridden, verify and document that the corresponding data point bound to the BAS graphics also changes. Also, verify that the binary output data point bound to the graphic changes color to indicate that it has been overridden. While the binary output is overridden, the programmed control logic no longer controls the binary output and it will remain in the overridden state until the override is released.
9. Using the binary output field bound to the BAS graphics (not the binary output data point), verify that the controlled

equipment (chiller, boiler, humidifier, rooftop air-handling units, VFD, etc.) energizes and de-energizes on command. Also, verify that the BAS graphic provides a visual indication that this binary output point is currently overridden. The following example state table applies for equipment that is wired to the normally-closed relay contacts (as opposed to the normally-open). This allows the equipment to operate when there is no BAS signal.

Field Measurements/Observations				
Command	R-1 Coil Voltage (VAC)	R-2 Coil Voltage (VAC)	Equipment Contact Status	Observed Equipment Status
Off	27.1	27.1	Open	Off
On	0	0	Closed	On
Fail-Safe	0	0	Closed	On

Table 154 - Control Signals versus Equipment Command State Table

10. Verify that the fail-safe operating status of the controlled equipment (chiller, boiler, VFD, packaged air-handling unit, etc.). The easiest way to do this is to remove power from the BAS controller while leaving all other circuits (safety circuits, actuators (damper/valves) and controlled equipment live. This simulates both the loss of BAS controller power and the loss of control signal from the binary output.
11. Verify that the LED status indicators of the isolation relays illuminate to indicate their commanded state with each cycle of the binary output. If it does not illuminate, replacement is recommended. Many Controls Contractors make a note with a permanent marker or label near the isolation relay if it is wired to disable the controlled equipment upon enabling the BAS binary output.
12. Verify that the isolation relay and its wires at the controller end have been labeled to indicate the binary output data point (BO-X) and what equipment or system it is associated with. For example, a humidifier enable relay may be marked or labeled with the following information: BO-3/Humidifier Enable. A label is useful for indicating when an enable command is disabled to enable the equipment as is the case when it is connected to the normally-closed enable relay contacts.
13. If the isolation relay controlled by the binary output is equipped with an H-O-A switch, verify that it functions in all positions. If it does not, troubleshoot the wiring and retest. The Functional Devices, Inc. model RIBU1S or RIBU1S-NC (or similar) is typically used for this application. In the Hand position, the controlled equipment is enabled permanently. In the Off position, the controlled equipment will not operate at all. In the Auto position, the binary output signal from the BAS controller (or time clock) will control the operation of the controlled equipment.
14. Verify that the facets of the binary output data point are correctly displayed. The facets should be consistent with the commanded states of the controlled equipment. Equipment with its own packaged controls such as chillers, boilers, humidifiers, and rooftop air-handling units are typically given the facets of "Enabled/Disabled," but you may also see "Start/Stop" or "Run/Stop."
15. If the status of the controlled equipment is monitored by a status monitoring device (air differential pressure switch, hydronic differential pressure switch, end-switches, position feedback contacts, or current-sensing relay), this is the ideal time to test that device as well.
16. Verify that the binary output that controls the isolation relay controls the equipment over time by reviewing trend data. If the binary output can be verified by other sensors, trend those points as well. For example, if a chiller command is enabled, then the chilled water supply temperature would also be trended to confirm that the command was executed. Trending the command only does not confirm that the command was followed.
17. Document the results of all testing. Screenshots of the binary output point data as well as the BAS graphics are useful for documenting the ability of the BAS to control the binary output device.

32.5 Review

1. True or False: It is uncommon for two isolation relays to be used to energize the controlled equipment.

   Answer: _________
2. True or False: The Functional Devices, Inc. model _____________________ is the most utilized equipment enable relay.
3. The isolation relay _____________________ provides a quick and reliable visual indication of the relay's coil status.
4. The presence of an _____________________ on a piece of equipment (boiler, chiller, humidifier, etc.) or nearby electrical enclosure is a positive sign that it is controlled by the BAS.
5. A modular boiler plant has four boilers and each boiler has a circulating pump. If the boiler and its pump must be

enabled at the same time and the BAS controller only has four binary outputs available, how many poles must each isolation relay have? Answer: ____________________.

6. To allow a boiler to operate during a BAS control failure, the _________________ contacts of the isolation relay are wired to the remote enable terminals of the boiler.

Chapter 33 - Electric Load Control (BO)

33.1 Description

The BAS controller is commonly tasked with controlling the operation of single-phase and three-phase circuits of much higher capacity. Isolation relays, contactors, and starters are used in various configurations to allow the low-power binary output of the BAS controller to control high-power circuits. These loads may be resistive as is the case with electric resistance heaters or they may be inductive as is the case with loads driven by induction motors. The choice of load control devices depends on the load type and its power capacity.

Single-phase loads (electric resistance heaters, pump motors, fan motors, and compressors) are powered by 120 VAC, 230 VAC, and 277 VAC circuits. Single-phase equipment not equipped with a contactor or starter will be wired such that the current required to operate the single-phase load will pass through the switched contacts of the isolation relay. Therefore, it is important to verify that the contact ratings of the isolation relay exceed the voltage and current ratings of the single-phase load. It is very common to see Functional Devices, Inc. model RIBU1C used for applications smaller than 1/3 HP motor at 120 VAC. In applications requiring higher power ratings, you may see a Functional Devices, Inc. model RIB24P which is rated for a 1 HP motor at 120 VAC. Small horsepower loads typically do not have a dedicated control cabinet where the isolation relay can be mounted, so you will typically find them installed in the closest junction box or wire trough. This is where labeling becomes important. Without labeling the isolation relays to indicate what binary output controls them and what they are controlling, significant time can be spent troubleshooting power and control issues.

Photo 341 - RIB® Used for Single-Phase Pump Enable

Photo 342 - RIBs® Used for Enabling Terminal Unit Heat Stages

Photo 343 - RIB® Used for Electric Finned-Tube Radiation

If the single-phase equipment has a higher power rating than can be safely controlled by an isolation relay, it will typically be equipped with a contactor or motor starter. These devices have coils just like a typical isolation relay that allow a low-voltage circuit to control a high-voltage circuit. The binary output of the BAS controller controls the coil of the isolation relay thereby controlling the switched contacts of the isolation relay to finally control the coil of the contactor or starter. The current required to operate the single-phase load passes through the switched contacts of the contactor or starter, not the isolation relay. It is very common to see Functional Devices, Inc. model RIBU1C isolation relays used in this application. The controlling isolation relay is typically mounted on the control/electrical enclosure of the controlled equipment. If it has no electrical enclosure, it will typically be installed on a nearby junction box.

When the electrical load exceeds the limitations of single-phase power sources, three-phase contactors, and starters will be required. They are used to safely energize high-power loads such as fans, pumps, compressors, and electric resistance heaters with the low-power binary outputs of the BAS controller through the use of isolation relays. The isolation relays allow the binary output of the BAS controller to control the contactor/starter control circuit which, in turn, controls the three-phase power circuit which may be up to 480 VAC. This isolation relay is often called the "Start/Stop" or "Enable" relay. The contactor/starter control circuit is often called the "safety circuit" because it directly or indirectly incorporates the status contacts of the included safety devices. If any of the safety devices actuate, their contacts open to disable the starter control circuit or VFD safety circuit. Air-handing units are typically equipped with one or more smoke detectors, low-temperature detectors, and high-static safety switches. Depending on system design, many other safety devices may also be included: low-static safety, smoke isolation dampers, fire alarm relay module, etc. The inclusion of the safety devices in the safety circuit is accomplished in two ways. They are either directly wired in series in the control circuit or they may be part of a separate safety circuit whose status is indicated by a "safety" interlock relay. Refer to Chapter 6: Wiring Practices for Safety Devices for more information on this topic.


Photo 344 - RIB® Used for Three-Phase Exhaust Fan Enable


Photo 345 - RIB® Used for Three-Phase Air-Handling Unit Enable

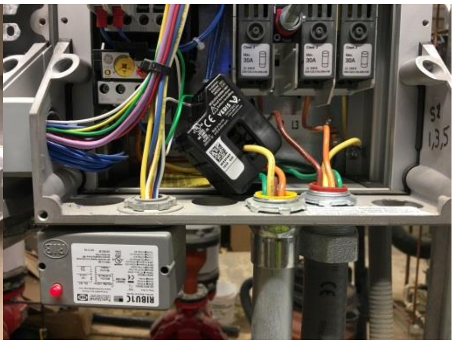


Photo 346 - RIB® Used for Three-Phase Pump Enable

33.2 Application

Binary outputs for the control of single-phase and three-phase loads are applicable to a wide variety of equipment which includes, but are not limited to, the following:

1. Air-Handling Unit Supply and Return Fan Motor Control.
2. Exhaust Fans Motor Control.
3. Terminal Unit Fan Control.
4. Electric Resistance Heat Control.
5. Circulating Pump Control.
6. Compressor Control.

33.3 Typical Control Wiring

33.3.1 Miscellaneous Uses of Isolation Relays

It is important to recall from Chapter 3: BAS Inputs and Output that binary commands originate from BAS controller binary outputs with either dry contacts or Triac circuits. The actual wiring strategy used changes slightly depending on the output type. For simplicity, the binary outputs depicted in this chapter are of the Triac output type because they required less wiring and are easier to understand, but in the real world either binary output type may be encountered.

It is also important to recall that the binary output signal will pass through at least one insolation relay, but the use of two isolation relays is very common. Electrical isolation between the BAS controller and the controlled equipment is very important to the electrical protection of the BAS controllers. The LED status indicators of the isolation relays are a very useful troubleshooting tool because they provide a visual indication of whether the BAS is calling for this binary output to be energized. The first relay is typically located inside the LCP and the second is located at the controlled equipment. If a contactor or motor starter is equipped with an H-O-A switch, an isolation relay such as the Functional Devices, Inc. RIBU1S which is also equipped with an H-O-A switch is not recommended. Two H-O-A switches in series will cause confusion for all involved in its use and operation. If a contactor or motor starter is equipped with an H-O-A switch, a RIBU1C or a similar isolation relay is recommended to control the coil of the contactor or motor starter.

Normally, binary or On/Off control of the equipment is implemented through the use of the normally-open switched contacts. When operation of the controlled equipment is required, the BAS controller binary output is enabled which energizes the coil of the interlocking isolation relay. This causes the normally-open switched relay contacts to close which enables the controlled equipment. If the BAS controller were to fail, by whatever means, the binary output would not energize unless the controlled equipment or the isolation relay were equipped with an H-O-A switch. If manual operation of the controlled equipment is required should the BAS controller ever fail, the normally-closed contacts of the isolation relay are connected to the equipment control circuits. This could also be implemented through the use of a RIBU1S or RIBU1S-NC or similarly with a combination motor starter/disconnect switch with an H-O-A switch.

33.3.2 Single-Phase Load (Load Current Through Isolation Relay Contacts)

When the current demand of the driven loads are within the power rating of typical isolation relays, the switched contacts of the isolation relay may be part of the power circuit that drives the single-phase load. This wiring strategy is typically used to control the operation of small electrical loads such as single-phase exhaust fans, coil circulation pumps, electric resistance heaters, domestic water recirculation pumps, dampers, valves, etc.

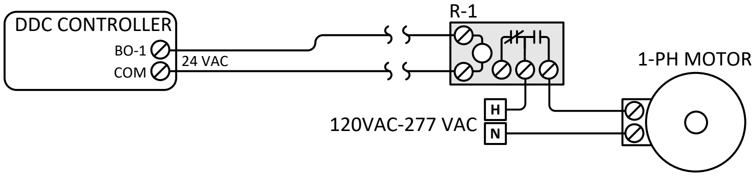


Figure 257 - Single Phase Load Powered by Relay Contacts

The wiring example above shows a BAS controller binary triac output BO-1 that energizes to power the coil of isolation relay R-1. Once the coil of R-1 is energized, its normally-open switched contacts close to energize the single-phase load.

33.3.3 Single-Phase Load (Load Current Through Contactor Contacts)

The following diagram shows a double-pole contactor that is used to control a single-phase load. Contactors do not have overload protection, so they are typically not used to control induction motor operation unless they are small. Contactors are ideal for the control of electric resistance heaters because most electric resistance heaters typically have low inrush current when initially energized. In many installations, the neutral leg is directly connected to the load and only the hot leg is interrupted by the switched relay contacts. In this case, a double-pole, single throw contactor is utilized. The BAS controller binary output (BO-1) controls an isolation relay whose switched contacts control the coil control circuit of the contactor. When enabled, the binary output of the BAS controller applies 24 VAC to the coil of the contactor. Once energized, the switched contacts of the contactor close to power the load.

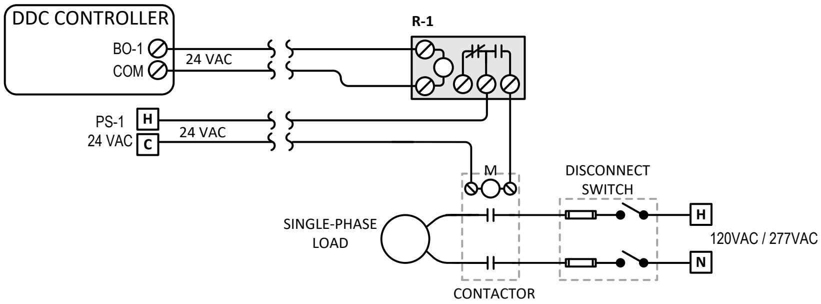


Figure 258 - Single Phase Load Powered by Contactor (24 VAC Coil)

The following diagram shows an isolation relay that is used to control the operation of a contactor with an H-O-A switch. The coil voltage ratings of the contactor can vary widely. It can range from 24 VAC as indicated above to 480 VAC. Therefore, it is important to match the switched contact ratings of the contactor to the load. The binary output contacts are typically 24 VAC or are dry contacts which are typically rated for at least 24 VAC. At least one isolation relay will be used by the BAS controller to control higher power circuits.

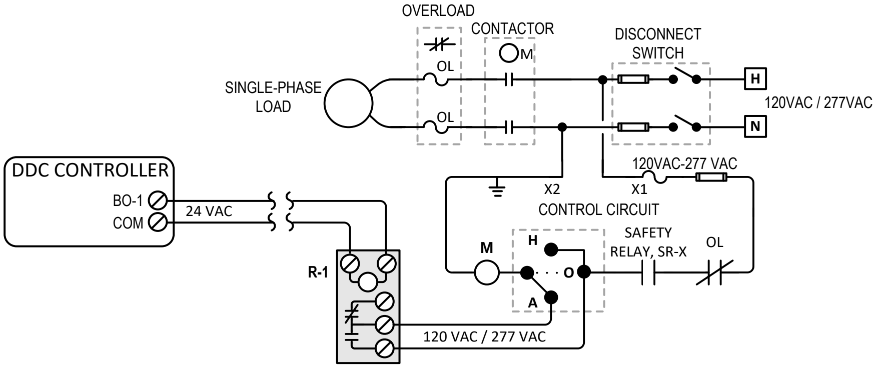


Figure 259 - Single Phase Load Powered by Contactor (120 VAC Coil)

33.3.4 Three-Phase Load (Load Current Through Contactor Contacts)

The following diagram shows a 480 VAC three-phase contactor that is controlled by the BAS. In this example, a transformer is used to step the 480 VAC voltage down to 120 VAC for use in controlling the 120 VAC coil of the contactor.

The isolation relay's switched contacts control the 120 VAC circuit which powers the coil of the contactor thereby allowing the 24 VAC signal of the BAS controller to control the 480 VAC circuit which powers the load.

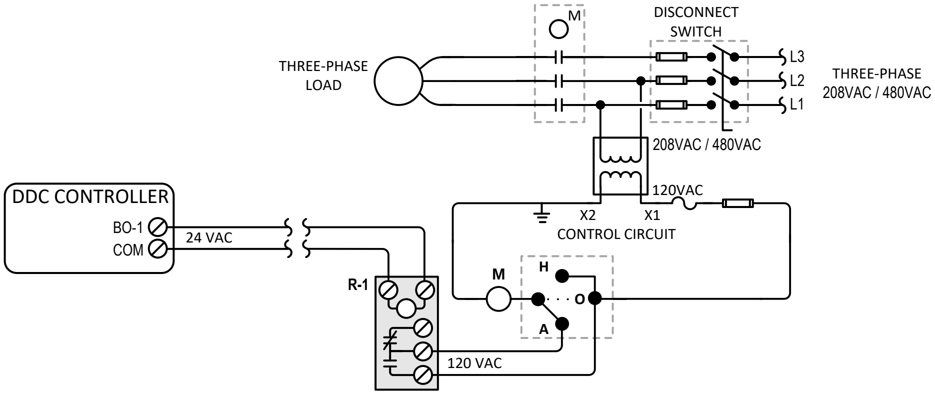


Figure 260 - Double Relay Single-Phase Load Control Circuit

33.3.5 Single-Phase Load (Load Current Through Motor Starter Contacts)

The following diagram represents a single-phase load that is controlled by a single-phase motor starter. In this example, the BAS controller's binary output controls the isolation relay (R-1) through the leg of the H-O-A switch which, in turn, controls the contactor's coil control circuit of the contactor. The load could be a fan motor, pump motor, or compressor motor, or electric resistance heater. The motor starter protects the driven induction motor from high temperatures which could damage the motor windings.

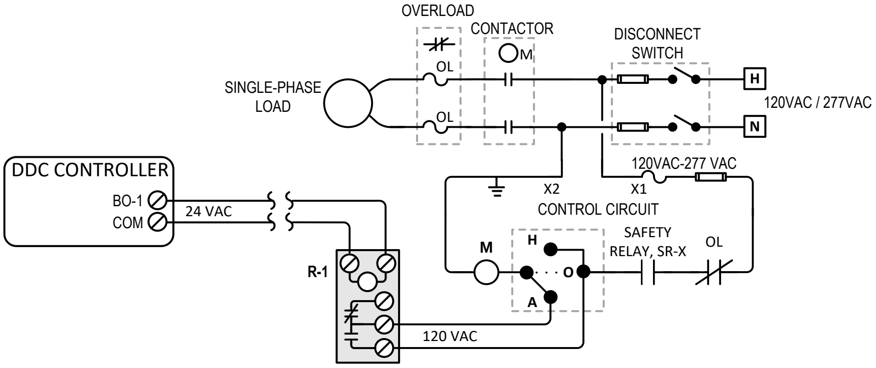


Figure 261 - Double Relay Single-Phase Load Control Circuit

The thermal overload monitors the current flow through the conductors and interrupts the coil circuit of the contactor should the current limits exceed their setpoints. Induction motors can have very high inrush currents which must be initially allowed to get the motor moving but quickly reduce to normal levels once the motor's normal operating speed is attained.

33.3.6 Three-Phase Load (Load Current Through Motor Starter Contacts)

The following wiring example is typical of three-phase loads controlled by a motor starter. The only difference between a contactor and a motor starter is the inclusion of overload protection for the induction motor. The BAS controller binary output controls an isolation relay whose switched contacts control the coil control circuit of the contactor. Also included in this control circuit example are the H-O-A contacts, overload status contacts, and the interlocking safety relay switched contacts whose coil is controlled by the fan safety alarm circuit.

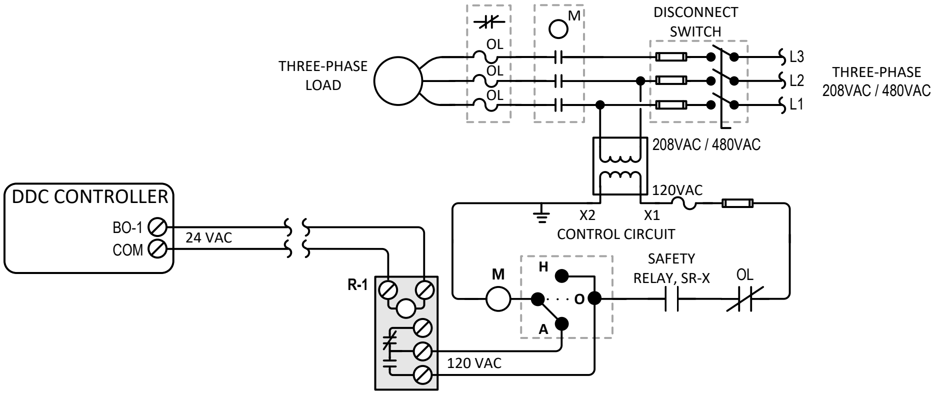


Figure 262 - Binary Output Controlling Three-Phase Load Through an Isolation Relay

33.4 Binary Output Testing and Verification

Testing and verification of Electric Load Control may pose an electrical hazard because of the potential exposure to high-voltage (120 VAC and higher) electrical conductors. De-energize the electrical power whenever possible. Use the appropriate personal protective equipment to ensure your safety and those around you when access to live electrical enclosures is required. The general test procedures for Electric Load Control include the following:

1. Verify that the isolation relay(s) has the capabilities, capacity, and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The mounting (DIN rail, base plate, knockout, snap track, etc.), weather-rating, H-O-A switch, coil voltage, LED status indications, switched contacts ratings, number of poles, and wiring requirements are some of the features that should be verified.
2. Review the sequences of operation to verify if the controlled equipment's circuit should fail safe to the enabled or disabled state.
3. Verify that the isolation relays have been installed in the correct or optimum location. They are typically mounted in a knockout or hole drilled in the enclosure of the control cabinet, junction box, or wire trough. Isolation relays should not be inside these enclosures hanging by the wires. It is good practice to mount the isolation relay so that its status LED is visible from the outside of the electrical enclosure. This provides a very useful visual indication of whether this piece of equipment has been called to run by the BAS.
4. Verify that the isolation relays have been installed per the manufacturer's installation recommendations.
5. Verify that the isolation relays have been correctly wired. Review the ladder logic diagrams typically included in the control submittal. Drawings or sketches are typically best for documenting the wiring strategies used. Also verify that any unused isolation relay wires are secured to prevent clutter and confusion.
6. Verify and document how all hard-wired interlocks are implemented. When a safety device of an air-handling unit activates, its fans are disabled, power to spring-return valve and damper actuators is disabled, and an alarm is generated. With no power, the dampers and valves assume their fail-safe or normal positions. Drawings or sketches are typically best for documenting the wiring strategies used.
7. Verify that the binary output device is connected to the correct BAS controller binary output. Using the binary output data point (not the BAS graphics), cycle the controlled equipment (fan, pump, compressor, electric resistance heat, etc.) to verify that it energizes and de-energizes on command. The following example state table applies for a circuit that is wired to the normally-open relay contacts. An H-O-A switch (part of motor starter or relay) is required to enable the controlled circuit when the BAS command is off or disabled.

Field Measurements/Observations				
Command	R-1 Coil Voltage (VAC)	R-2 Coil Voltage (VAC)	Equipment Contact Status	Observed Equipment Status
Off	0	0	Open	Off
On	27.1	27.1	Closed	On
Fail-Safe	0	0	Open	Off

Table 155 - Control Signals versus Load Control Command State Table

8. As the BAS controller binary output is overridden, verify and document that the corresponding data point bound to the BAS graphics also changes. Also, verify that the binary output data point bound to the graphic changes color to indicate that it has been overridden. The color change provides a visual notification on the BAS graphics that this

point has been overridden. While the binary output is overridden, the programmed control logic no longer controls the binary output and it will remain in the overridden state until the override is released.

9. Using the binary output field bound to the BAS graphics (not the binary output data point), verify that the controlled electrical circuit energizes and de-energizes on command. Also, verify that the BAS graphic provides a visual indication that this binary output point is currently overridden.
10. Verify the fail-safe position of the controlled circuits. The easiest way to do this is to remove power from the BAS controller while leaving all other circuits (safety circuits, actuators (damper/valves) and controlled equipment live. This simulates both the loss of BAS controller power and the loss of control signal from the binary output.
11. Verify at the LED status indicators of the isolation relays illuminate to indicate their commanded state with each cycle of the binary output. If it does not illuminate, replacement is recommended.
12. Verify that the isolation relay and its wires at the controller end have been labeled to indicate what binary output data point (BO-X) controls it and what equipment or system/component it is controlling. For example, a supply fan enable relay may be marked or labeled with the following information: BO-3/SAF Enable. In addition, for equipment wired to the normally-closed switched relay contacts (instead of the normally-open), Controls Contractors typically make a note with permanent marker or place a label on or near the isolation relay to indicate that its coil is enabled to disable the controlled equipment.
13. If the contactor or motor starter are equipped with an H-O-A switch, very that it functions in all switch positions. If it does not, troubleshoot the wiring and retest. In the Hand position, the controlled equipment is enabled permanently. In the Off position, the controlled equipment will not operate at all. In the Auto position, the binary output signal from the BAS controller (or time clock) will control the operation of the controlled circuit. Isolation relays with H-O-A switches are not recommended if an H-O-A switch is already provided with the controlled equipment. This will cause confusion for all involved.
14. Verify that the facets of the binary output data point are consistent with the commanded states of the controlled equipment. Equipment directly controlled by the binary output, like fans, pumps, and electric resistance heaters typically display “Start/Stop,” “Run/Stop,” or “True/False” facets.
15. If the status of the controlled equipment is monitored by a status monitoring device (air differential pressure switch, hydronic differential pressure switch, end-switches, position feedback contacts, or current-sensing relay), this is an ideal time to test that device as well.
16. Verify that the operation of the equipment controlled by the BAS controller binary output over time by reviewing trend data. Change-of-State trends are typically utilized to minimize memory requirements. Verify that the readings are continuously operational and vary in accordance with the programmed logic. If the binary output can be verified by other sensors, trend those point as well. For example, if a pump enable point is trended, also trend the pump status to confirm that the command was executed. Trending the command only does not confirm that the command was followed. Review the sequences of operation to verify what controls the operation of the controlled equipment to determine the appropriate points to trend.
17. Document the results of all testing. Screenshots of the binary output point data as well as the BAS graphics are useful for documenting the ability of the BAS to control the binary output device.

33.5 Review

1. Electric resistance heaters typically have low ____________________ when initially energized.
2. A ____________________ provides a graphical representation of how the relay coils and relay contacts are wired to implement the associated logic.
3. ____________________ is required for when induction motors are controlled by motor starters to protect them from excessively high motor currents which could over heat the motor windings.
4. An air-handling unit motor starter control (or safety circuit) circuits may include: ____________________.
    A. Overload status contacts
    B. Smoke detector status contacts
    C. High static safety contacts
    D. All of the above
5. The voltage used by most BAS controllers to power isolation relays is ___________ VAC.
6. The typical current limitation for a single-phase circuits is typically ______________ Amps.

7. A Functional Devices, Inc. model ___________________ isolation relay is the most commonly observed relay in controls installations.
8. If a motor starter is already equipped with an H-O-A, the installation of a RIBU1S is ____________________.
   - A. Recommended
   - B. Not recommended
   - C. Not a problem

Chapter 34 - Two-Position Electric Actuators (BO)

34.1 Description

Electric actuators that are controlled by binary signals (On/Off) are typically called two-position actuators. Electric actuators utilize electricity instead of air pressure to actuate damper and valves. At the heart of most electric actuators is an electrical motor that turns a set of gears that multiply the motor's torque. However, the gear reduction increases the time required to stroke from one extreme position to the other. Stroke times for electric actuators range from 30 seconds to 120 seconds depending on the manufacturer and whether they are equipped with the spring-return option. Where actuators generate linear motion, the gears are connected to screws, cams, or rack-and-pinion arrangements which turn the rotary motion into linear motion. They may be equipped with an internal spring that returns the damper or valve to its normal or fail-safe position when there is no BAS control signal or power is interrupted. When power is applied to the actuator, its motor drives toward the opposite position or until it hits its mechanical stop or limit switch. If the actuator does not have the spring return option, it will fail in place because there is no mechanism to drive the damper or valve upon loss of power.

Photo 347 - Two-Position Boiler Isolation Control Valve

Photo 348 - Two-Position ERU Isolation Control Damper (Open)

Photo 349 - Two-Position ERU Isolation Control Damper (Closed)

Two-position actuators are typically rated for 24 VAC or 120 VAC. The transformer that powers the electric two-position actuator may be the same as that which powers the BAS controller or it may be different. When air-handling unit control systems are designed, the actuators are typically grouped and powered by dedicated transformers. If the electric actuators are rated for something other than 24 VAC, they are powered by a separate power supply (or transformer). Actuators are rated in terms of power or Volts-Amps (VA) and they typically have a "Driving" power consumption and a "Holding" power consumption. The driving power is typically the higher of the two values and is used to size the required 24 VAC power supply. The following table provides the power (VA) requirements for a spring return actuator (Honeywell model MS7510A2008) typically used in air-handling unit dampers. This actuator is versatile because it can be used for two-position, floating, and modulating control.

Models	Power Input		Power Consumption (VA)					
			44 Lb.-In. (5 m-N)		88 Lb.-In. (10 m-N)		175 Lb.-In. (20 m-N)	
	Voltage	Frequency	Driving	Holding	Driving	Holding	Driving	Holding
Floating, Modulating	24 VAC ±20%(Class2), 24 VDC	50/60 Hz	13	5	14	5	16	5
Two-Position, Low-Voltage	24 VAC ±20%(Class2), 24 VDC	50/60 Hz	25	8	30	8	40	8
Two-Position, Line-Voltage	100-250 VAC	50/60 Hz	45	13	45	13	60	13

Table 156 - Power Consumption (VA) of Electric Actuator (Data from Honeywell Model MS7510A2008)

If a transformer is powering several damper/valve actuators, it must be rated for more than the sum of the driven actuators. Most controls specifications indicate that the connected load for class 2 transformers shall not exceed 80% of the transformer capacity. Therefore, a 100 VA transformer can have no more than 80 VA of load connected to it. If the required load exceeds 80 VA, then additional transformers will be required to comply with this requirement. If a transformer is overloaded, the power available to each actuator will be reduced. During system balancing and commissioning, it is very likely that most or all of the actuators in an air or hydronic system may be simultaneously commanded open (or closed) and this is the best time to identify this issue. If terminal unit reheat coil control valves are commanded open during hydronic balancing, they may not be open fully as indicated by low water flow readings and low discharge air temperatures. Upon troubleshooting, you may find that the voltage supplied to the 24 VAC actuator is only 17.3 VAC (not the minimum 24 VAC required by the valve actuators). This is a good indicator of an overloaded LVT. At low supply voltages, the electric actuator will not be able to generate the forces necessary to fully actuate the connected dampers and/or valves.

Direct-Coupled Actuators (DCA) present a distinct challenge when it comes to the control of ball-type control valves. It is typically more difficult to verify that the position of ball valves after mounting because there are typically no mechanical stops and the valve ports cannot be seen once installed in the piping system. The markings on the control valve shaft which indicate the valve porting are not always provided. Three-way control valves typically have the letter "T" on the end of the valve shaft which indicates its porting. Two-way control valves typically have a line that represents the direction of the valve port. If the line is aligned with the piping axis in which it connected, this indicates a 100% open valve. If it is perpendicular to the piping axis, this indicates that the ball valve is fully closed. It is typically best to mount the actuator to the valve shaft before it is mounted in the piping system because the valve ports can still be visually confirmed. However, this is not always possible.

DCAs provide a unique ability that other actuator types cannot replicate. If the normal or fail-safe position of the damper or valve is incorrect, DCAs can be flipped, so they drive to the correct fail-safe position upon power outage or loss of control signal. Without this option, replacement of the valve, and/or actuator may be required. To ensure that the actuator is properly mounted, the damper or valve shaft should first be positioned in its fail-safe position (either opened or closed). With its electric, two-position actuator also in its fail-safe position, it is then mounted to the damper/valve shaft and secured.

The jaws of the Honeywell model MS7510A2008 DCA have a self-centering shaft adapter which ensures that the centers of the damper or valve shaft and the actuator jaws are perfectly aligned. Other actuators have spacers and inserts that are used to center the driven shaft within the jaws of the DCA. The opposite end of the DCA must be secured to prevent it from rotating as the actuator torque is applied to the damper or valve shaft. This is typically accomplished with the use of the included mounting bracket which may be formed into a variety of configurations depending on the field conditions. The back end of the actuator has a slotted tab in which the anchor pin on the mounting bracket is located. The bracket is mounted so that the anchor pin is located in the slot of the actuator body and is secured to something solid with self-tapping sheet metal screws.

Photo 350 - Two-Position Water Source Heat Pump Control Valve

Photo 351 - Two-Position Condenser Water Isolation Control Valve

Photo 352 - Two-Position Heat Exchanger Control Valve

If the centers of the jaws of the DCA and the damper/valve shaft are not aligned, linear forces (pushing and pulling) along the line between the actuator/shaft connection and the mounting point are generated. This typically results when the shaft diameter is smaller than the jaws of the DCA. These linear forces are generated because the distance between the actuator/shaft connection and the mounting bracket slot changes as the DCA rotates. It is the same linear motion that a valve cam produces as it pushes a rod in a combustion engine. This is why the pin on the mounting bracket is located in the slot of the actuator, but not secured to it. This slot allows any linear actuator movement to be absorbed when the centers of the actuator jaws and damper or valve shafts are not perfectly aligned. However, for this to happen, the actuator must remain free to move up and down this slot. The DCA should never be secured to a bracket or base plate such that movement within the slot is not possible.

Electric actuators can be ordered with other accessories which include the following:

A. **Auxiliary Contacts**. Auxiliary contacts or end switches provide a means to verify that a specific point in the damper/valve stroke has been attained. In many sequences, identifying the fully opened and/or fully closed damper/valve position is required. These contacts are configured to open or close when a certain actuator position has been reached. These are useful if you want to energize a fan or pump only when an isolation damper or valve actuator has reached the fully opened position.

B. **Spring Return**. Two-position electric actuators may be equipped with the spring return option which allows the damper or valve to assume its normal or fail-safe position upon a loss of power or control signal. Many sequences of operation require that dampers and valves go to certain positions upon loss of power or activation of certain safety devices (smoke detector, low-temperature detector, high static safety switch, etc.). If you find that a damper actuator actuates to a position opposite to which it was intended, Direct-Coupled Actuators (DCAs) with the spring return option can be removed and installed in the reverse direction. This typically cannot be done for other actuator types. Valves and their electric actuators must be selected as an assembly or you run the risk of incompatibility with each other and with the design requirements.

C. **Manual Override**. Most two-position electric actuators come with a manual crank or a release button or lever that allows the movement of the actuator manually. After the manual override is engaged, many two-position electric actuators require that the electrical power to the actuator be cycled before it resumes normal control by the control signal.

D. **Mechanical Stops**. Many two-position electrical actuators have adjustable mechanical stops that are used to limit the stroke. Most two-position DCAs have a 90-degree rotation. If the damper or valve fully opens at 60 degrees, the mechanical stop would be installed to provide a 60-degree stroke. The mechanical stops adjust the maximum and minimum actuator positions. It is also possible to limit the control signal range to 6 VDC (given a 0-10 VDC range), but the mechanical stops should still be installed.

E. **Linkages**. Globe valves may be equipped with a linkage kit that allows the use of direct-coupled actuators to actuate the valve stem. This device converts the rotary motion of the direct-coupled actuator into the linear motion required to push the globe valve stem in a linear (up and down) fashion. The linkage utilizes a rack and pinion design and has the ability to change its fail-safe position if it is incorrect. Installation of this linkage requires additional vertical clearance above the valve body.

34.2 Applications

1. **Space Temperature Control**. In heating-only applications (cabinet unit heaters, heating & ventilating units, make-up air units, convectors, and finned-tube radiation units, unit heaters, etc.), two-position, electrically-actuated control valves are often used for space temperature control. Two-position electric actuators may be used to control the outdoor/return air dampers of smaller air-handling units that provide minimum outdoor air damper control (non-economizing). Extra care and consideration must be exercised when two-position control valves are used with air-handling units that deliver outdoor air and provide cooling operation. When the space or discharge air temperature setpoint is satisfied, the control valve will close allowing the flow of unconditioned mixed air (mixture of return and outdoor air) to the space which can introduce large quantities of humid air into the conditioned zone. This can facilitate a host of other unwanted issues (mold, condensation, duct corrosion, water damage, etc.). Two-position control valves are typically not a problem with air-handling units that do not condition outdoor air.

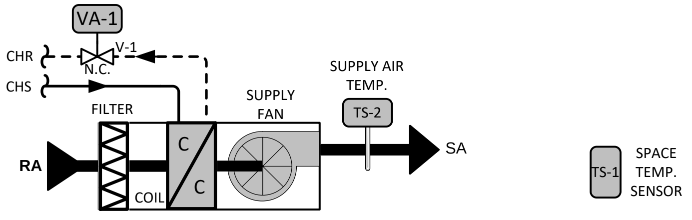


Figure 263 - Fan Coil Unit Controlled with a Two-Position, Electric Control Valve

2. **Heating/Cooling Changeover Control**. Electric two-position actuators are used to implement the automatic changeover of dampers and valves to switch between the heating and cooling modes of operation. The following diagram shows a condenser water system that directs the condenser water either through the heat exchanger or around the heat exchanger. When the temperature of the condenser water loop needs to be reduced, the condenser water

flow is directed through the heat exchanger and the cooling tower fan speed is modulated to maintain the building condenser water supply temperature (TS-2) at setpoint. When cooling is no longer required, the condenser water bypasses the heat exchanger. With this configuration, the building's condenser water system is closed. The heat exchanger keeps the dirt and debris typically accumulated in open cooling tower piping system from circulating throughout the building's hydronic piping and its water-cooled equipment. A binary output commands the changeover valve (V-1) to either the heating or cooling position.

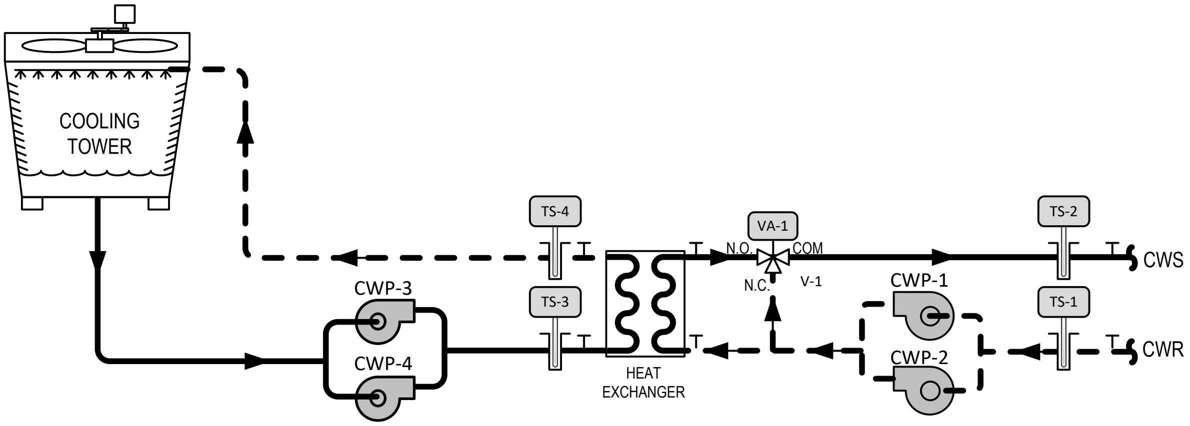


Figure 264 - Electric Two-Position Changeover Valves in a Dual-Temperature System

3. **Equipment Isolation**. Two-position, electric actuators are used in air-handling units that are equipped with smoke isolation dampers. The air-handling unit fans (supply and return) only function while the isolation dampers are proven 100% open by auxiliary contacts or position switches.

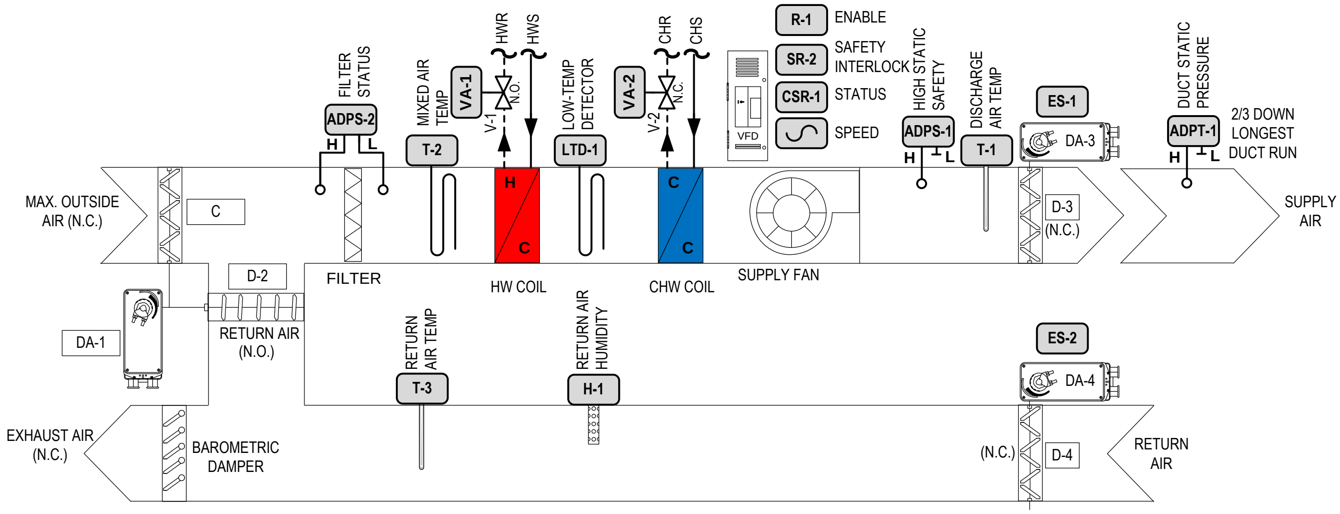


Figure 265 - Air-Handling Unit Fan with Two-Position Electric Isolation Dampers

Mechanical equipment room exhaust and supply fans are typically equipped with two-position isolation dampers that close when they are not in operation and open when operation is required. Like the air-handling unit isolation dampers, this exhaust fan may be interlocked with a damper position switch.

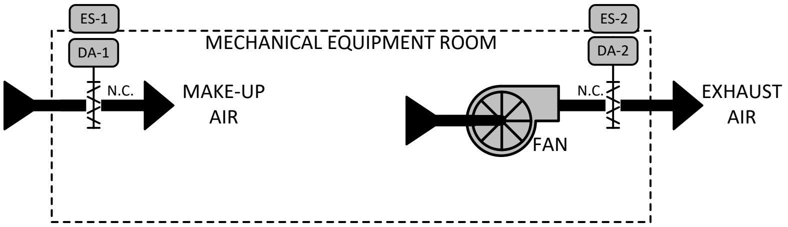


Figure 266 - Exhaust Fan and Supply Air Ducts Controlled with Electric Two-Position Dampers

Chillers and boilers in central plants are often equipped with two-position isolation valves. While the boiler/chiller is inactive, its two-position isolation valve is closed. When operation of the boiler/chiller is required, its two-position isolation valve opens allowing the flow of hot/chilled water through its heat exchanger. As the heating load reduces, the number of operational chillers/boilers reduces one by one and their isolation valves close after a predetermined time delay to take away any residual heat.

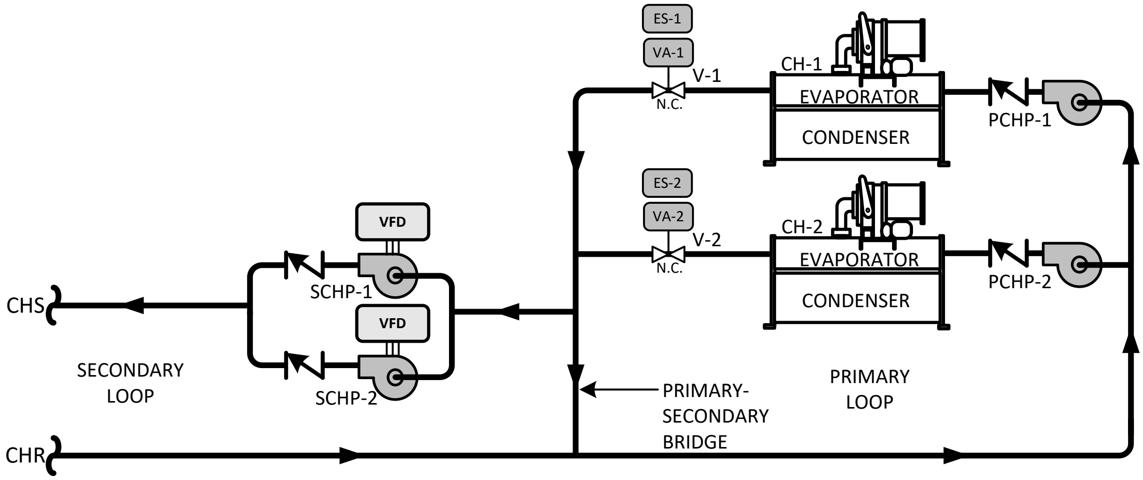


Figure 267 - Equipment Isolation Valves in a Central Plant Equipment

Water Source Heat Pump (WSHP) air-handling units may be equipped with two-position electric isolation valves to isolate them from the condenser water system when their operation is not required. The condenser water distribution system is often includes VFD-driven pumps to take advantage of the variable condenser water flow. When either heating or cooling operation is required, the condenser water isolation valve opens to provide flow through the refrigerant-to-water heat exchanger. This allows the refrigerant circuit to exchange heat with the condenser water loop. There may also be additional sensors such as hydronic differential pressure switches or flow switches to confirm that condenser water flow has been established. When the call for heating or cooling operation is disabled, the condenser water isolation valve closes after a predetermined time delay to dissipate any residual heat.

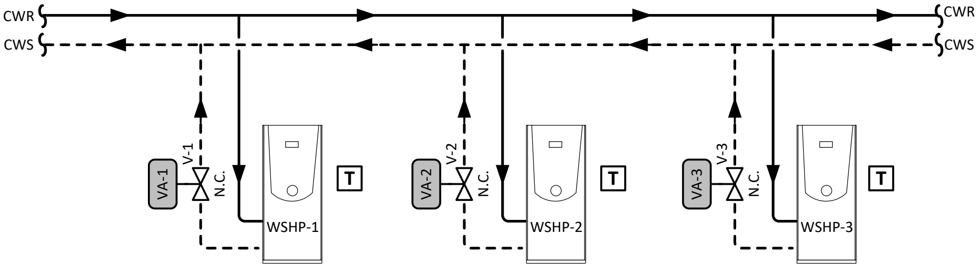


Figure 268 - Water Source Heat Pump with Condenser Water Isolation Valve

34.3 Typical Control Wiring

The following diagrams provide examples of low-voltage control and power wiring strategies commonly used for electric two-position actuators. The first example shows a low-voltage (24 VAC), two-position, spring-return actuator, and a control damper. Spring-return actuators are utilized when fail-safe damper/valve positioning is required. When the coil is not energized, the switched contacts of the isolation relay are in their normal de-energized state - open. As a result, the integral actuator spring actuates the damper/valve to its normal or fail-safe position. When actuator operation is required, the BAS controller's binary output is enabled which energizes the isolation relay's coil causing its switched contacts to actuate. When this occurs, the normally-open contacts close or make to complete the isolation damper's electrical circuit which drives the actuator to its fully actuated position. For air-handling unit isolation dampers, the normal or fail-safe position is typically closed and its energized position is typically open. The fail-safe position of outdoor air dampers is typically closed. The fail-safe position for cooling coils in northern regions of the country subject to freezing conditions is the closed position. However, in the southern regions that are cooling-dominant, the fail-safe position of cooling coils is open.

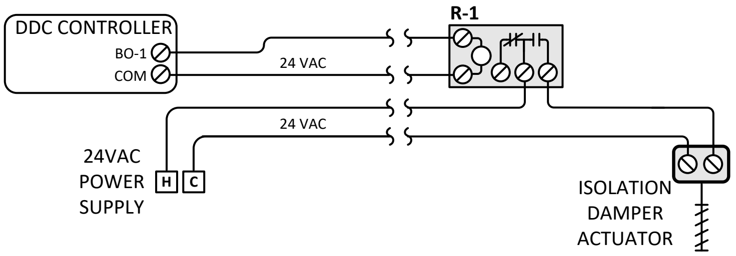


Figure 269 - On/Off Control Wiring with Isolation Relay

The second wiring example provides the same function as the first, but this actuator is powered by a 120 VAC circuit and is referred to as a "line-voltage" actuator. When the binary output is disabled, the switched contacts of the isolation relay are in their fail-safe, de-energized state - open. As a result, the integral actuator spring actuates the damper/valve to its fail-safe position. When the binary output is enabled, the coil of the isolation relay is energized which closes the normally-open switched contacts. When this occurs, the 120 VAC, two-position actuator drives towards the opposite (energized) position. When this circuit is disabled, the actuator and its connected damper/valve return to their fail-safe position.

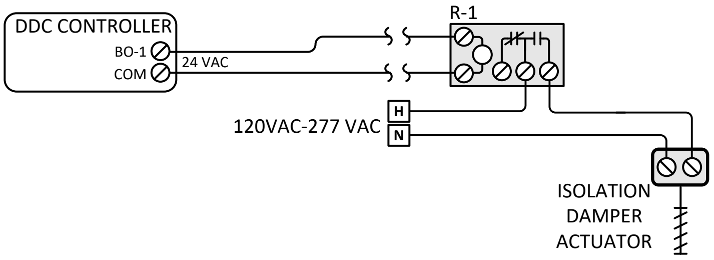


Figure 270 - Line Voltage Wiring Example

The third example shows another possible wiring strategy for a damper or valve actuator without the internal spring-return option. As the diagram illustrates, the clockwise contacts are always energized by the 24 VAC power supply. Upon reaching the end of the stroke, the actuator motor is disabled. The clockwise rotation is associated with either the open or closed command. When the opposite damper/valve position is required, the binary output is enabled which switches application of 24 VAC power from the clockwise (CW) contacts to the counter-clockwise (CCW) contacts. This drives the actuator in the opposite direction and upon reaching the end of the stroke, it is disabled.

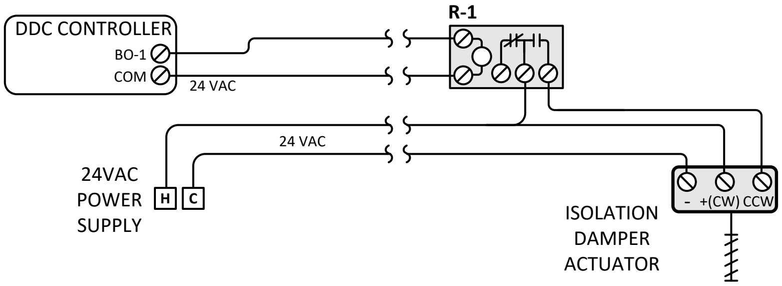


Figure 271 - On/Off Control Wiring with Isolation Relay – Alternate Method

Occasionally, two-position, spring-return, 24 VAC actuators are inadvertently connected to binary triac circuits. The two-position actuators must not only drive the control dampers/valves that they are connected to, but they must also drive against the spring which returns it to its fail-safe position upon loss of power or control signal. Therefore, the current requirement of the actuator can quickly overcome the current capability of the binary triac output circuit. When this occurs, the binary triac circuit can fail catastrophically or it may be impaired. As previously stated, triac circuits have specific current limitations which must be observed. The binary triac circuit should be wired directly to a properly selected isolation relay and the power from a separate low-voltage transformer through the switched contacts as indicated above. If the actuator load (VA rating) falls within the current range of the binary triac outputs, then it can be directly wired to the actuator. If the current requirements of the two-position actuator exceed the binary triac ratings, then isolation relays and an alternate actuator power supply (transformer) will be required.

34.4 Binary Output Testing and Verification

Testing and verification of Two-Position Electric Actuators may pose an electrical hazard because of the potential exposure to high-voltage (120 VAC and higher) electrical conductors. De-energize the electrical power whenever possible. Use the appropriate personal protective equipment to ensure your safety and those around you when access to live electrical enclosures is required. The general test procedures for Two-Position Electric Actuators include the following:

1. Verify that the isolation relays and two-position electric actuators have the capabilities, capacity, and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The mounting, weather-rating, H-O-A switch, spring return, auxiliary contacts, fail-safe position, damper/valve shaft diameter, torque, coil voltage/current ratings, switched contact voltage/current ratings, binary triac output ratings, and wiring requirements are some of the features of the isolation relays that should be verified.
2. Review the sequences of operation to verify that the fail-safe position (open or closed) of the damper or valve. Coordination of damper and their actuators is much easier to contend with because the damper blades and actuator are typically visible and accessible. Valves are not as forgiving because the valve ports are typically not readily visible.
3. Verify that the isolation relay and electric two-position actuator have been installed in the correct or optimum location. The isolation relays are typically mounted in a knockout or hole drilled in the enclosure of the control cabinet, junction box, or wire trough. Isolation relays should not be inside these enclosures hanging by the wires. It is good practice to mount the isolation relay so that its status LED is visible without opening any doors or enclosures. This provides a very useful visual indication of whether the actuator has been called to run by the BAS.
4. Verify that the isolation relay and the electric two-position damper or valve actuator have been installed per the manufacturer's installation recommendations. The base of the electric two-position actuator is securely mounted to the anchor points. The mechanical connections between the actuator and damper/valve should be secure. Dampers often require jackshafts to redirect the torque or adjust the length of the stroke applied to the damper. Adjustments may be required to ensure that full closure and full open positions can be attained by the stroke of the actuator. There should not be any looseness or play in the connections as this can affect the range of motion. Excess play can prevent the damper or valve from fully opening and/or closing. Also check for the presence of binding or jerky motion as the stroke progresses. Valve actuators may either require a rotational or linear motion to actuate the valve stem depending on the control valve type. Verify that the damper or valve stem driven by the electric two-position actuator is at the center of the clamping jaws to avoid undue pushing and pulling forces on the damper or valve shaft and the actuator mounting point. If the electric, two-position actuator is equipped with a visual position indicator, adjust it so that it may be used during testing and verification tests.
5. Verify that the isolation relay and the electric actuator have been correctly wired. Review the ladder logic diagrams typically included in the control submittal. The devices may have multiple sets of normally-open and normally-closed contacts which must be properly landed and coordinated to provide the desired control logic.
6. Verify and document how all hard-wired interlocks are implemented. When a safety device of an air-handling unit activates, its fans are disabled, power to spring-return valve and damper actuators is disabled, and an alarm is generated. With no power, the dampers and valves assume their fail-safe or normal positions. Drawings or sketches are typically best for documenting the wiring strategies used.
7. Verify that the binary output device is connected to the correct BAS controller binary output. Override the binary output data point to the opposite state (Open/Close) and verify that the controlled damper or valve follows the commanded states. Verify that the damper or valve fully opens and closes without binding or large jumps. Dampers, especially old ones, are notorious for having a jerky stroke because of the wear and tear, corrosion, friction, binding, looseness in the connections, and misalignment of jackshaft linkages. Make any adjustments to the connections between the damper or valve and the electric, two-position actuator required to establish a smooth and full stroke. Existing dampers may also require cleaning and lubrication to achieve satisfactory performance. Measure the voltage provided to the valve or damper actuator to verify that it has the correct voltage. If the measured voltage is below 24 VAC, the transformer providing the power may be overloaded.

Field Measurements/Observations				
Command	R-1 Coil Voltage (VAC)	R-2 Coil Voltage (VAC)	Actuator Voltage (VAC)	Observed Actuator Status
Closed	0	0	0	Closed
Open	27.1	27.1	119.5	Open
Fail-Safe	0	0	0	Closed

Table 157 - Control Signals versus Actuator Command State Table

8. As the BAS controller binary output is overridden, verify and document that the corresponding data point bound to the BAS graphics also changes as the controlled damper or valve is enabled and disabled. The color change provides a visual notification on the BAS graphics that this point has been overridden. While the binary output is overridden, the programmed control logic no longer controls the binary output and it will remain in the overridden state until the override is released.
9. Using the binary output field bound to the BAS graphics (not the binary output data point), verify that the controlled damper or valve actuator actuates on command. Override the binary output data point to the opposite state (Open/Close) and verify that the controlled damper or valve actuator follows the commanded states. Also, verify that the BAS graphic provides a visual indication that this binary output point is currently overridden.
10. Verify that the fail-safe position of the damper or valve actuator. The easiest way to do this is to de-energize the power supply (transformer) that powers the electric two-position actuator. If the power supplies are not labeled, it may be necessary to de-energize the 120 VAC circuits that power the 24 VAC power supplies. All damper and valve actuators will be affected by de-energizing the 120 VAC circuit, so it is typically more time-efficient to verify that the fail-safe positions of all dampers and valves associated with the affected power supplies at the same time. If the damper or valve does not go to the required fail-safe position, verify that the actuators are properly mounted, the wiring and linkages are properly configured, and the correct actuator has been installed.
11. Verify that the LED status indicator of the isolation relay (or relays) illuminates to indicate their commanded state with each cycle of the binary output. If it does not illuminate, replacement is recommended.
12. Verify that the isolation relay(s), actuator, and their wires at the controller end have been labeled to indicate what binary output data point (BO-X) and what equipment, system, or component it is associated with. For example, an air-handing unit minimum outdoor air damper may be marked or labeled with the following information: BO-2/OAD/AHU-3. If the shaft of the damper or valve is not marked by the factory, then it should be marked with a permanent marker so that quick visual verification of the damper or valve position is possible. In addition, for actuators wired to the normally-closed switched relay contacts (instead of the normally-open), Controls Contractors typically make a note with a permanent marker or place a label (on or near the isolation relay) to indicate that its coil is enabled to disable the actuator.
13. If the isolation relay controlled by the binary output is equipped with an H-O-A switch, verify that it functions in all positions. If it does not, troubleshoot the wiring and retest. The Functional Devices, Inc. model RIBU1S or RIBU1S-NC is often used for this application. In the Hand position, the controlled damper or valve is enabled permanently. In the Off position, the controlled damper or valve will assume its fail-safe position if equipped with the spring-return option or will remain in its current position. In the Auto position, the binary output signal from the BAS controller controls the operation of the controlled damper or valve actuator.
14. Verify that the facets of the binary output data point are consistent with the commanded states of the controlled equipment. Damper and valve actuators controlled by binary outputs typically display “Open/Close” facets.
15. If the status of the controlled damper or valve actuator is monitored by a status monitoring device (end-switches, position feedback contacts, or others), this is an ideal time to test and adjust that device as well.
16. Verify that the operation of the damper or valve actuator is controlled by the BAS controller binary output over time by reviewing trend data. Change-of-State trends are typically utilized to minimize memory requirements. Verify that the readings vary in accordance with the programmed logic. If the binary output can be verified by other sensors, trend those points as well. For example, if a binary valve command point is trended, also trend the discharge air temperature to confirm that the command was executed. Trending the command only does not confirm that the command was followed. Review the sequences of operation to verify what controls the operation of the controlled damper or valve to determine the appropriate points to trend.
17. Document the results of all testing. Screenshots of the binary output point data as well as the BAS graphics are useful for documenting the ability of the BAS to control the binary output device.

34.5 Review

1. True or False: Direct coupled actuators need to be replaced if the fail-safe position is incorrect.

   Answer: ________
2. What step should be executed to verify that the fail-safe position of the damper or valve? Answer: ________

   A. Command the damper or valve to the fail-safe position.
   B. De-energize the actuator power supply

   C. Disconnect the damper or valve from the actuator.

3. Which of the following status monitoring devices would not be used to monitor the position of the damper or valve controlled? Answer: ________
   A. End switch
   B. Actuator auxiliary contacts
   C. Electromagnet

4. Which of the following are used to prove an actuator's position? Answer: ________
   A. End switch
   B. Position switch
   C. Current-sensing relay
   D. A & B

5. Which of the following is not a typical electric, two-position actuator voltage? Answer: ________
   A. 120 VAC
   B. 120 VDC
   C. 24 VAC

Chapter 35 - Two-Position Pneumatic Actuators (BO)

35.1 Description

Pneumatic actuators are devices that use compressed air to provide the motive force to open and close pneumatically-actuated dampers and valves. This chapter focuses on the control of pneumatic, two-position damper and valve actuators. In many applications, two-position or binary control is sufficient to maintain control of the process variable. Pneumatic controls are the predecessor of Direct Digital Controls. The use of pneumatic controls in new construction projects has fallen off substantially, but there are still many existing pneumatic control systems and applications where pneumatic controls make sense. Pneumatic controls have three main advantages over electric actuators. They are inherently explosion proof. They have very fast actuation speed. In addition, they provide lots of power in a compact actuator package. If any of these advantages are a performance requirement, then pneumatic actuators are often utilized. For example, two-position pneumatic actuators are typically used to control high-temperature hot water control valves because of their quick actuation speed. When DDC systems are installed at sites that were previously equipped with pneumatic controls, utilizing the existing pneumatic valve and damper actuators make financial sense because their replacement costs can be deferred to a later time as long as they still function.


Photo 353 - Pneumatic Two-Position Condenser Water Valve Actuator


Photo 354 - Pneumatic Two-Position Outdoor Air Damper Actuator


Photo 355 - 24 VAC Solenoid Air Valve

Pneumatic actuators use the power of compressed air and a spring to actuate the connected dampers and valves. Most pneumatic actuators create a force that acts in a linear motion. They essentially extend and retract. The body of a typical pneumatic actuator is hollow, constructed of two halves, and contains a shaft, piston, spring, and diaphragm. The shaft and piston have a mechanical connection between them making them essentially a single piece. To contain the compressed air in pneumatic actuators, diaphragms or bladders are typically utilized. They typically employ a telescoping design that is conducive to installation in cylindrical enclosures in which the pistons travel.

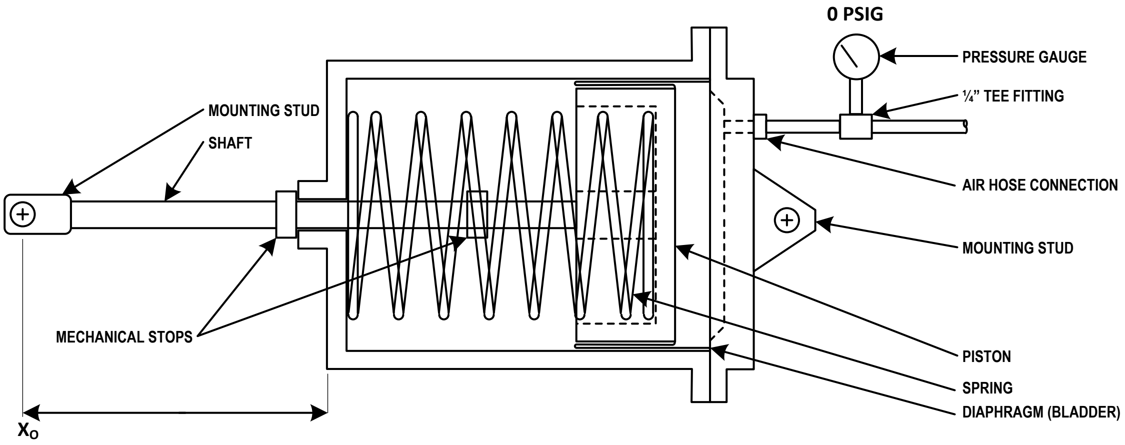


Figure 272 - Pneumatic Actuator without Branch Pressure

Should the diaphragm develop a crack or tear, it will have either limited or total loss of compressed air containment. To have the full range of position control, the diaphragm must be replaced. The spring forces the damper/valve to its fail-safe position when no air pressure is applied to the pneumatic actuator. A diaphragm covers the piston and is sealed by the clamping force created by the connection between the two halves of the actuator body. When compressed air is applied to the actuator, the force created by the compressed air upon the piston face acts in the opposite direction of the spring force. The actuator shaft begins to move when the force produced by the compressed air applied to the piston face exceeds the force of the spring, the friction of the connected device and linkages, and dynamic forces created by the controlled air or fluid flow. The relationship between force (F), pressure (P), and area (A) and is governed by the following equation. As the equation shows, the force produced by the pneumatic actuator is directly proportional to the pressure applied to the piston head's surface area (A). The equation also shows that the force produced by the compressed air is also proportional to the area upon which the pressure acts. Larger pistons produce larger forces for the same applied pressure.

(Equation 115) $F = P * A$

For the BAS controller to have binary control of pneumatic damper and valve actuators, a solenoid air valve is typically utilized. A solenoid air valve is very much like an isolation relay. The difference is that it uses the electromagnet coil to actuate a two-position air control valve (rather than switched electrical contacts). When the solenoid air valve's electrical contacts are energized, its ports move to their powered or enabled position and when it is de-energized, they assume their normal or fail-safe position. By controlling the application of power to the solenoid air valve electromagnet, the pneumatic end device (damper or valve) can also be controlled. Solenoid air valves are available in many voltage ratings. The most frequently encountered single-phase voltages for solenoid air valves are 24 VAC and 120 VAC, but several other voltages are available. An isolation relay allows the low-voltage signal (24 VAC) from the BAS to control the application of air pressure to one or more two-position pneumatic actuators through solenoid air valves.

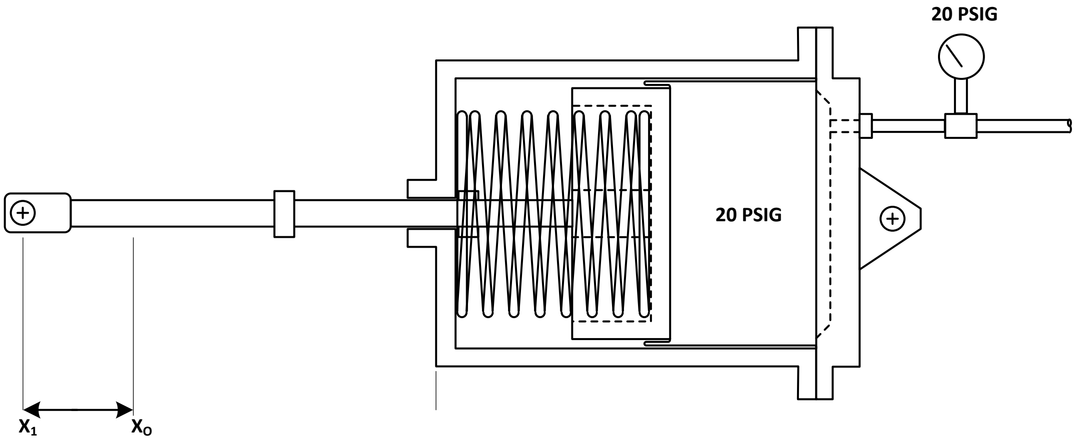


Figure 273 - Pneumatic Damper Actuator Pressurized

Pneumatic actuators typically have spring range labels or markings on its body. This is a rating from the manufacturer that represents the combination of diaphragm plate diameter and spring constant. It may be labeled 9-13 PSIG and this represents the operating pressure range required to fully stroke this actuator before it is connected to the damper or valve. The damper/valve that it actuates produces additional forces that the pneumatic actuator must also overcome. This is why field testing is so important. A pneumatic actuator that indicates a range of 9-13 PSIG may require a pressure range of 10.0-14.0 PSIG to stroke from the fully closed to the fully open position. Each damper/valve and actuator combination and its flow characteristics are unique, so in situ pressure testing of each pneumatic actuator is required to determine the maximum and minimum pressures required to fully stroke the damper or valve assembly under normal conditions. This test data is used to confirm that the air pressure applied to the pneumatic actuator is sufficient to fully stroke the valve or actuator that it is connected to.

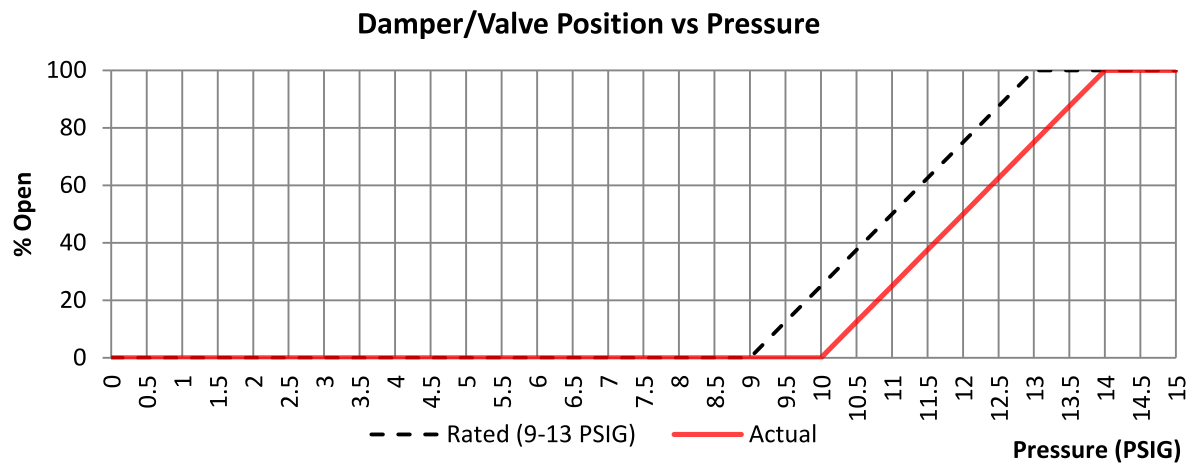


Figure 274 - Two-Position Pneumatic Actuator Test Pressure

The pneumatic actuator is typically connected to the common port of the solenoid air valve and the normally-closed port is connected to the compressed air source which is typically the building's compressed air system. The normally-open port of the solenoid air valve is left open to the atmosphere. Valve, damper, and possibly actuator damage can occur when the compressed air is abruptly applied and suddenly vented. Restrictors may also be used on the compressed air supply line to limit the actuation speed of the controlled damper or valve. In some installations, a restrictor is installed on the normally-open port to slowly vent the compressed air to the atmosphere when the solenoid air valve is de-energized.

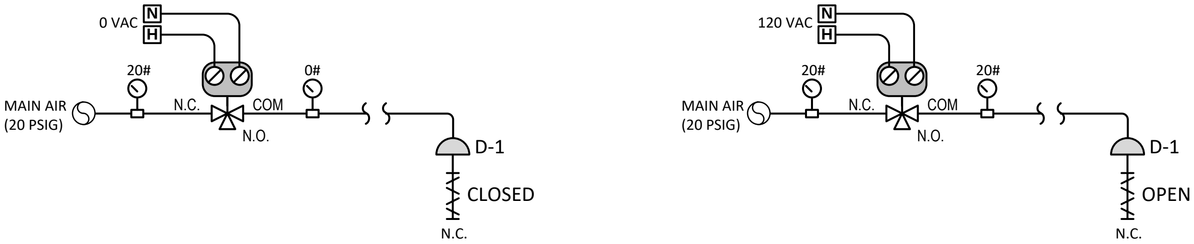


Figure 275 - Actuator Pressures – Energized versus De-energized States

When no power is applied to the solenoid air valve, the common and normally-opened ports are open to one another. Therefore, the controlled device (damper or valve pneumatic actuator) is open to the atmosphere, and the main air connection is isolated by the normally-closed port. When power is applied to the solenoid air valve, its ports actuate to their powered position and the common and normally-closed ports are opened to one another. This allows the compressed air signal to pass through the solenoid air valve and pressurize the damper or valve pneumatic actuator.

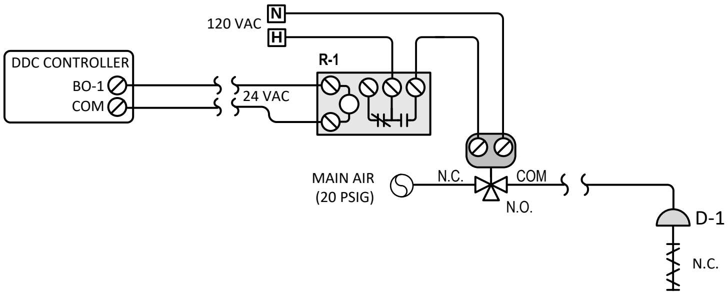


Figure 276 - Normally-Closed Pneumatic Damper

Because the control damper's fail-safe position is normally closed, pressure must be applied to open it. Voltage must be applied to the solenoid air valve's electrical contacts to allow the air pressure to pass from the source to the actuator. For this to occur, the BAS controller's binary output contacts are energized (Triac output) or closed (dry contact output). This completes the circuit that powers the isolation relay's coil contacts. The solenoid air valve's electrical contacts are wired to the isolation relay's normally-open contacts. Therefore, when the isolation relay's coil is energized, the isolation relay's contacts actuate to the opposite position. Because the normally-open contacts are used, when power is applied to the relay's coil, the contacts close. The contact closure completes the 120 VAC circuit which energizes the solenoid air valve opening the pneumatic path between the normally closed and common ports. When this occurs, the compressed air pressure is applied to the pneumatic actuator causing it to open. The following logic or state table applies to a control damper or valve (shown above) with a normally closed fail-safe position and the normally open relay contacts in use.

Field Measurements/Observations					
Command	Binary Output Contacts	R-1 Coil Voltage (VAC)	Voltage on Solenoid Air Valve (VAC)	Pressure on Actuator (PSIG)	Device Position
Close	De-energized	0	0	0	Closed
Open	Energized	24	120	20	Open
Fail-Safe	De-energized	0	0	0	Closed

Table 158 - Control Signals versus Command for Two-Position Pneumatic Actuators

Troubleshooting two-position pneumatic actuators requires knowledge of the damper or valve's normal or fail-safe position (when no pressure is applied to the pneumatic actuator). Knowing this, it is possible to determine the required logic to control the damper or valve. Most of the time, two-position dampers and valves are closed when no control voltage is applied and opened when a control voltage is applied. The typical exception would be when a control valve is used on a preheat coil in an air-handling unit or a heating-only terminal unit utilized in an area subject to freezing conditions.

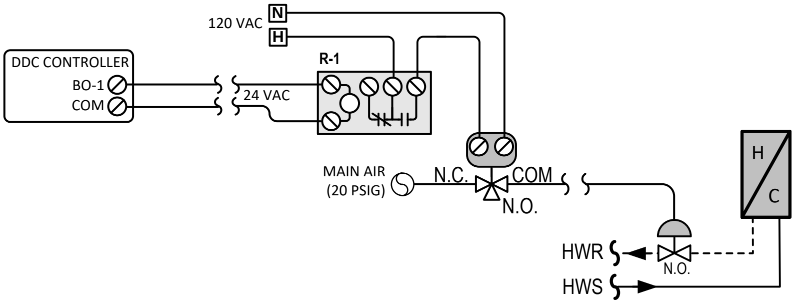


Figure 277 - Normally-Open Pneumatic Valve

When no power is applied to the solenoid air valve, the hot water flows through the hot water (or steam) coil to provide freeze protection while the air-handling unit is de-energized or suffers a power loss. This protects against freezing of the water in the heating coil and the resulting water damage that typically follows. Air-handling units installed in areas subject to freezing conditions are typically equipped with a low-temperature detector. If freezing condition conditions are detected, the low-temperature detector trips causing the air-handling unit supply fan to de-energize. When this occurs the solenoid air valve also loses power and vents the compressed air pressure applied to the valve actuator causing it to open fully. Under normal operating conditions, the BAS controller would be programmed to cycle the control valve of the air-handling unit, unit heater, fin-tube radiation, convectors, etc., to maintain a space at its temperature setpoint. The same signal may also be used to cycle a supply fan or damper, if required.

Command	R-1 Coil Voltage (VAC)	Voltage on Solenoid Air Valve (VAC)	Actuator Pressure (PSIG)	Device Position
Close	24	120	15	Closed
Open	0	0	0	Open

Table 159 - Control Signals versus Command

Depending on the application, the binary output of a BAS controller may control the operation of the solenoid air valve to ultimately control the actuation of a two-position pneumatic actuator. Solenoid air valves may be controlled by other means including:

1. Actuator Auxiliary Contacts: The auxiliary contacts of electric actuators may be used to control the application of power to the solenoid air valve. The auxiliary contacts can be normally-open or normally-closed depending on the required control logic. These contacts actuate when either the fully-closed or fully-open actuator positions have been achieved.
2. Contactor Auxiliary Contacts: Auxiliary contacts are accessories to a magnetic contactor that actuate when it is energized. These contacts are electrically isolated from the contactor and its coil control circuit, so the voltage of each

set of auxiliary contacts can be whatever (typically 24 VAC or 120 VAC) is needed to control the solenoid air valve. The auxiliary contacts can be normally-open or normally-closed depending on the application. These contacts are in their powered position as long as power is available, the contactor is enabled, and the included safety devices are in their normal state. If the contactor control circuit is opened, the contactor and any auxiliary contacts will actuate to their de-energized positions.

3. Multi-Pole Isolation Relays: Solenoid air valves may be electrically interlocked with a set of switched contacts of a multipole relay controlled by another system or component. With this wiring strategy, when the isolation relay's coil is energized, several circuits can be made or broken simultaneously. When the relay coil is de-energized, the switched contacts return to their fail-safe positions. The normally-closed or normally-open contacts can be used depending on the required relay logic.

35.2 Applications

Two-position, pneumatically-actuated dampers and valves are typically represented as a semicircle or half-moon in control drawings. They have many applications which include, but are not limited to the following:

1. **Space Temperature Control**. In heating-only applications such as cabinet unit heaters, heating & ventilating units, make-up air units, convectors, and finned-tube radiation units, and unit heaters two-position, pneumatically-actuated control valves may be used for space temperature control. They may also be used to control the outdoor/return air dampers of smaller air-handling units that provide minimum outdoor air damper control (non-economizing). Extra care and consideration must be exercised when two-position control valves are used with air-handling units that condition outdoor air in the cooling mode. When space or discharge air temperature setpoint is satisfied, the control valve will close allowing the flow of unconditioned mixed air (return air and outdoor air) to the space which can introduce large quantities of humid air into the ductwork and space. This can facilitate a host of other unwanted issues (mold, condensation, duct corrosion, water damage, etc.). Two-position control valves are typically not a problem with air-handling units that do not condition outdoor air.

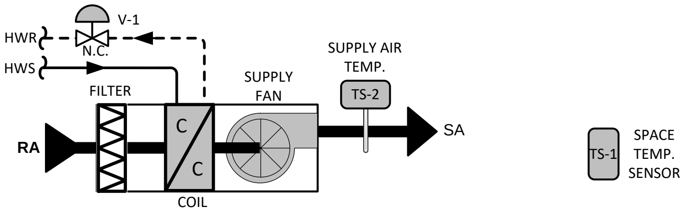


Figure 278 - Unit Heater Controlled with a Two-Position, Pneumatic Control Valve

2. **Terminal Equipment Seasonal Isolation**. Pneumatic, two-position control valves are utilized to implement seasonal isolation of heating-only terminal equipment such as unit heaters, convectors, and finned-tube radiation units in dual-temperature hydronic systems. Heating-only equipment connected to two-pipe hydronic systems is not designed to handle the condensate that forms when chilled water flows through them. They also have no condensate drain pan to collect the condensate and convey it to a receptor. Therefore, they must be isolated from the two-pipe system when it operates in the cooling mode. When the central plant changes over to the cooling mode or when the dual-temperature water supply water temperature drops below a certain threshold (60°F), the isolation valve(s) close to the heating-only equipment.

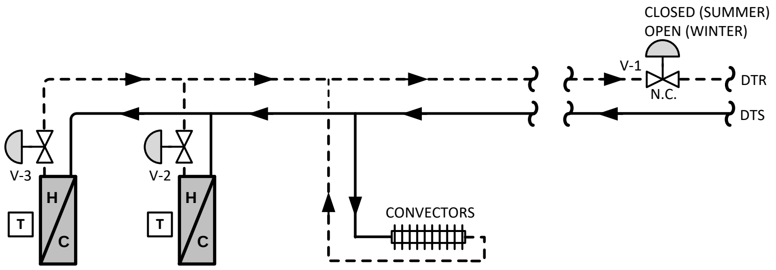


Figure 279 - Pneumatic Two-Position Isolation Valve to Isolate Heating-Only Equipment

3. **Heating/Cooling Mode Change-Over**. Some pneumatic, two-position control valves are utilized to implement seasonal changeover of two-pipe central plant piping. In the following example, the dual-temperature water bypasses

the chiller while operating in heating mode and flows through the chiller while operating in cooling mode. With this piping configuration, a single binary output (from the BAS) and solenoid air valve could be used to control the position of multiple pneumatic control valve. As the heating and cooling needs of the school change, the central plant can be configured for the appropriate operating mode. Other operators determine the change-over mode by calendar schedule. In either case, the change-over is automated precluding the need for operators to manually configure change-over valves.

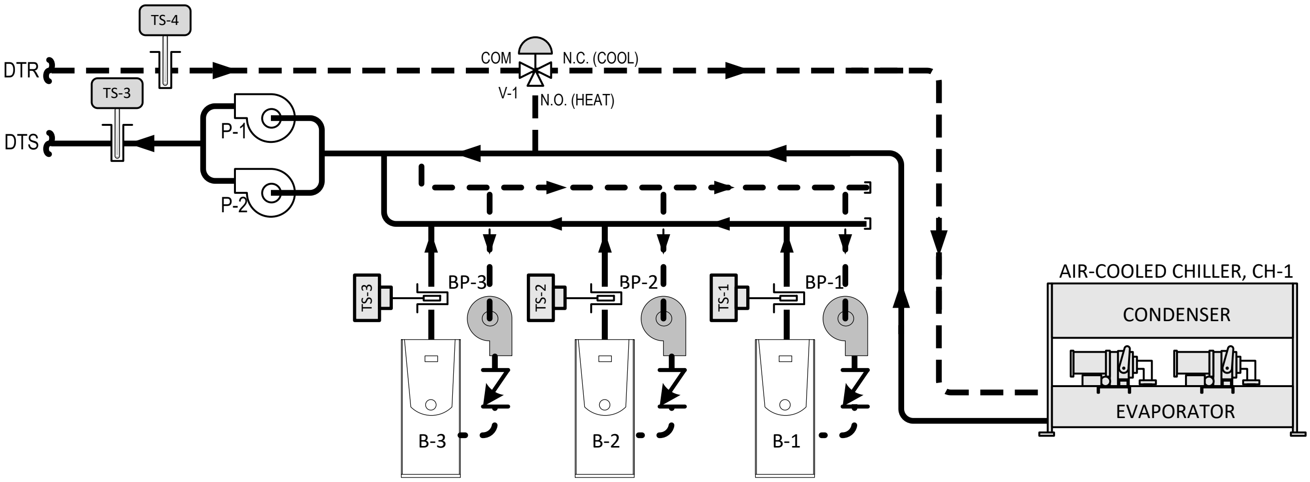


Figure 280 - Pneumatic, Two-Position Changeover Valve in a Dual-Temperature System

4. **Equipment Isolation**. Some pieces of equipment are equipped with pneumatic, two-position isolation dampers or valves to isolate them when they are not in operation. For example, water-source heat pumps (as well as chillers, boilers, etc.) may have pneumatic equipment isolation valves that close when their operation is not required. They may also have a flow-proving device that provides confirmation of flow before energizing.

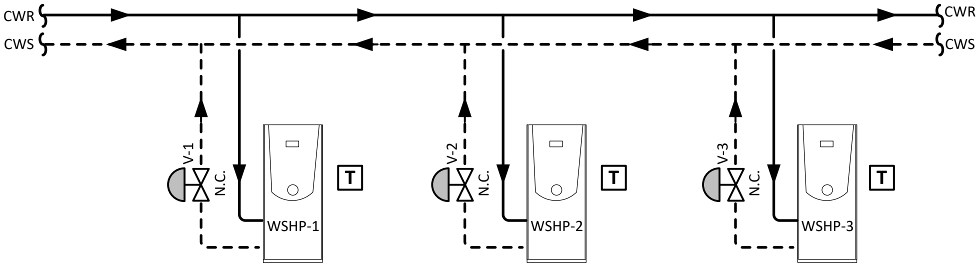


Figure 281 - Pneumatic Isolation Valves for Water-Source Heat Pump Air-Handling Units

Likewise, mechanical equipment room exhaust fans typically have isolation dampers that close when they are disabled to prevent the flow of air through the exhaust and/or intake openings while the fan is disabled.

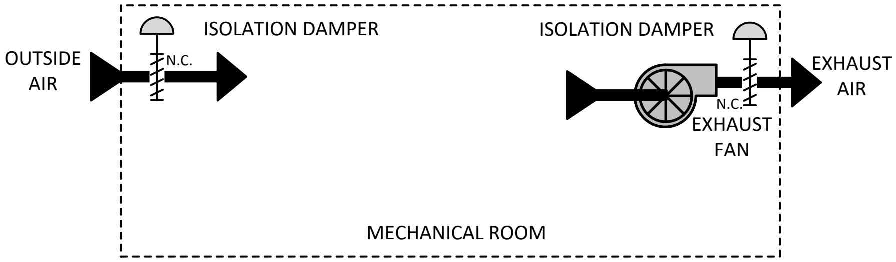


Figure 282 - Exhaust fan with Pneumatic Isolation Dampers

35.3 Typical Control Wiring/Tubing

35.3.1 Two-Position Control

A BAS controller's binary output may be used to control pneumatic, two-position damper or valve actuators. The following diagram provides an example of two isolation dampers that are controlled by the BAS controller through a solenoid air valve. When the binary output is enabled, the isolation relay's coil is energized causing its switched contacts to actuate to their energized state - closed. This contact closure completes the 120 VAC circuit that powers the solenoid air valve and allows the control air to pass through it to the two-position pneumatic isolation dampers which stroke to the open position. When the same binary output is disabled, the isolation relay's coil is disabled causing its switched output contacts to return to their normal, de-energized position - open. Without power, the solenoid air valve ports revert to their normal, de-energized positions and air pressure for the pneumatic two-position isolation dampers is vented to the atmosphere which causes them to return to their fail-safe positions. The following wiring diagram is an example of how solenoid air valves are used to open pneumatic isolation dampers.

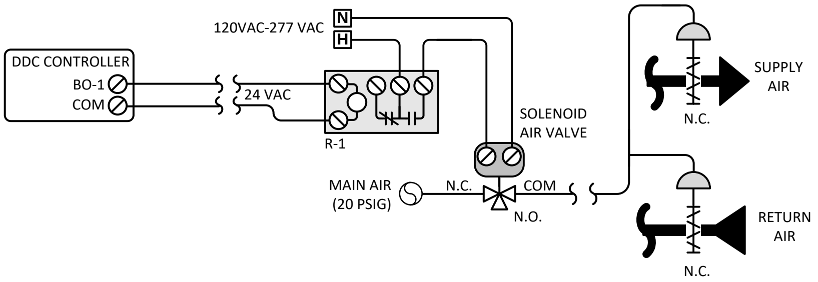


Figure 283 - Air-handling Unit Isolation Damper Control with Solenoid Air Valve

The following diagram provides an example of an exhaust fan motor and pneumatic, two-position isolation damper that are controlled through a solenoid air valve. The control damper is equipped with a shaft-mounted position switch that confirms that it is fully open before energizing the exhaust fan motor. When the solenoid air valve is energized by the BAS controller, main air pressure is applied to the normally-closed pneumatic damper actuator which opens the damper. When the position switch contacts (ES-1) reach the confirmation position, the coil of the exhaust fan interlock relay (R-2) is energized. This actuates the relay's switched contacts and completes the fan motor power circuit. The damper remains open as long as the solenoid air valve is energized and power is available. When fan operation is no longer required, the isolation relay (R-1) coil is de-energized which also de-energizes the solenoid air valve. This causes the release of the air pressure resulting in the closure of the pneumatic damper. When the damper is no longer proven fully open by the end switch (ES-1) contacts, the exhaust fan is disabled.

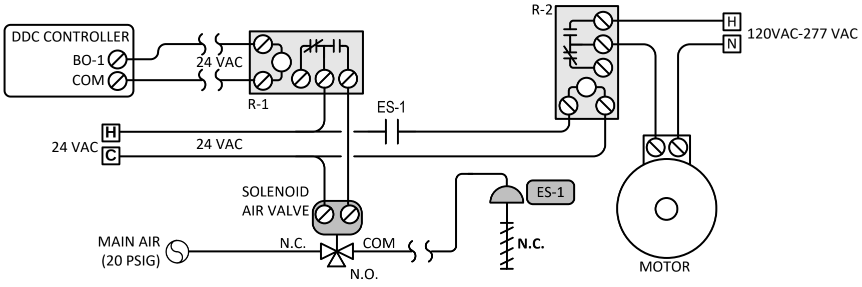


Figure 284 - Solenoid Air Valve for Exhaust Fan Isolation Damper

The following diagram provides an example of how a solenoid air valve may be used to control a pneumatic, two-position, diverting control valve to isolate a heat exchanger (or similar equipment) during seasonal changes in operation. When heating is required in the condenser water loop, the condenser water bypasses the cooling heat exchanger. The diverting control valve is normally open to the bypass port, so all that is required to bypass the cooling heat exchanger is to relieve the air pressure applied to this pneumatic, two-position control valve actuator. Without air pressure, the control valve will assume its normal position. When cooling operation is required, the coil of the isolation relay is energized by the BAS controller which energizes the solenoid air valve and applies main air pressure to the pneumatic, two-position control valve actuator. The condenser water flow is now diverted to the cooling heat exchanger instead of bypassing it.

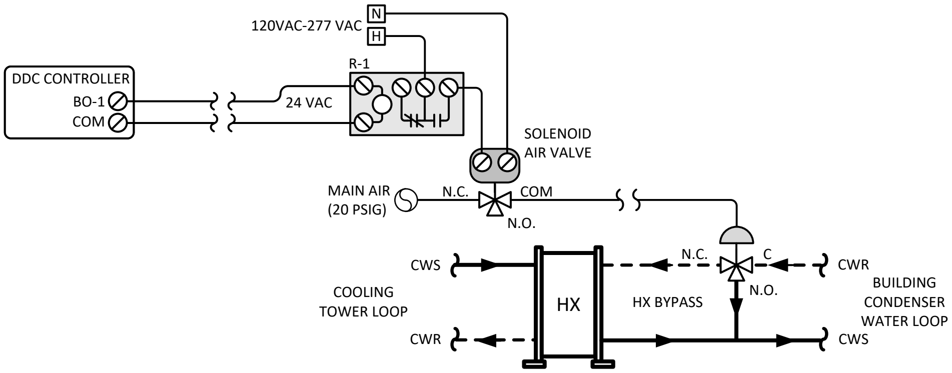


Figure 285 - Solenoid Air Valve for Seasonal Diverting Valve Control

35.4 Binary Output Testing and Verification

The general test procedures for Two-Position Pneumatic Actuators include the following:

1. Verify that the isolation relay, electric solenoid air valve, and the controlled pneumatic actuator have the capabilities, capacity, and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The control dampers and valves and their pneumatic actuator combinations must be properly selected to provide the required action and fail-safe positions. The mounting, coil voltages, switched contacts ratings, pressure range, porting, fail-safe positions, end switches, tubing requirements, torque ratings, valve/damper shaft diameter, and wiring requirements are some of the features that should be verified.
2. Review the sequences of operation to verify that the required fail-safe positions (open or closed) of the damper and valve actuators. In the absence of the BAS control signal, as could happen if the power to the BAS local control panel should fail, the pneumatic actuators assume their fail-safe position.
3. Verify that the isolation relays, solenoid air valve, and pneumatic, two-position actuator have been installed in the correct or optimum location. Isolation relays are typically mounted in a knockout or hole drilled in the enclosure of an adjacent control cabinet, junction box, or wire trough. It is good practice to mount the isolation relay so that its status LED is visible. This provides a very useful visual indication of whether this piece of equipment has been called to run by the BAS. Solenoid valves are often installed inside the local control panels or in an electrical enclosure for protection from mechanical damage.
4. Verify that the isolation relays, pneumatic actuator, and solenoid air valve have been installed per the manufacturer's installation recommendations. The base of the pneumatic, two-position actuator is securely mounted to the anchor points as well as to the driven damper or valve. Adjustments may be required to ensure that full closure and fully open positions can be attained by the stroke of the actuator.
5. Verify that the BAS controller binary output, isolation relay, and solenoid air valve have been correctly wired. Review the ladder logic diagrams typically included in the control submittal. Verify and document how all hardware interlocks associated with the binary output are implemented. Damper or valve actuators used in air-handing units are often interlocked with the status of safety devices.
6. Verify and document how all hard-wired interlocks are implemented. When a safety device of an air-handling unit activates, its fans are disabled, power to spring-return valve and damper actuators is disabled, and an alarm is generated. With no power, the dampers and valves assume their fail-safe or normal positions. Drawings or sketches are typically best for documenting the wiring strategies used.
7. Verify that pneumatic tubing connections between the solenoid air valve and the controlled pneumatic actuator have been correctly connected. Review the solenoid air valve and pneumatic, two-position actuator literature to verify the required tubing connections. Also review the ladder logic diagrams typically included in the control submittal. If none exist, drawings or sketches are typically best for documenting the wiring strategies used. Verify that the pneumatic tubing connections are tight and properly connected. Ultrasonic leak detectors are very effective at locating compressed air leaks so that they may be corrected.
8. Verify whether the solenoid air valve is equipped with a pressure gauge at its discharge. This provides a visual indication of the pressure applied to the pneumatic actuator. If the solenoid air valve and the pneumatic actuator are separated from one another (out of sight), it is highly recommended that another pressure gauge be installed at the pneumatic actuator. These pressure gauges are a huge help when troubleshooting is required.

9. Determine the actual minimum and maximum pressures required to stroke the damper/valve actuator from the fail-safe position to the fully-actuated position (fully-closed or fully-open) by applying test pressure to the actuator while connected to the damper/valve under normal operating conditions. The goal is to determine the pressure at which the damper/valve just starts to move and the pressure when it reaches the opposite, full-stroke position. Without testing of the pneumatic actuator, it is typically initially configured based on the rated pressure range which is typically stamped or indicated on the actuator label.

	Actuator Position (%)	Actuator Pressure (PSIG)
Minimum	0	9
Maximum	100	13.5

Table 160 - Pneumatic Actuator Pressure Test Results

10. Verify that the binary output device is connected to the correct BAS controller binary output. This step is typically performed by overriding the BAS controller binary output and verifying whether or not the output device follows the command. Measurements may also be performed at the BAS controller's binary output contacts, the isolation relay, solenoid air valve contacts, and any other downstream components necessary to implement binary control of the end device or equipment. For example, if overriding the damper/valve command causes it to open and close over multiple cycles, this provides a clear indication that the overridden binary output controls that device. Verify that the damper or valve fully opens and closes without binding or large jumps. Dampers, especially old ones, are notorious for having a nonlinear stroke because of the friction (wear, corrosion, and misalignment of linkage components), binding, and looseness in the connections. Existing dampers may also require cleaning and lubrication to achieve satisfactory performance. Observe the actuator stroke as it extends and retracts to determine if the speed of the actuator stroke is too high or too noisy when the compressed air is vented to the atmosphere by the solenoid air valve. The following example state table applies for a two-position, pneumatic minimum outdoor air actuator that is controlled by a 120 VAC solenoid air valve and normally-open relay contacts.

	Field Measurements/Observations				
Command	Binary Output Contacts	R-1 Coil Voltage (VAC)	Voltage on Solenoid Air Valve (VAC)	Actuator Pressure (PSIG)	Device Position
Close	De-Energized	0	0	0	Closed
Open	Energized	27.4	119.5	14.0	Open
Fail-Safe	De-Energized	0	0	0	Closed

Table 161 - Control Signals versus Command State Table

11. As the BAS controller binary output is overridden, verify and document that the corresponding data point bound to the BAS graphics also changes as the controlled damper or valve is enabled and disabled. Also, verify that the binary output data point bound to the graphic changes color to indicate that it has been overridden. While the binary output is overridden, the programmed control logic no longer controls the binary output and it will remain in the overridden state until the override is released.
12. Using the binary output field bound to the BAS graphics (not the binary output data point) associated with the binary output, verify that the controlled damper or valve actuator actuates on command. Override the binary output data point to the opposite state (Open/Close) and verify that the controlled damper or valve actuator follows the commanded states. Also, verify that the BAS graphic provides a visual indication that this binary output point is currently overridden.
13. Verify that the LED status indicators of the isolation relays illuminate to indicate their commanded state with each cycle of the binary output. If it does not illuminate, replacement is recommended. Many Controls Contractors make a note with a permanent marker or label near the isolation relay if it is wired to close the damper or valve upon enabling the BAS binary output.
14. Measure and document the air pressure at the point of use and the source. If the solenoid air valve is a long distance from the compressed air plant, the measured pressures may differ substantially. This could also indicate the presence of water and/or oil in the pneumatic distribution piping. To check for moisture, observe the compressed air as it is blown over a piece of white paper.
15. Verify the fail-safe position of the damper or valve actuator. The easiest way to do this is to de-energize the BAS controller and the solenoid air valve power circuits. All pneumatic actuators supplied by the solenoid air valve will be vented, so it is typically more time-efficient to verify the fail-safe positions of all affected damper and valve actuators. If the damper or valve does not go to the required fail-safe position, verify that the actuators are properly mounted,

the damper/valve action is correctly coordinated with the binary control of the compressed air, tubing connections are properly terminated, no air leaks exist, wiring is properly connected, and that mechanical linkages are properly configured. Correct and retest, as necessary.

16. Verify that the isolation relay(s), tubing, solenoid valve, and their wires at the controller end have been labeled to indicate the binary output (BO-X), equipment, and system or component it is associated with. For example, an air-handing unit minimum outdoor air damper may be marked or labeled with the following information: BO-4/OAD/AHU-3. If the label indicating the model number and operating pressure range of the pneumatic actuator is not visible in its final installed location, it is a good idea to indicate this data with permanent parker where it is visible. This information helps out all who follow.
17. If the isolation relay controlled by the binary output is equipped with an H-O-A switch, verify that it functions in all positions. If it does not, troubleshoot the wiring and retest. The Functional Devices, Inc. model RIBU1S is often used for this application. In the Hand position, the controlled damper or valve is enabled permanently to one position or the other. In the Off position, the controlled damper or valve will assume the fail-safe position. In the Auto position, the binary output signal from the BAS controller passes through this wire and controls the operation of the controlled damper or valve.
18. Verify that the facets of the binary output data point are consistent with the commanded states of the controlled equipment. Damper and valve actuators controlled by binary outputs typically display “Open/Close” facets.
19. If the status of the controlled damper or valve actuator is monitored by a status monitoring device (actuator end-switches or position switch contacts), this is an ideal time to test and adjust that device as well.
20. Verify that the damper or valve actuator controlled by the BAS controller binary output functions over time by reviewing the trend data. Change-of-State trends are typically utilized to minimize memory requirements. Verify that the readings vary per the programmed logic. If the binary output can be verified by other sensors, trend those points as well. Review the sequences of operation to verify what controls the operation of the controlled damper or valve to determine the appropriate points to trend. Trending the command only does not confirm that the command was followed.
21. Document the results of all testing. Screenshots of the binary output point data as well as the BAS graphics are useful for documenting the ability of the BAS to control the binary output device.

35.5 Review

1. The ____________________ position is the position that the pneumatically actuated damper or valve assumes when there is no signal from the BAS controller is applied.
2. The pneumatic actuator is connected to the ________________ port of the solenoid air valve.
3. A ________________ is recommended at the discharge of the solenoid air valve for verifying its status.
4. Which of the following is installed in the line connected to the normally-closed solenoid air valve connection when the actuation speed of the damper or valve actuator is too high? Answer: ________

    A. Silencer
    B. Restrictor
    C. Attenuator

5. An ____________________ is a machine that is used to remove moisture from the compressed air after it has been compressed.
6. The ____________________ is the part of the pneumatic actuator that contains the compressed air and allows the air pressure to push the piston within the housing.
7. In order for a BAS controller to control a 120 VAC solenoid air valve, an ____________________ is required.

Chapter 36 - Staged Electric Heating Coils (BO)

36.1 Description

Electric resistance heating coils use electrical current to provide heat for space conditioning and domestic water heating. This chapter focuses on electric air heating coils that are controlled by cycling the power to maintain a space at its temperature setpoint. When the heating load varies or tighter temperature control is required, electric resistance heating coils with multiple stages or elements are utilized. The higher the number of stages of electric heat, the more accurately the heat capacity can match the heating load. Each stage of heat is individually energized in succession to provide the required temperature control.

Photo 356 - Staged Electric Duct Heater on Make-Up Air Unit

Photo 357 - Staged Electric Duct Heater for VAV Box

Photo 358 - Electric Duct Heater Control Panel

When a BAS controller is used to control multiple stages of electric resistance heat, it must have a sufficient number of binary output contacts to control them. Each electric resistance heating stage is controlled by a dedicated binary output. The BAS controller controls an isolation relay for each contactor that powers a stage of electric resistance heat. The binary control strategy is no different from a supply fan in a constant-air-volume air-handling unit. The only difference is that there are typically multiple stages. If an electric resistance heater has four stages, then four binary outputs of the BAS controller are required.

The BAS controller utilizes a PID loop to maintain the process variable (space or discharge temperature) at setpoint. It continuously calculates the output signal required to minimize the error between the process variable and the setpoint. Since the electric resistance heat is energized in stages, the BAS controller is programmed to energize stages of heat when the PID loop signal reaches certain thresholds. For example, if an electric resistance heater has three stages of heat, each stage may be enabled when the PID loop output surpasses consecutive thresholds of 33% (100%/3). At 100% PID loop output, the heating demand is at a maximum and all three stages of electric resistance heat will be energized. As the heating demand reduces, the PID loop output reduces and the electric resistance heat stages are de-energized at the same threshold levels used previously to energize the stages.

PID Loop Output (%)	Stage 1 (BO-1)	Stage 2 (BO-2)	Stage 3 (BO-2)
0	Off	Off	Off
33	**On**	Off	Off
66	**On**	**On**	Off
100	**On**	**On**	**On**

Table 162 - Electric Resistance Heat Staging versus PID Output

Electric resistance heaters have minimum velocity/flow requirements that must be observed to provide the rated heat output, prevent overheating of the heating element, and maintain the manufacturer's warranty. Electric heating elements can quickly overheat and catastrophically fail if operated with insufficient airflow. Electric resistance heaters are typically equipped with an air-proving safety switch that interlocks the electric resistance heater operation with the supply fan status by verifying that the supply duct is pressurized. It does not, however, ensure that the minimum velocity/flow is occurring. To determine that the minimum velocity/flow is provided requires airflow measurements. If you cannot measure the airflow yourself, then coordinate with a TAB Contractor to provide this service. Airflow is typically measured by flow hood readings and duct traverse method. Once the airflow through the duct is known, the velocity through the electric resistance coil can be calculated. The measured velocity and airflow should be above the manufacturer's minimum specified values. If not, adjustments to the airflow must be made to satisfy the minimum velocity/flow requirements.

Electrical heating coils are rated in Kilowatts (KW) and can be used with single-phase or three-phase power sources. When an electric resistance heating coil is selected, it is based on the maximum demand. This value is determined by heating and cooling load calculations on a design heating day. However, during the rest of the year, this quantity of heat is not required and would likely cause discomfort because of the resultant temperature swings. Therefore, electric resistance heaters are typically selected that have multiple stages of heat to provide more acceptable part-load performance. The higher the number of heat stages available, the lower the level of overshoot and undershoot of the temperature setpoint.

Suppose that we have a rooftop unit with a supply airflow rate of 8,000 CFM and 100 KW of electric resistance heat provided by four equal stages of heat. If the full 100 KW of heat were applied, the supply air temperature would increase by 39.5˚F. Each 25 KW stage of heat would cause an increase in supply air temperature of 9.9˚F (39.5˚F/4). Knowing that the heat absorbed by the air is equal to the heat produced by the electric resistance heater, the air temperature rise can be calculated.

(Equation 116) $$Q_{Air} = Q_{Heater}$$

(Equation 117) $$Q_{Heater} = 100\ KW * \frac{3{,}413 Btu/h}{KW} = 341{,}300\ Btu/h$$

(Equation 118) $$Q_{Air} = 1.08 * CFM * (T_2 - T_1)$$

(Equation 119) $$Q_{Air} = 1.08 * 8{,}000\ CFM * (\Delta T)\ Btu/h$$

(Equation 120) $$1.08 * 8{,}000\ CFM * (\Delta T)\ Btu/h = 341{,}300\ Btu/h$$

(Equation 121) $$(\Delta T)\ Btu/h = 39.5^{\circ}F$$

If only a single 100 KW stage of heat were available, then space temperature control would be difficult during periods of low to moderate heating demand. If the coil entering air temperature was 68˚F and the entire 100 KW of heat capacity was energized, the leaving air temperature would increase by

39.5˚F to 107.5˚F. Supply air at this temperature is entirely too high and could result in space temperature swings of several degrees that would result in occupant discomfort and temperature stratification. This is where capacity control becomes so important. An air temperature rise of 39.5˚F might be appropriate when the outdoor air temperature is 10˚F, but would be entirely too high when the outdoor air temperature is 55˚F. Having some capacity control, even if it is only two stages, is better than having none. The higher the number of heat stages available, the more accurately the space temperature can be maintained. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55 recommends that the supply air temperature not exceed 15˚F above the desired space temperature to avoid temperature stratification. Multiple stages of electric resistance heat is required to comply with this recommendation.

Control Technicians familiar with ASHRAE Standard 55 and temperature stratification will add a discharge air temperature limit (typically 90˚F to 95˚F) to the discharge air temperature control loop of air-handling units and supply air terminal units with reheat capacity to prevent the discharge air temperature from exceeding this maximum threshold. This additional programming prevents the supply air temperature from exceeding the predetermined temperature threshold which will improve occupant comfort, reduce temperature stratification, maximize service life, and reduce operating costs.

36.2 Applications

1. **Air-Handling Unit Discharge/Space Temperature Control**. In locations where fossil fuels are not available and heating capacity is required, electric resistance heating coils will likely be utilized. Electric resistance heating coils may be duct-mounted to provide heating capacity for rooms on the perimeter of a building during the heating season. Electric resistance heating coils may also be used at the interior spaces to prevent overcooling. The available stages of electric resistance heat are energized in sequence to control the space or discharge air temperature to setpoint.

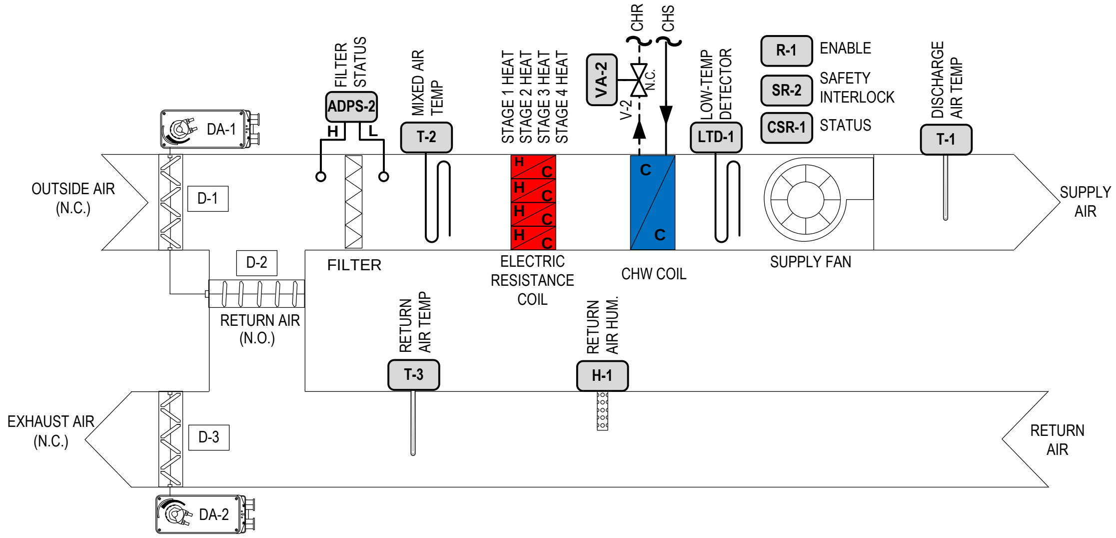


Figure 286 - AHU Schematic with Staged Electric Resistance Heat

2. **VAV Terminal Unit Reheat**. The following example is a variable-air-volume terminal unit equipped with two stages of electric resistance heat. The primary airflow typically reduces to the minimum airflow setpoint before the heat stages are energized. The airflow rate at the minimum airflow setting should be verified to ensure that the minimum velocity/airflow rate recommended by the manufacturer is provided to the electric resistance heating coil. Occasionally, the air-proving switch will not make at the low airflow setpoint. This will require an increase in the minimum airflow setpoint until the air-proving switch makes and allows operation of the electric resistance heating circuits. Alternatively, the airflow proving switch (ADPS) may be adjusted. However, it is recommended that the manufacturer or their local representative be consulted to verify that this does not void the warranty. The available stages of electric resistance heat are energized in sequence to control the space temperature to setpoint.

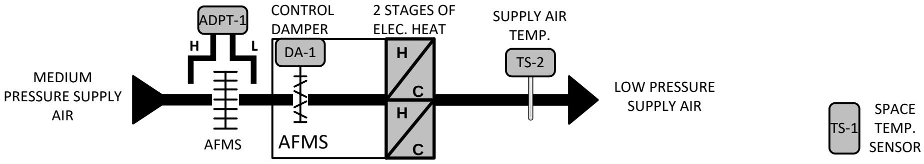


Figure 287 - VAV Terminal Unit with Staged Electric Heating

3. **Supply Duct Reheat Coil**. Electric resistance heating coils are often duct-mounted to provide heating capacity for specific rooms and zones. The available stages of electric resistance heat are energized in sequence to control the space or discharge air temperature to setpoint. These units come in slip-in or flanged designs. The following diagram illustrates a two-stage electric resistance heating coil used to provide space conditioning for a room.

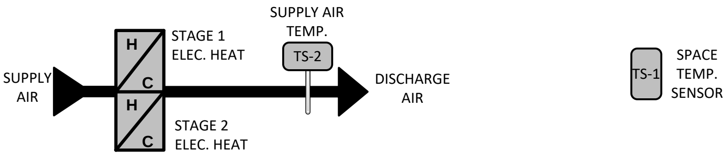


Figure 288 - Two-Stage Duct Reheat Coil

36.3 Typical Control Wiring

The following diagram is an example of the control and power wiring that might be encountered in single-phase electric resistance heaters. In this application, contactors are typically used to control the electric load. A contactor serves the same function as a relay, but is rated for higher voltages and current flows. The control circuit safeties consist of the isolation relay (enabled by the BAS), and fan proving switch, and thermal overload contacts. The thermal cutout contacts are indicated on the high-voltage circuit, but they may also be found in the low-voltage circuit.

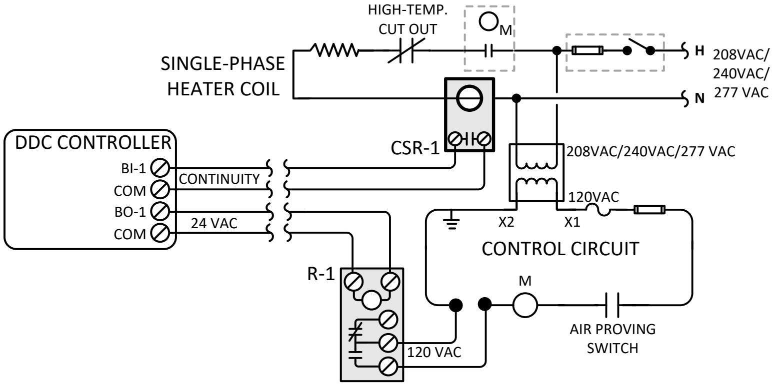


Figure 289 - Single-Phase Electric Heating Control Wiring

The following diagram is an example of the control and power wiring that might be encountered in three-phase electric resistance heaters. The contactors are typically used to control the high-voltage circuit. The low-voltage (24 VAC) control circuit controls the high-voltage (120 VAC) contactor control circuit of the electric resistance heater. The control circuit safeties consist of the thermal cutouts and air-proving switch contacts that are used to determine that the supply duct system is operational.

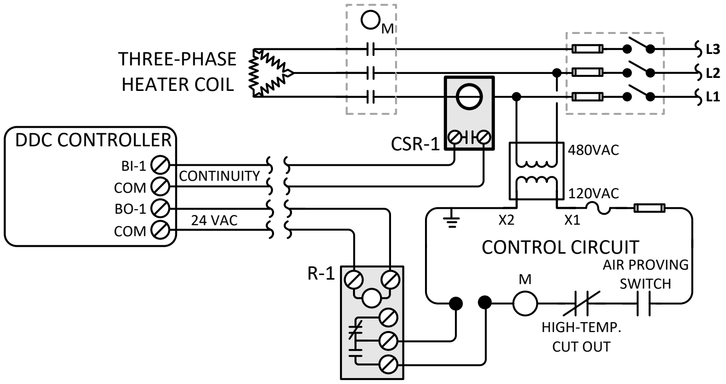


Figure 290 - Three-Phase Electric Heating Control Wiring

In some installations, you may find that all of the electrical and control wiring for the electric heater stages is pre-packaged. All that is required in the field is to provide contact closure to a set of terminals corresponding to each stage of heat available. The power and control wiring indicated in the previous two diagrams are included in the electric resistance heater assembly. In most cases, Controls Contractors will protect their local control panels from the inadvertent application of high voltages by using isolation relays. These isolation relays may be located in the LCP or may be located at the controlled electric resistance heater.

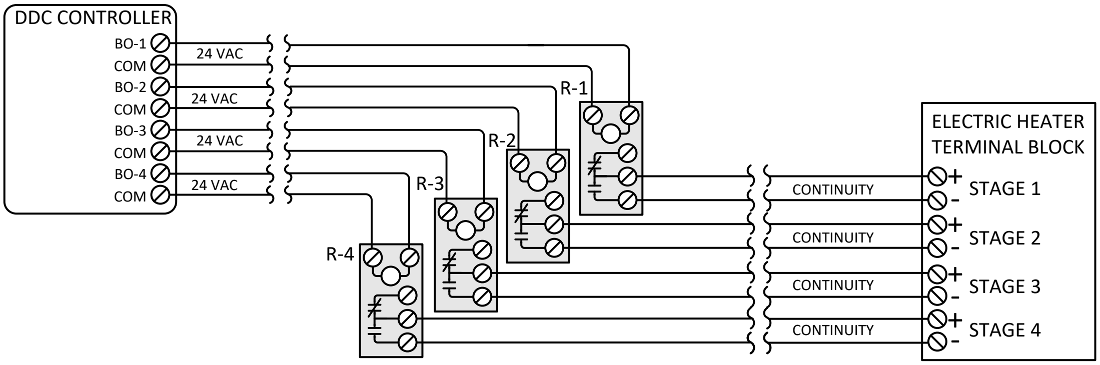


Figure 291 - Simplified Electric Heater Wiring

36.4 Binary Output Testing and Verification

Testing and verification of Staged Electric Heating Coils may pose an electrical hazard because of the potential exposure to high-voltage (120 VAC and higher) electrical conductors. De-energize the electrical power whenever possible. Use the appropriate personal protective equipment to ensure your safety and those around you when access to live electrical enclosures is required. The general test procedures for Staged Electric Heating Coils include the following:

1. Verify that the isolation relays and the electric reheat circuits have the capabilities, capacity, and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal.
2. Verify that the airflow through the electric resistance heater has been tested, adjusted, and balanced to the design airflows. Proper airflow is required to fully evaluate the operation and performance of electric resistance heaters. Temperature rise is an important performance metric that must be evaluated, but this evaluation must be based on the correct airflow through the coil. Terminal units may require adjustment of either the airflow setpoint or the air-proving switch setpoint to allow the electric resist
3. ance heat to energize.
4. As applicable, posture the HVAC system or the required components to prevent unwanted system changes during the sensor/transmitter calibration. Testing of electric resistance heating coils requires supply air at the design conditions (typically 55°F) and the supply airflow rate at the minimum heating airflow rate. Verify that the supply air temperature is stable. Also, verify that the supply airflow indication is stable with only minimal variation. The resultant temperature rise when the electric resistance heat is energized is dependent on the supply air temperature and airflow being correct. Document these values because they will be used in the following steps.
5. Review the sequences of operation for the electric resistance heater stages. In the absence of the BAS control signal, electric resistance heater stages are typically de-energized.
6. Verify that the isolation relays and electric resistance heater stages have been installed in the correct or optimum location. They are typically mounted in a knockout or hole drilled in the enclosure of the control cabinet, junction box, or wire trough. Isolation relays should not be inside these enclosures hanging by the wires. It is good practice to mount the isolation relay so that its status LED is visible. This provides a very useful visual indication of the number of stages of heat that have been enabled by the BAS. Electric resistance heaters may be installed as an independent duct-mounted unit or they may be integral to an air-handling unit or terminal unit. Their final location should be consistent with its intended service and associated system.
7. Verify that the isolation relays and the electric resistance heater stages have been installed per the manufacturer's installation recommendations. Pay particular attention to the installation of slip-in electric resistance heaters. It is not uncommon to find them unsecured to the duct and after years (or less) of operation because the vibration has caused them to pull away from the supply duct. This can result in burnout of the electric resistance heater elements because of low airflow. Also, pay attention to the minimum airflow setpoints of the variable-air-volume terminal units. The minimum flow setpoints should be high enough to provide the minimum required velocity and flow.
8. Verify that the isolation relays and the electric resistance heater stages have been correctly wired. In general, a binary output is dedicated to each stage of electric resistance heat.
9. If the airflow varies in response to another variable (duct static pressure, flow, or temperature), override the controls to provide constant airflow at a constant air temperature during the electric resistance heater testing. When testing variable-air-volume terminal units, the supply airflow is typically set to the heating airflow rate. Electric resistance heater testing should not proceed until the airflow rate has been calibrated. Accurate discharge air temperature readings depend on the terminal unit providing the correct airflow.
10. Verify and document how all hardware interlocks associated with the electric heater control are implemented. Electric resistance heater stages are typically interlocked with a thermal cutout switch (also referred to as a high temperature switch) and airflow proving switch. The thermal cutout switch disables power to the heating elements if its temperature setpoint is exceeded. The airflow proving switch is typically either a sail switch or an air differential pressure switch. The setpoints of these devices are initially set by the factory and should only be tested and adjusted if the field test results indicate that there may be an issue with the current setpoints. Use the manufacturer's instructions when making adjustments. The electric resistance heat must be disabled when the airflow is insufficient because catastrophic damage will result.
11. Verify that the binary output device is connected to the correct BAS controller binary output. This step is typically performed by cycling the BAS controller binary output command and verifying whether the associated electric resistance heat stage energizes on command. Measurements may also be performed at the BAS controller's binary

output contacts, the isolation relay, and the terminals of the electric resistance heater. If the electric resistance heat does not enable, the minimum airflow setpoint may require an increase or its static pressure pickup may require relocation. Airflow must be proven, before the electric resistance heater control circuit is enabled.

12. As each electric heater stage is enabled, measure and document the discharge air temperature, voltage by phase, and current reading by phase as each stage of electric resistance heat is enabled. Also measure and record the voltages and current at the disconnect switch as each stage of electric resistance heat is successively energized. This step verifies that the individual phase and total voltage and amperage readings are within the manufacturer's specifications. If the electric resistance heater voltage and/or amperage readings do not match the manufacturer's rating, have a qualified electrician review and verify that the wiring, connections, switches, contactors, etc. are properly installed and that the electrical power supplying the electric heaters are at the proper voltage and current. A duct penetration or supply air diffuser at least 5-10 feet downstream of the electric resistance heat coil typically provides fully mixed discharge air temperature. This data may be documented in a table similar to that which is shown below. Equipment summary screens and overrides of the heating command are very effective at reducing the time required to test staged electric resistance heaters when there are large quantities to test and calibrate. If the discharge air temperature exceeds ~20°F of the desired space temperature, consider adding maximum discharge air temperature limits in the control logic.

Field Measurements								
Stage	Rated Power (KW)	Airflow (CFM)	Discharge Temp. Rise (°F)	Voltage by Phase (VAC)	Current by Phase (Amps)	Total Current (Amps)	Output Power (KW)	Thermal Output (MBH)
1	15	2409	19.7	476/474/475	18.2/18.3/18.25	18.2	15.0	51.0
2	15	2409	19.6	476/474/475	18.3/18.25/18.3	18.3	15.1	51.3
Total	30	2409	39.5	476/474/475	36.5/36.4/36.4	36.5	30.1	102.3

Table 163 - Electric Resistance Heater Performance

13. As the BAS controller binary outputs are overridden, verify and document that the corresponding data points bound to the BAS graphics also change as the electric resistance heater stages are enabled and disabled. Also verify that the binary output data points bound to the graphic change color to indicate that they have been overridden. The color change provides a visual notification on the BAS graphics that this point has been overridden. While the binary outputs are overridden, the programmed control logic no longer controls the binary outputs and they will remain in the overridden state until the overrides are released.
14. Verify that the LED status indicator of the isolation relay (or relays) illuminates to indicate their commanded state with each cycle of the binary output. If it does not illuminate, replacement is recommended.
15. Verify that the isolation relay(s), electric resistance heater stages and their wires at the controller end have been labeled to indicate what binary output data point (BO-X) and what equipment, system, or component it is associated with. For example, an air-handing unit electric resistance heater may be marked or labeled with the following information: BO-1/VAV-1-1/Stage #1. Many Controls Contractors make a note with a permanent marker or label near the isolation relay if it is wired to disable the heater stage upon enabling the BAS binary output.
16. Verify that the facets of the binary output data point are consistent with the commanded states of the electric resistance heating coil. Electric resistance heater stages controlled by binary outputs typically display "Start/Stop," "Enabled/Disabled," or "True/False" facets.
17. If the status of the controlled electric resistance heater stages is monitored by a status monitoring device (discharge air temperature sensor, current-sensing relay, or current transmitter), this is an ideal time to test and adjust that device as well.
18. Disable the air handling unit that provides the supply air to the electric resistance heater and place a clamp meter on the main electrical leads to monitor current flow. Enable each resistance heater stage individually and verify that they do not energize. This test verifies that the operation of the electric resistance heater is interlocked with the airflow proving switch status. If the electric resistance heat energizes, there is likely an issue with the airflow proving switch, its setpoint, or its wiring. Troubleshoot and retest, if required.
19. Release all overrides used to posture the system for testing and calibration.
20. Verify that the operation of the electric resistance heater stages over time by reviewing trend data. Verify that the readings vary per the programmed logic. Change-of-State trends are typically utilized to minimize memory requirements. If the binary output can be verified by other sensors, trend those points as well. For example, if a binary heater stage command point is trended, also trend the discharge air temperature and current-sensing relay status (if installed) to confirm that the command was executed. Trending the command only does not confirm that the

command was followed. Review the sequences of operation to verify what controls the operation of the controlled electric resistance heater stages to determine the appropriate points to trend.

21. Document the results of all testing. Screenshots of the binary output point data as well as the BAS graphics are useful for documenting the ability of the BAS to control the binary output device.

36.5 Review

1. True or False: Binary inputs are used to control each stage of electric resistance heat. Answer: ________
2. True or False: ASHRAE 55: Standard for Thermal Environmental Conditions for Human Occupancy recommends that the supply air temperature introduced to a room not exceed ________ above the desired room temperature.
3. A ____________________ is typically used to monitor the operating status of the electric resistance heater.
4. The ____________________ is disables the electric resistance heater when the discharge air temperature exceeds its setpoint.
5. Electric resistance heaters are typically equipped with an air-proving switch which confirms the presence of ___________________ prior to allowing it to energize.
6. A ___________________ is required to control each stage of electric resistance heat capacity.

    A. Isolation damper
    B. Binary output
    C. Binary input

36.6 References

1. American Society of Heating, Refrigeration, and Air Conditioning Engineers. 2020. Standard 55: Thermal Environmental Conditions for Human Occupancy.

Section 5: Analog Output (AO) Devices

Chapter 37 - Equipment Setpoint/Capacity Adjustment (AO)

37.1 Description

Many HVAC systems come equipped with manufacturer-provided controls that incorporate the use of remote setpoint/capacity adjustment by an external signal. This allows the output capacity of a boiler, chiller, humidifier, air-handling unit, electric resistance heater, Variable Frequency Drive (VFD), etc. to be remotely adjusted by a BAS controller to meet the current demands. If a building is equipped with a BAS, it is typically utilized to adjust the equipment capacity through its remote setpoint/capacity contacts. The BAS can also monitor and trend the resultant change in process variable (chilled water supply temperature, hot water supply temperature, return air humidity, return air temperature, discharge air temperature, etc.).

Photo 359 - Chilled Water Supply Temperature Setpoint Adjustment

Photo 360 - Boiler Steam Pressure Setpoint Adjustment

Photo 361 - Pump VFD Speed Command

Manufacturers of large and expensive equipment typically prefer to allow setpoint adjustment, as opposed to capacity adjustment, to ensure that their controller safely and efficiently operates the equipment. Other equipment such as VFDs, electric resistance heaters, and humidifiers are more likely to allow direct capacity control by the BAS. In either case, the equipment remote control parameters are typically configurable, so they need to be confirmed and the BAS controller's analog output signal configured to exactly match it.

37.1.1 Setpoint Adjustment:

Suppose that a heating plant equipped with four modular hot water boilers has been installed at a local elementary school. These boilers are controlled by a boiler plant controller that stages and controls the output of each boiler to maintain the hot water supply temperature at setpoint. Hot water supply temperature reset is a typical control sequence where the hot water supply temperature setpoint may be reset from 160°F to 120°F as the outdoor air temperature changes from 20°F to 60°F. This is implemented by using a remote reference signal (0-10 VDC, 2-10 VDC, 1-5 VDC, etc.) and the following table shows what the hot water supply temperature setpoint will be at various levels of remote reset signal.

Hot Water Supply Temp. Reset Schedule		Control Signal Reset Schedule		
OAT (°F)	Hot Water Supply Temp. Setpoint (°F)	% Reset	°F Reset	BAS AO (VDC)
60	120	100	40	10.0
50	130	75	30	7.5
40	140	50	20	5.0
30	150	25	10	2.5
20	160	0	0	0

Table 164 - Hot Water Supply Temperature Reset Schedule

At the same example school mentioned above, the design chilled water supply temperature setpoint is reset from 42°F to 48°F as the outdoor air temperature reduces from 90°F to 60°F. Using a 0-10 VDC remote reference signal, the following table shows what the chilled water supply temperature setpoint will be at various levels of remote reset signal.

Chilled Water Supply Temp. Reset Schedule		Control Signal Reset Schedule		
OAT (°F)	Chilled Water Supply Temp. Setpoint (°F)	% Reset	°F Reset	BAS AO (VDC)
90	42	00	0	0.0
82.5	43.5	25	1.5	2.5
75	45	50	3	5.0
67.5	46.5	75	4.5	7.5
60	48	100	6	10.0

Table 165 - Chilled Water Supply Temperature Reset Schedule

37.1.2 Capacity Adjustment:

Equipment capacity can be directly controlled through a remote control signal and VFDs are the best example of this concept. VFDs are typically utilized to control a process variable (discharge pressure, differential pressure, space temperature, condenser water supply temperature, etc.) by modulating the speed of the driven equipment (fan, pump, or compressor). The maximum and minimum VFD operating speed and the remote input signal range are configured through the VFD's user interface. The remote input signal range of the VFD and the analog output signal range of the BAS controller should exactly match. It is not uncommon to find that they do not match at the low end of the signal range. If the VFD is configured for a 0-10 VDC control signal, but the analog output of the BAS controller is set up for a 2-10 VDC control signal, the VFD will operate at 20% once it is enabled because the minimum control voltage from the BAS controller has been set up to provide a 2.0 VDC signal instead of 0.0 VDC.

BAS AO VDC	% Output	Operating Speed(Hertz)
0	0	12
2.5	25	15
5	50	30
7.5	75	45
10	100	60

Table 166 - Typical VFD Output Signal Schedule

Most VFDs are programmed to have a minimum operating speed of 10 Hertz, 12 Hertz, or 15 Hertz. This is the minimum speed that will allow the integral fan of the driven electric motor to cool its windings while operating. This minimum operating speed should be defined by the motor manufacturer and/or the VFD manufacturer. Operating below this minimum speed increases the probability of insulation failure due to overheating. Notify the installing contractor if a VFD is encountered with no internally programmed minimum speed (minimum speed = 0 Hertz). In the absence of a minimum VFD speed setting, a minimum operating speed of 15 Hertz through the BAS is recommended until the actual manufacturer-recommended minimum speed setting has been determined and programmed in the VFD.

37.1.3 Multi-Stage Capacity Control

Modulating control typically costs more than binary or on/off control. Because of the higher cost of the equipment (SCR electric resistance heat, VFDs, etc.) with fully modulating output capacity, many equipment manufacturers opt to provide multiple stages of capacity in place of a single, modulating stage of capacity. Each stage is controlled by a binary signal – not analog. For example, larger air-handling units are often provided with multiple constant-speed compressors which are staged, as required, to maintain the space (or supply air) temperature at setpoint. As the cooling demand increases, additional compressor stages are energized until all available stages are enabled. Likewise, compressor stages de-energize as the cooling demand reduces. Although this form of capacity control is stepped control, the steps are controlled by a modulating analog output from a PID loop.

PID Loop Output (%)	Stage 1 (BO-1)	Stage 2 (BO-2)	Stage 3 (BO-3)	Stage 4 (BO-4)
0	Off	Off	Off	Off
25	**On**	Off	Off	Off
50	**On**	**On**	Off	Off
75	**On**	**On**	**On**	Off
100	**On**	**On**	**On**	**On**

Table 167 - Electric Resistance Heat Staging versus PID Output

The control of multiple stages of capacity can also be implemented through the use of a multi-stage sequencer. A multi-stage sequencer is a solid-state circuit that accepts an analog signal from a BAS controller and enables multiple sets of switched contacts in successive order as the analog signal exceeds fixed or adjustable thresholds. The result is that the same control is achieved that was described in the previous paragraphs, but only one analog output is required. For example, an air-handling unit six stages of electric resistance heat would typically require six binary outputs of a BAS controller to control each stage of heat capacity. However, a single analog output of a BAS controller and a multi-stage sequencer could provide the same control freeing up six binary outputs for control of other HVAC equipment. The multi-stage sequencer may be part of the factory-installed equipment control package or may be provided and installed by the Controls Contractor. In either case, the operation and testing of this type of equipment are the same. Sequencing modules with H-O-A switches and LED status indicators on each stage are preferred because they provide a means to quickly test the operation and control of each equipment stage. In addition, they can be used to manually take a stage out of operation for service or maintenance while allowing the remaining stages to continue staging to meet the operating demand.

37.2 Application

1. **Remote Setpoint Adjustment**. Equipment such as chillers and boilers allow their control setpoints to be controlled by a remote analog signal from the BAS.
2. **Remote Capacity Adjustment.** The same equipment may also be controlled by modulating its output capacity (speed, cooling capacity, heating capacity, humidification output) to match the current demand. A VFD is a commonly encountered example of this type of control.

37.3 Typical Control Wiring

The following diagram is an example of the typical capacity/setpoint adjustment wiring. The capacity control signal provided to the controlled equipment is typically polarity sensitive. Therefore, the installer must be sure to verify that the controlled equipment correctly interprets the control signal provided by the BAS controller. If the signal polarity is reversed, controlled equipment may not recognize the control signal and in some cases, it may cause damage. The BAS controller signal and the equipment's remote adjustment parameters must be coordinated.

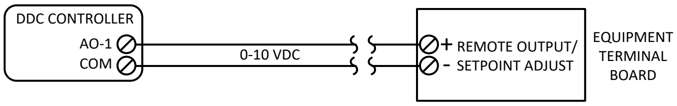


Figure 292 - Remote Capacity/Setpoint Adjustment Wiring

37.4 Analog Output Testing and Verification

The general test procedures for Setpoint/Capacity signals include the following:

1. Verify that the controlled equipment has the capabilities, capacity, and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The capacity control signal, its range, and wiring requirements are some of the features that should be verified.
2. Verify whether the analog output signal from the BAS controller is used to control the setpoint or the capacity of the controlled equipment. Also, verify whether the setpoint adjustment is relative to the current setpoint or absolute. The equipment manufacturer's operation and maintenance manuals typically provide this information, or it may be configurable with the equipment controller settings. This information is essential to determining how the remote setpoint/capacity signal is programmed.
3. Verify that the controlled equipment has been installed per the manufacturer's installation recommendations.
4. Identify and document the process variable, setpoint, its output signal range, and action (direct-acting or reverse-acting) of the PID loop that calculates the control signal to be used by the end device (VFD, boiler, chiller, humidifier, electric resistance heat, etc.).
5. Verify that the analog output for the controlled device has been correctly wired. Capacity/setpoint signals are typically provided by a direct current voltage signal, including, but not limited to 0-10 VDC, 2-10 VDC, 0-5 VDC, and 1-5 VDC. Be especially sure that the signal wires have been connected with the correct polarity. If the polarity is not correct, the equipment may not respond to the analog signal. Verify and document how all hardware interlocks are implemented, if applicable. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify that the terminals of the controlled device (VFD, boiler, chiller, humidifier, etc.) are connected to the correct BAS controller analog output. This step is typically performed by overriding the analog output and measuring the analog output signal at the BAS controller and at the controlled device contacts.
7. Verify that the wires that transmit the analog control signals have been labeled to indicate what data point and what system, equipment, or component it is associated with. If a multistage sequencer is used, then labeling of all related

input and output wiring is recommended.

8. Verify that the facets of the analog output signal that controls the equipment capacity are correctly displayed. Most analog outputs signals that control equipment capacity or setpoint use the percent sign (%) to indicate the commanded output or the units appropriate for the equipment setpoint.
9. Verify that the precision of the capacity or setpoint signal for the controlled equipment is appropriately set. Setpoints should be whole numbers and the precision of the analog output signal associated with the commanded capacity or setpoint should be no more than one decimal place for most applications.
10. Verify that the BAS controller's analog output point has been properly configured to transmit the commanded capacity or setpoint signal.

	Output (%)	Volts (VDC)
Minimum	0	2
Maximum	100	10

Table 168 - Initial Analog Input Configuration

If the output configuration is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs.

Volts (DCV)	% Output
2	0
10	100

Calculated Scale= 12.50
Calculated Offset= -25.00

Table 169 - Initial Scale-Offset Calculation for Analog Output Configuration

11. Using the analog output data point (not the BAS graphics), verify that the controlled equipment responds to the capacity/setpoint adjustment commands. Override the output signal to 0%, 25%, 50%, 75%, and 100% and verify that the equipment assumes the commanded capacity or setpoint. If it does not, review the configuration of the analog output, the wiring, and terminals of the controlled equipment. Modification of the sequences of operation may be required based on the actual capabilities of the controlled equipment. At each increment of commanded output, record the voltage signals (at the BAS and controlled equipment terminals) and the actual output or setpoint indicated at the controlled equipment. If there is a difference between the voltage readings, review the signal requirements of the controlled equipment and troubleshoot as required.

Field Measurements/Observations			
Command	BAS Analog Output Signal (VDC)	Equipment Signal (VDC)	Equipment Output/Setpoint
0	2.22	2.22	25%
25	4.12	4.12	25%
50	6.1	6.1	50%
75	8.08	8.08	75%
100	10.12	10.0	100%

Table 170 - Control Signals versus Equipment Output State Table

12. Update the configuration of the analog output of the BAS controller, if required, and retest to confirm proper control.

	Output Command (%)	Volts (VDC)
Minimum	0	2.22
Maximum	100	10.12

Table 171 - Updated BAS Controller Configuration

If scale and offset factors are used to configure the parameters of the BAS controller analog output, update them accordingly using the same methodology explained in Chapter 3: BAS Inputs and Outputs. Confirm the accuracy of the analog output configuration by overriding the analog output to various output levels (typically 0%, 25%, 50%, 75%, and 100%) and verifying the results.

Volts (DCV)	% Output
2.22	0
10.12	100

Calculated Scale= 12.66
Calculated Offset= -28.10

Table 172 - Updated Scale-Offset Calculations

13. As the BAS controller analog output is overridden, verify and document that the corresponding data point bound to

the BAS graphics also changes. The color change provides a visual indication on the BAS graphics that this point has been overridden. While the analog output is overridden, the programmed control logic no longer controls the analog output and they will remain in the overridden state until the overrides are released.

14. Using the analog output field bound to the BAS graphics (not the analog output data point) associated with the capacity/setpoint adjustment signal, verify that the controlled equipment responds appropriately. Also, verify that the BAS graphic provides a visual indication that these analog output points are currently overridden.
15. If the status of the controlled equipment is monitored by a status monitoring device (temperature sensor, VFD speed feedback, current transmitter, etc.), this is an ideal time to test and adjust that device as well.
16. Verify that the analog output controls the equipment capacity over time by reviewing trend data. Numeric interval trend extensions are used to collect trend data at the programmed time intervals. If the analog output can be verified by monitoring other sensors, trend those points as well. For example, if a VFD speed command is trended, also trend the VFD/pump current flow or VFD speed feedback. Trending the speed command only does not confirm that the speed commands were followed.
17. Document the results of all testing. Screenshots of the analog output point data as well as the BAS graphics are useful for documenting the ability of the BAS to control the analog output device.

37.5 Review

1. True or False: The BAS controller analog output signal must exactly match the equipment's remote setpoint adjustment input signal range to function correctly. Answer: ________
2. If a VFD with a 60 Hertz maximum operating speed requires a 0-10 VDC setpoint adjustment signal and the BAS provides a 3.0 VDC signal, then the VFD will operate at ________ Hertz.
3. True or False: The VFD minimum operating speed is determined by the minimum insulation cooling requirements of the driven motor. Answer: ________
4. Per the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55, the supply air at temperatures should not exceed 15°F above the room temperature because of the potential for temperature ______________________.
5. A multistage sequencer allows an ______________________ signal of a BAS controller to control multiple stage of capacity which are typically controlled by binary output signals.
6. A ______________________ may be used to test the response of the controlled equipment to changes in the control signal even before the BAS controller is installed.
7. If the controlled equipment does not respond to a remote control signal change, the most likely culprit is:

    A. No power to controlled equipment
    B. No power to BAS controller
    C. Signal wires are not correctly landed

37.6 References

1. American Society of Heating, Refrigeration, and Air Conditioning Engineers. 2020. Standard 55: Thermal Environmental Conditions for Human Occupancy.

Chapter 38 - Modulating Electric Actuators (AOs)

38.1 Description

Modulating electric actuators are devices that use electric power through motors, gears, cams, and screws to provide the motive force to modulate valves and dampers. In the commercial HVAC industry, electric actuators have taken over the market. However, pneumatic actuators still have a distinct advantage in terms of speed, power, small size, and their inherent explosion-proof design. Because of the gear reduction required by electric motor-driven actuators, they can take significantly longer to actuate. In most comfort control applications, speed is not an issue. Modulating electric actuators provide damper/valve positions that vary anywhere from fully closed to fully open and are controlled by an analog output signal from a BAS controller.


Photo 362 - Modulating Electric Actuator on Return Air Damper

Photo 363 - Modulating Electric Actuator on Two-Way Control Valve


Photo 364 - Modulating Electric Actuator on Two-Way Control Valve

For example, suppose an electric control valve is modulating the flow of hot water through a heating coil to maintain a constant discharge air temperature. The BAS controller compares the process variable (discharge air temperature) to the setpoint. Depending on whether the process variable is above or below the setpoint, how far from setpoint it is, and for how long it has been away from setpoint, a new valve position command is sent to the control valve actuator. The BAS controller's PID loop continually adjusts the analog output signal to minimize the difference between the process variable and its setpoint.

The control signal for modulating electric actuators is typically a 2-10 VDC range. If the modulating electric actuator is provided with a 2 VDC signal, the damper/valve is closed but ready for movement. When 6 VDC is applied to the modulating electric actuator, it assumes the 50% open position. When 10 VDC is applied to the modulating electric actuator, it assumes the 100% open position. For clarity, it is a good idea to mark the fully-open and fully-closed positions of the damper or valve actuators if they do not come with position indicators or they are obscured from view. As you will see in the following chapter, modulating electric actuators vastly simplify the calibration and troubleshooting processes because the mechanical drive system of modulating electric actuators provides accurate and precise position control of dampers and valves.


Photo 365 - Modulating Electric Valve Actuator


Photo 366 - Modulating Electric Return Air Damper Actuator

Photo 367 - Modulating Electric Damper Actuator

Documenting the electric actuator's input signal type and range is critical. The most common configuration error is for the BAS controller's analog output to be set up for one range and the modulating electric actuator configured for another. For example, if a modulating electric actuator is configured for a 2-10 VDC input and the BAS controller's analog output signal is configured as a 0-10 VDC, the actuator will not move until the voltage signal reaches 2 VDC. Likewise, if the modulating electric actuator is configured for 0-10 VDC and the BAS analog output is configured for 2-10 VDC the damper/valve will be 20% open when commanded fully closed. This could cause a significant energy penalty if this was a preheat control valve in an air-handling unit because the cooling coil would have to offset this heat capacity. The range of the BAS controller's output signal must match the actuator's input signal range. To verify the calibration of a BAS controller's analog output signal and its modulating electric actuator, it is recommended that the command, the control signal, and the observed damper/valve position be recorded at 0%, 25%, 50%, 75%, and 100% open commands. If you feel inclined to go a step further, graph the commanded versus control signal and actual position data. The data and graph make it very clear when the commanded position is not followed.

Electric actuators can be ordered with other accessories which include the following:

A. **Position feedback**. Position feedback is an option that provides the ability to monitor the actual position of the actuator. Without position feedback, we have to trust that the damper/valve actuator is following the commanded position. Position feedback also provides a means to identify failed actuators. When the commanded position does not match the position feedback signal, an alarm can be generated. This signal provides a quantitative assessment of damper/valve position. A temperature sensor installed downstream of a heating/cooling coil can also indicate whether or not the valve command was followed. However, this indication is qualitative. It can tell us that a damper/valve actuator has moved, but it cannot tell us how much the actuator has moved nor its current position.

B. **Auxiliary Contacts**. Auxiliary contacts or end switches provide a means to verify that a specific point in the damper/valve stroke has been attained. In many sequences, identifying the fully opened and/or fully closed damper/valve position is required. These are useful if you want to energize a fan or pump only when an isolation damper or valve actuator has reached the fully opened position.

C. **Spring Return**. Modulating electric actuators may be equipped with the spring return option which allows the damper or valve to assume its normal or fail-safe position upon a loss of power or control signal. Many sequences of operation require that dampers and valves go to certain positions upon loss of power or activation of certain safety devices (smoke detector, low-temperature detector, high static safety switch, etc.). If you find that a damper actuator actuates to a position opposite to which it was intended, Direct-Coupled Actuators (DCAs) with the spring return option can be removed and installed in the reverse direction. This typically cannot be done for other actuator types. Valves and their electric actuators must be selected as an assembly or you run the risk of incompatibility with each other and with the design requirements.

D. **Reversing Switches**. Reversing switches are a convenient modulating electric actuator feature which allows the action of an actuator to be reversed with the flip of a switch. This switch changes the direction of the stroke and will not affect the direction of the spring return. The direction in which spring return actuates typically determines how it is mounted to the damper/valve shaft.

E. **Manual Override**. Most modulating electric actuators come with a manual crank or a release button or lever that allows the movement of the actuator manually. After the manual override is engaged, many modulating electric actuators require that the electrical power to the actuator be cycled before it resumes normal control by the control signal.

F. **Mechanical Stops**. Most modulating electrical actuators have adjustable mechanical stops that are used to limit the stroke. Most modulating DCAs have a 90-degree rotation. If the damper or valve fully opens at 60 degrees, the mechanical stop would be installed to provide a 60-degree stroke. The mechanical stops adjust the maximum and minimum actuator positions. It is also possible to limit the control signal range to 6 VDC (given a 0-10 VDC range), but the mechanical stops should still be installed.

G. **Linkage**. Globe valves may be equipped with a linkage kit that allows the use of direct-coupled actuators to actuate the valve stem. This device converts the rotary motion of the DCA into the linear motion required to actuate the globe valve stem in a linear (up and down) fashion. The linkage utilizes a rack and pinion design and has the ability to change the fail-safe position if it is incorrect. The spring-return DCA is simply flipped and reinstalled to change the fail-safe position. Installation of this linkage requires additional vertical clearance above the valve body.

38.2 Applications

1. Modulating Damper and Valve Control.

38.3 Typical Control Wiring

The following diagram is an example of how modulating electric valve or damper actuators are wired. There are many other configurations, but this is the wiring configuration typically used by most Controls Contractors.

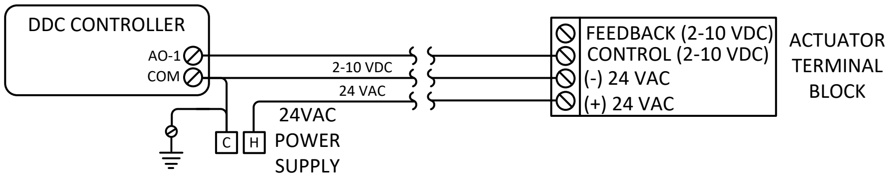


Figure 293 - Modulating Actuator Wiring (Three-Wire Voltage Control)

38.4 Analog Output Testing and Verification

The general test procedures for Modulating Electric Actuators include the following:

1. Verify that the modulating electric actuator has the capabilities, capacity, and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The operating voltage, mounting, fail-safe position, position feedback, auxiliary contacts, spring return, reversing switches, torque ratings, valve/damper shaft diameter, manual override, output signals, wiring requirements are some of the features that should be verified.
2. Verify that the modulating electric actuator has been installed in the correct or optimum location.
3. Verify that the modulating electric actuator has been installed per the manufacturer's installation recommendations. The shafts of dampers and valves should be centered in the jaws of the direct-coupled actuators. All actuators should be firmly mounted to prevent movement and disconnection upon actuation. In addition, the zero (or fully closed) and fully open positions of the damper/valve should exactly correspond with the zero and fully open positions of the actuator.
4. Verify that the analog output for the modulating electric actuator has been correctly wired. The modulating electric actuator may have multiple contacts which must be properly landed and coordinated to provide the desired control.
5. Verify and document how all hard-wired interlocks are implemented. When a safety device of an air-handling unit activates, its fans are disabled, power to spring-return valve and damper actuators is disabled, and an alarm is generated. With no power, the dampers and valves assume their fail-safe or normal positions. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify that the terminals of the modulating electric actuator are connected to the correct BAS controller analog output. This step is typically performed by overriding the analog output and measuring the analog output signal at the BAS controller and at the controlled device and by verifying that the controlled damper/valve responds correctly.
7. Verify that the wires that transmit the analog control signals have been labeled to indicate what data point and what system, equipment, or component it is associated with. It is also good practice the mark the fully-closed and fully open positions on the actuator body with a permanent marker or other means if the position indicator does not clearly identify these positions (Photograph 366). These markings are critical during testing and troubleshooting.
8. Verify that the facets of the analog output signal that controls the modulating electric actuator are correctly displayed. Most analog outputs signals that control damper and valve actuators use the percent sign (%) to indicate the percentage open. It is typically beneficial to use the same facets for all damper and valve actuator position indications rather than using "% Open" for one and "% Closed" for another. If face-and-bypass dampers are displayed, I have found that there is less confusion if both the face and bypass commands are displayed. Displaying only one percentage can invite confusion especially if it is not clear to which damper the bound data tag belongs.
9. Verify that the precision of the analog output reading for the damper or valve actuator is appropriately set. Position setpoints should be whole numbers and the precision of the electric actuator command should be no more than one decimal place for most applications.
10. Verify that the BAS controller's analog output point has been properly configured to transmit the commanded damper or valve position. In this example, the 2-10 VDC signal produced by the BAS controller is proportional to the commanded damper or valve position.

	Output (%)	Volts (VDC)
Minimum	0	2
Maximum	100	10

Table 173 - Initial Analog Input Configuration

If the output configuration is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs.

Volts (DCV)	% Output
2	0
10	100

Calculated Scale= 12.50
Calculated Offset= -25.00

Table 174 - Initial Scale-Offset Calculation for Analog Output Configuration

11. Using the analog output data point (not the BAS graphics), verify that the electric actuator responds to the capacity/setpoint adjustment commands. Override the output signal to 0%, 25%, 50%, 75%, and 100% and verify that the electric actuator assumes the commanded positions. Modification to the sequences of operation may be required based on the actual capabilities of the controlled equipment. At each increment of commanded output, record the commanded position, the damper or valve's actual position, and voltage signal (VDC) at the terminals of the BAS controller and electric actuator. If there is a difference between the readings at the BAS controller and the actuator terminals, troubleshoot as required. There should be no difference in the control signal readings.

Field Measurements/Observations			
Command	BAS Analog Output Signal (VDC)	Equipment Signal (VDC)	Observed Position
0%	2.12	2.12	0%
25%	4.1	4.1	25%
50%	5.98	5.98	50%
75%	8.1	8.1	75%
100%	9.91	9.91	100%
Fail-safe	0.0	0.0	0%

Table 175 - Initial Transmitter/BAS Calibration Check

Stroke the damper or valve to verify that it fully opens and closes without binding or large jumps. The stroke should be linear and proportional to the control signal. Problems typically exist at the extremes of the stroke. Either it does not fully open or it does not fully close. Dampers, especially old ones, are notorious for having a nonlinear stroke because of the wear and tear of service, corrosion, friction, and looseness in the linkages. Make any adjustments to the connection between the damper/valve and the modulating electric actuator that may be required. This may also require adjustment of the control signal parameters. When existing dampers are controlled, they may also require cleaning and lubrication to achieve satisfactory performance. If the control signal provided by the BAS controller is provided to multiple actuators, verify that each damper or valve actuator follows the position commands. Air-handling unit dampers are typically controlled by a common control signal. Recall that the return air damper stroke is inversely proportional to the outdoor air and exhaust (or relief) damper command. If it does not, review the configuration of the analog output, the wiring, and the terminals of the actuator.

12. Update the configuration of the analog output of the BAS controller, if required, and retest to confirm proper positioning of the damper or valve. When the valve shaft has not been exactly aligned with the valve actuator, the zero and the full open positions may not be attained. Ball and plug valves do not have mechanical stops. Instead of stopping at the true zero position, the valve may pass the zero point and begin to open again. The same can issue can occur in butterfly dampers as well. However, multiple-blade dampers do not reopen if the shaft is over-rotated. The damper blades hit a mechanical stop and eventually the damper blades, control shaft, or linkages prematurely fail if the actuator continues to drive past the zero or fully open positions. The correct solution is to correct the alignment of the damper/valve and actuator and adjust the mechanical stops. Alternatively, the control signal can be adjusted so that the valve stops at zero. Using the true zero position and its corresponding voltage signal, the control signal can be rescaled so that the valve stops at zero. This method will not work if the valve does not reach zero. The valve/actuator misalignment must be corrected.

	Valve Position (%)	Volts (VDC)
Minimum	0	2.12
Maximum	100	9.91

Table 176 - Updated BAS Controller Configuration

If scale and offset factors are used to configure the parameters of the BAS controller analog input, update them accordingly using the same methodology explained in Chapter 3: BAS Inputs and Outputs. Confirm the accuracy of the analog output configuration by overriding the actuator to various positions and verifying whether the commands were followed.

Volts (DCV)	% Output
2.12	0
9.91	100

Updated Calculated Scale=	12.84
Updated Calculated Offset=	-27.21

Table 177 - Updated Scale-Offset Calculations

13. As the BAS controller analog output is overridden, verify and document that the corresponding data point bound to the BAS graphics also changes. Also, verify that the analog output data point bound to the graphic changes color to indicate that it has been overridden. While the analog output is overridden, the programmed control logic no longer controls the analog output and it will remain in the overridden state until the override is released.
14. Using the analog output field bound to the BAS graphics (not the analog output data point) associated with the analog output, verify that the electric modulating actuator modulates on command. Override the analog output data point to other values and verify that the controlled electric modulating actuator follows the commanded positions. Also, verify that the BAS graphic provides a visual indication that these analog output points are currently overridden.
15. If the status of the controlled electric actuator is monitored by a status monitoring device (position feedback signal or position switch), this is an ideal time to test and adjust that device as well.
16. Verify control of the modulating, electric actuator over time by reviewing its trend data. Numeric interval trend extensions are used to collect trend data at the programmed time intervals. If the analog output can be verified by monitoring other sensors, trend those points as well. For example, if the outdoor air damper position is trended, also trend the outdoor air damper position feedback and/or the mixed-air temperature.
17. Document the results of all testing. Screenshots of the analog output point data as well as the BAS graphics are useful for documenting the ability of the BAS to control the analog output device.

38.5 Review

1. True or False: When no voltage is applied to the control signal terminals of a modulating electric actuator with spring return it assumes its fail-safe position. Answer: _________
2. True or False: Modulating electric actuators have faster actuation speeds than pneumatic actuators.

   Answer: _________
3. If a control damper is wide open at only 45 degrees rotation and a 90 degree actuator has been installed, the 0-10 VDC control signal can be limited to ___________ VDC to prevent the damper from being driven past its fully open position.
4. True or False: In most air-handling units, the outdoor air, return air and relief air (also called exhaust) damper are controlled by dedicated control signals. Answer: _________

Chapter 39 - Floating Electric Actuators (BOs)

39.1 Description

Floating control simulates the valve and damper modulation provided by a typical analog output with two binary outputs of a BAS controller. Floating control is also known as tri-state control because the actuator has three possible states – driving open, driving closed, and not driving at all (staying in its current position). Floating control is often called the "Poor man's analog control," but it is no less effective than modulating electric actuators. Many Control Technicians prefer floating actuators because they are easy to test and don't require any configuration. Floating actuators have been included in the analog outputs of this book because of the modulating action that they provide. Because binary outputs are much more economical to produce and are typically more plentiful than their analog output counterparts, floating control actuators make a lot of sense. They are typically utilized in smaller HVAC terminal equipment such as fan coil units, unit ventilators, VAV terminal units, etc., but can be used anywhere a modulating actuator is required. Caution must be exercised with floating actuators because they are typically non fail-safe which means that they fail in place when power or control signal is lost.

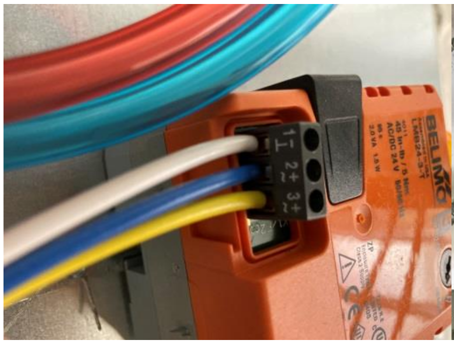


Photo 368 - Terminal Unit Floating Actuator

Photo 369 - Hot Water Control Valve with a Floating Actuator

Photo 370 - VAV Controller with a Floating Damper Actuator

Floating control relies on time to control the actuator position. The actuator stroke time is initially entered into the BAS controller's configuration. Many actuators take 90 seconds to drive from one extreme to the other. If a 50% open valve position is required and the actuator is fully closed, it will energize the assigned binary output that opens the valve to drive open for 45 seconds. As with modulating electric actuators, a PID loop is used to calculate the valve or damper position required to maintain the process variable (typically space temperature) at setpoint. During normal operation, many small position adjustments are made to control the process variable at setpoint.

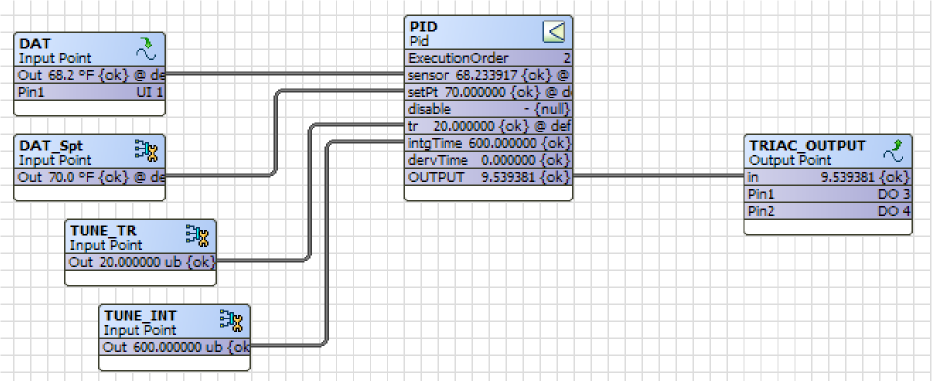


Figure 294 - Binary Triac Output Using DO-3,4 to Control Floating Actuator

Over time, the actual damper/valve position can diverge from the commanded position. Therefore, floating point control requires periodic calibration or float synchronization to verify and reset its indicated position. The float synchronization process involves the BAS controller stroking the actuator to one extreme (fully open or fully closed) to reset its position. This calibration process is typically performed automatically at some standard interval such as every 12 hours or could also be based on other criteria like occupancy changes. Instead of a typical analog output block, a Triac Output block is used which has two binary outputs assigned to it. One output drives the actuator in one direction and the other drives the actuator in the opposite direction.

Floating control provides an economic advantage over control dampers and valves controlled by analog output signals. This is especially true when an installation has a large number of dampers and valves that must be controlled. Larger commercial HVAC systems may have hundreds, even thousands, of small dampers and valves that are driven by floating control actuators.

39.2 Applications

1. Valve and Damper Control

39.3 Typical Control Wiring

The following diagram is an example of how a floating damper actuator is typically wired to a BAS controller.

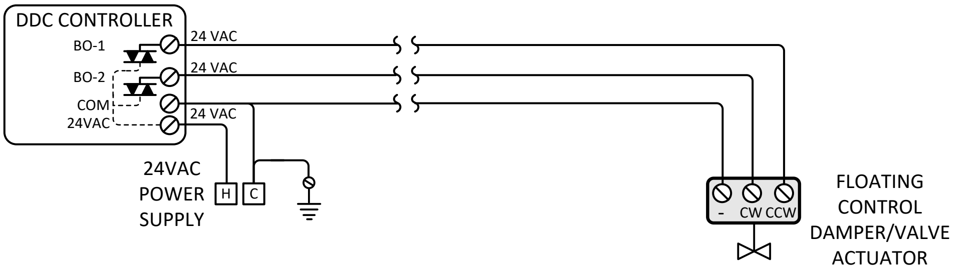


Figure 295 - Floating Point Control with Digital Triacs Outputs

39.4 Analog Output Testing and Verification

The general test procedures for Floating Electric Actuators include the following:

1. Verify that the floating electric actuator has the capabilities, capacity, and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The operating voltage, mounting, fail-safe position, position feedback, auxiliary contacts, spring return, reversing switches, manual override, control signals, and wiring requirements are some of the features that should be verified. Supply air terminal unit damper and valve actuators typically do not have the spring return option.
2. Verify that the floating electric actuator has been installed in the correct or optimum location.
3. Verify that the binary outputs of the floating electric actuator have been correctly wired. The floating electric actuator may have multiple contacts which must be properly landed and coordinated to provide the desired control signal. Drawings or sketches are typically best for documenting the wiring strategies used.
4. Verify that the floating electric actuator has been installed per the manufacturer's installation recommendations. The shafts of dampers and valves should be centered of the jaws of the direct-coupled actuators. All actuators should be firmly mounted to prevent movement and disconnection upon actuation. In addition, the zero (or fully closed) and fully open positions of the damper/valve should exactly correspond with the zero and fully-open positions of the actuator.
5. Verify and document how all hard-wired interlocks are implemented. When a safety device of an air-handling unit activates, its fans are disabled, power to spring-return valve and damper actuators is disabled, and an alarm is generated. With no power, the dampers and valves assume their fail-safe or normal positions. Drawings or sketches are typically best for documenting the wiring strategies used.
6. Verify that the terminals of the floating electric actuator are connected to the correct BAS controller binary outputs. One binary output drives the actuator to the open position and the other drives it to the closed position. This step is typically performed by overriding the damper/valve command to 0% open, 100% open, and finally 50% open. When the damper/valve is commanded to 0% open, one of the binary outputs will energize and drive it to that position. If the damper/valve instead goes to the fully open position, then either the terminal assignments or the binary output wires need to be reversed. Correct and retest to confirm that the floating actuator drives in the correct direction.
7. Verify that the wires that transmit the binary control signals have been labeled to indicate what data point and what system, equipment, or component it is associated with.
8. Verify that the facets of the analog output signal that controls the floating electric actuator are correctly displayed.

Most analog outputs signals that control damper and valve actuators use the percent sign (%) to indicate the percentage open. It is typically beneficial to use the same facets for all damper and valve actuator position indications rather than using "% Open" for one and "% Closed" for another which can be confusing.

9. Verify that the precision of the analog output reading for the damper or valve actuator is appropriately set. Position setpoints are typically whole numbers and the precision of actuator commands should be no more than one decimal place for most applications.
10. Verify and document the parameters that control when the floating output is synchronized. When the actuator enters float synchronization, it drives the actuator to the fully open and full closed position to calibrate its timing. Float synchronization is often activated on a change in occupancy or after a certain period (hours or days) of time has passed. If you observe repeating float synchronization, verify that the BAS controller has at least 24 VAC at its power terminals.
11. Using the analog output data point (not the BAS graphics), verify that the floating electric actuator responds to the position commands. Override the output command to 0%, 25%, 50%, 75%, and 100% and verify whether the floating electric actuator assumes the commanded positions. If it does not, review the configuration of the binary outputs, the wiring, valve timing, and terminals of the actuator. If the actuator strokes in the wrong direction, either switch the binary output wiring terminals or switch the terminal assignments in the control program. It is preferred for consistency that the software settings and the binary output wiring be consistently configured. At each increment of commanded output, record the commanded position and the observed position. The voltage generated by the binary triac outputs should be at least 24 VAC. Refer to Chapter 3: BAS Inputs and Outputs to review this procedure. If the binary triac output is found to be faulty, change to another binary output on the BAS controller.

Field Measurements/Observations	
Command	**Observed Position**
0%	0%
25%	25%
50%	50%
75%	75%
100%	100%

Table 178 - Initial Transmitter/BAS Calibration Check

12. Update the configuration of the analog output of the BAS controller, if required, and retest to confirm proper positioning of the damper or valve. When the valve shaft has not been exactly aligned with the valve actuator, the zero and the full open positions may not be attained. Instead of stopping at the true zero position, the valve may pass the zero point and begin to open again.
13. As the damper/valve position is overridden, verify and document that the corresponding data point bound to the BAS graphics also change. Placement of the damper position indications should be carefully considered. Ambiguous placement of the bound data can cause confusion. Also verify that the damper/valve command point bound to the graphic changes color to indicate that they have been overridden. While the analog output is overridden, the programmed control logic no longer controls the analog output and they will remain in the overridden state until the overrides are released.
14. Using the damper/valve command bound to the BAS graphics (not the analog output data point), verify that the electric floating actuator follows the commanded positions. Override the damper/valve command to other values and verify that the floating electric actuator follows the commanded positions. Also, verify that the BAS graphic provides a visual indication that this damper/valve position command point is currently overridden.
15. If the status of the controlled electric actuator is monitored by a status monitoring device (position feedback signal or position switch), this is an ideal time to test and adjust that device as well.
16. Verify control of the floating actuator over time by reviewing trend data. Numeric interval trend extensions are used to collect trend data at the programmed time intervals. If the floating actuator command can be verified by monitoring other sensors, trend those points as well. For example, if the outdoor air damper position is trended, also trend the outdoor air damper position feedback and/or the mixed-air temperature.
17. Document the results of all testing. Screenshots of the analog output point data as well as the BAS graphics are useful for documenting the ability of the BAS to control the analog output device.

39.5 Review

1. __________________ loops are used to calculate the required position of the damper or valve that is driven by the floating electric actuators.
2. Floating control of a damper or valve actuator requires
    - A. One analog output
    - B. Two analog outputs
    - C. One binary output
    - D. Two binary outputs
3. Floating control of actuators relies on ________________ to execute the position commands.
4. Floating actuators are often called __________________ because they have three possible states: Driving closed, Driving open, and disabled.
5. True or False: Modulating electric actuators have faster actuation speeds than pneumatic actuators.

    Answer: ________
6. If the actuator strokes in the wrong direction, the following can be done to correct it:
    - A. Switch the binary output wires for the two outputs
    - B. Switch the leads from the power supply
    - C. Switch the terminal assignment in the BAS controller program
    - D. A and C

Chapter 40 - Modulating Pneumatic Actuators (AO)

40.1 Description

Pneumatic actuators utilize compressed air to drive valves and dampers to the required position. To control pneumatic actuators through a BAS controller, an Electric-to-Pneumatic Transducer (EPT) is required. An EPT allows a 0-10 VDC analog control signal from the BAS controller to produce a proportional pneumatic control signal (0-15 PSIG). Pneumatic controls are the predecessor of Direct Digital Controls (DDC) and the use of pneumatic thermostats and receiver-controllers has significantly reduced because of electric actuators. There are still applications where pneumatic controls make a lot of sense. Pneumatic controls are inherently explosion proof. Pneumatic actuators are often used for larger valves and dampers because they produce a lot of force in a compact design. When actuation speed is absolutely required, the pneumatic actuator is chosen over electric actuators. When DDC systems are installed at sites that were previously equipped with pneumatic controls, the existing pneumatic valve and damper actuators are typically retained. Utilizing this existing infrastructure makes good financial sense because the purchase of new valve and damper actuators can be deferred to a later date.

Photo 371 - Pneumatic Chilled Water Valve Actuator

Photo 372 - Pneumatic High Temp. Hot Water Valve Actuators

Photo 373 - Pneumatic Inlet Guide Vane Actuator

The use of pneumatic actuators requires significant supporting infrastructure. A pneumatic actuator cannot function without a source of clean, dry, and regulated compressed air. It requires a compressed air system and a distribution network to make the compressed air available to the pneumatic actuators which are scattered throughout a building. Compressed air systems for pneumatic controls have common components which include, but are not limited to, compressors, tanks, piping, air dryers, oil/water filters, and pressure regulators. Besides the air compressor itself, the air dryer is perhaps the most important component of the compressed air system. An air dryer removes moisture in the compressed air and prevents it from proceeding throughout the compressed air distribution piping where it collects at the low points. Moisture in pneumatic lines can be very problematic for all pneumatic control components.

Photo 374 - Control Air Compressor

Photo 375 - Compressed Air Dryer

Photo 376 - Johnson Controls Electric to Pneumatic Transducer

Pneumatic actuators are typically equipped with an internal spring that provides the motive force required to return the connected valve or damper to its normal or fail-safe position if no control pressure is applied. Through the use of EPTs, the BAS controls pneumatically-actuated dampers, valves, and inlet guide vanes by modulating the air pressure applied to them. When power is interrupted or a safety device (smoke detector, low-temperature detector, etc.) is activated, the air pressure applied to the pneumatic actuators is vented by solenoid air valves to allow the pneumatic devices to return to their fail-safe position.

Friction in dampers, valves, linkages, and the actuator itself can vary significantly. This is why the repeatability of position commands in pneumatic actuators is often poor. Outdoor air dampers are often commanded to a predetermined minimum position to provide minimum ventilation airflow. To satisfy this fixed damper position command, the BAS controller applies a control voltage signal command that equates to the required damper position. For example, if an outdoor damper is required to assume a 20% damper position, the BAS controller provides the EPT a control signal that is 20% of the control signal range. The EPT, in turn, produces a pressure that is 20% of the actuator's operating pressure range. The force produced by the pneumatic actuator is the product of pressure and the area of the piston (F=P*A). However, the frictional forces that the pneumatic actuator must overcome can vary widely. In addition, the fluid pressure differentials on hydronic control valves can also produce dynamic forces that the pneumatic actuator also must overcome. As a result, the same applied control pressure does not mean that the same damper/valve position will be attained with each stroke of pneumatic actuators. Outdoor air dampers, their linkages and pivot points are notorious for being corroded which causes very sticky operation. This is especially true with older control dampers and valves. A 20% open outdoor air damper command today may result in 10% open today, 40% open tomorrow, and still another position the next day. The frictional forces and hysteresis can vary with each stroke of a pneumatic actuator.

Solenoid air valves are used in conjunction with an EPT to ensure that the pneumatic actuator assumes its fail-safe position upon a loss of power or control signal. The solenoid air valve is typically interlocked with the safety devices directly or through a fan safety alarm circuit. Should the power fail or a safety device actuate, the solenoid air valve loses power which vents the pneumatic control signal to the atmosphere causing the valve or damper to return to its fail-safe position. For example, when a low-temperature detector actuates, the supply fan de-energizes, the hot water preheat coil control valve typically opens fully to provide full heating capacity, the outdoor air (and exhaust air) damper closes, and the return air damper opens.

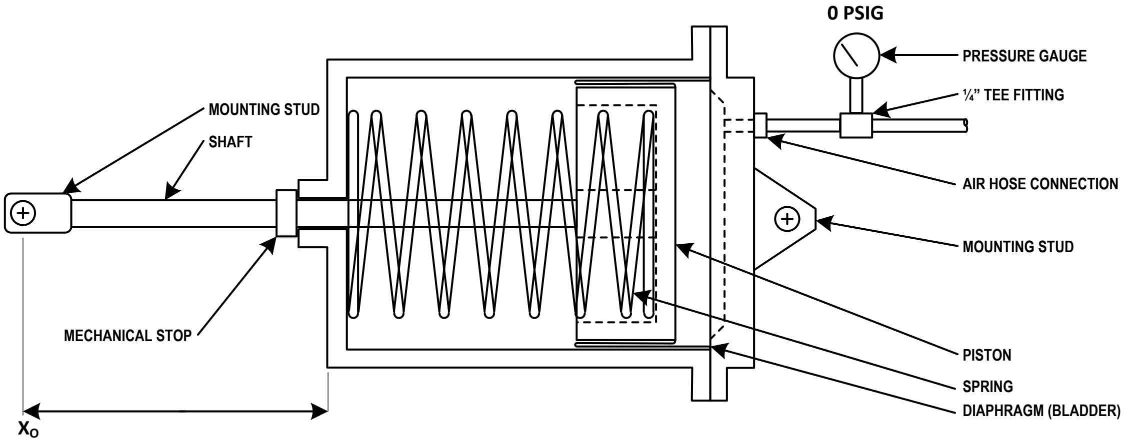


Figure 296 - Pneumatic Actuator Section View

Pneumatic actuators typically have spring range labels or markings on its body. This is a rating from the manufacturer that represents the combination of diaphragm plate diameter and spring constant. It may be labeled 3-15 PSIG and this represents the operating pressure range required to fully stroke this actuator before it is connected to the damper or valve. The damper/valve that it actuates produces additional forces that the pneumatic actuator must also overcome. This is why field testing is so important. A pneumatic actuator that indicates a range of 3-15 PSIG may require a pressure range of 3.5-16 PSIG to stroke from the fully closed to the fully open position. Each damper/valve and actuator combination and its flow characteristics are unique, so in situ pressure testing of each pneumatic actuator is required to determine the maximum and minimum pressures required to fully stroke the damper or valve assembly under normal conditions.

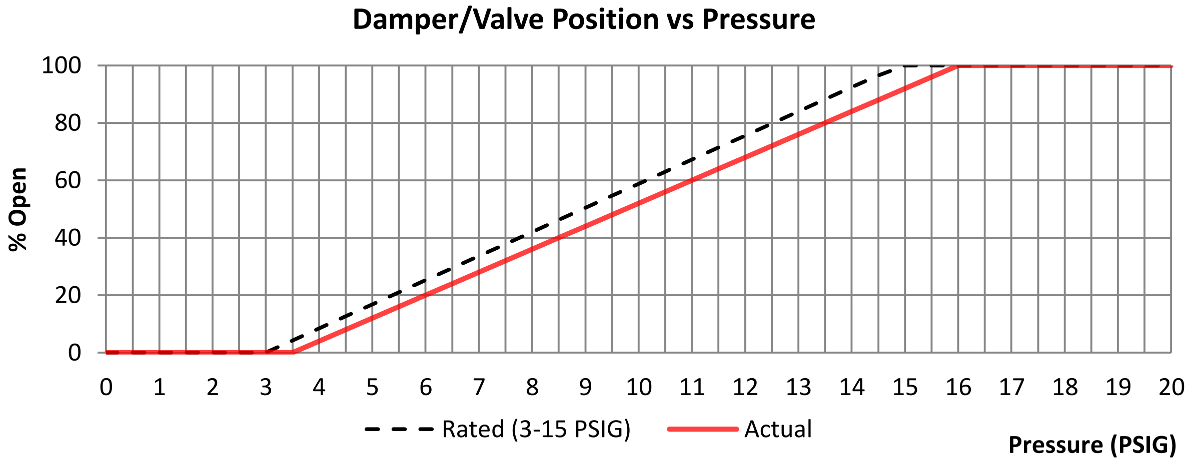


Figure 297 - Damper Position versus Test Pressure

The BAS controller typically uses a PID loop to maintain the process variable (typically temperature or pressure) at setpoint. It monitors the difference between the process variable and setpoint and calculates the new actuator command. The PID loop output typically varies from 0% to 100%. An analog output signal (typically 0-10 VDC) is generated that is proportional to the PID loop output. For pneumatic actuators, the entire range is typically not required because pneumatic actuators typically require a 5-6 PSIG range. For the PID loop to function correctly, a change in its output signal should produce a change in the damper/valve position used to control the process variable. Therefore, the minimum and maximum output signal of the PID loop should coincide with the minimum and maximum pressures of the controlled pneumatic actuator.

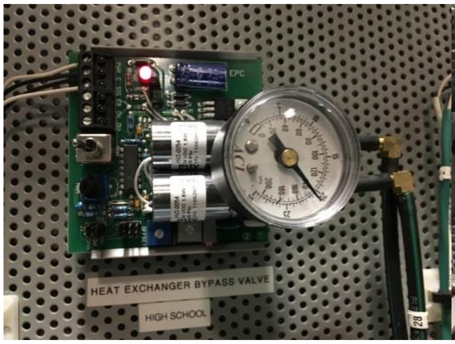


Photo 377 - Electric to Pneumatic Transducer

Photo 378 - Solenoid Air Valve

Photo 379 - Position Markings on Pneumatic Valve Actuator

To provide accurate control of dampers and valves driven by pneumatic actuators the minimum and maximum control pressures must be determined by in situ field testing. This is done by applying air pressure to the pneumatic actuator while connected to the controlled device (damper or control valve) and identifying the pressures associated with the fully opened and fully closed positions. In situ testing yields the best calibration results because the damper/valve will experience the same or nearly the same forces it would in actual operation. The compressed air for testing and calibration may be provided by any one of the following methods:

A. Compressed air from the building control air system and an EPT or pressure regulator.
B. Portable compressed air tank and pressure regulator.
C. Hand-actuated calibration pump.
D. Squeeze bulb.

Compressed air from a portable compressed air tank and pressure regulator is preferred to apply the pneumatic test pressures. The compressed air is connected to a pressure regulator equipped with a pressure gauge that provides an easy way to monitor and control the applied test pressure with a turn of the pressure regulator knob. In addition, this test methodology allows viewing of the actuator as the test pressure is applied. This is especially useful when testing pneumatically actuated control valves whose entire stroke may be less than two inches. To view movements this small requires that the person performing the pressure test be at the control valve actuator. Marking the minimum and maximum points of the pneumatic actuator stroke with a permanent marker or tape is useful during the actuator calibration process. The pneumatic tubing between the test regulator and pneumatic actuator should be as short as possible and the tubing diameter as small as possible to reduce the time lag between test pressure change and actuator movement and minimize the amount of compressed air lost during each pressure reduction cycle. Typical 1/4" pneumatic tubing works the best and is readily available. Pressurize the pneumatic actuator until the connected damper/valve just begins to move toward the opposite direction. Document this minimum control pressure. Continue to pressurize the pneumatic actuator until the fully open (or fully closed) position is reached. Document this maximum control pressure. Carefully vent the pressure from the pneumatic actuator by turning the regulator knob to the left. You will hear the compressed air vent as it is released and the actuator will return to its fail-safe position (by the internal spring force). Once these actuator control pressures have been determined, most Controls Contractors add 0.5 PSIG to 1 PSIG to the top and bottom of the pressure range. Therefore, if the final minimum and maximum pressures were found to be 4.5-7.5 PSIG, then the final control pressure range would be 4-8 PSIG. This slightly expanded pressure range ensures that the fully open and fully closed valve or damper positions are attained.

The final step in the pneumatic actuator calibration process is to determine the required control signal range (VDC) that the BAS controller provides the EPT to actuate the pneumatic actuator from 0%-100% or 100% to 0% open. EPTs produce a pressure that is proportional to the control signal input range. If the EPTs have selectable input and output ranges, these must be determined, set, and documented to avoid any confusion. This example assumes that the EPT has an input control signal range of 0-10 VDC and an output pressure modulation range of 0-15 PSIG. Therefore, 0.0 PSIG will be produced when a 0.0 VDC control signal is applied to its input terminals and 15.0 PSIG will be produced when 10.0 VDC is applied. It was previously determined that the control pressure range applied to the pneumatic actuator should be 4 PSIG (fully closed) to 8 PSIG (fully open).

We now calculate the control voltage signal (VDC) that corresponds to the minimum and maximum pressures by multiplying the minimum required control pressure by the ratio of the control voltage range to the pressure modulation range. To apply 4 PSIG to the pneumatic actuator, the BAS controller provides a 2.7 VDC control signal to the EPT. Likewise, to apply 8 PSIG to the pneumatic actuator, the BAS controller provides a 5.3 VDC control signal to the EPT. These control signal values define the range that actuates the damper/valve from its fully closed position to its fully open position, or vice versa. This also ensures that at least 4 PSIG is applied to the actuator at all times and when movement is required, it moves immediately because it is not ramping up from 0 PSIG. It also ensures that no more than 9 PSIG is applied to the pneumatic actuator. Pressures higher than 9 PSIG will not actuate the damper or valve any further.

(Equation 122) $$V_{Minimum} = P_{Min} * \frac{Voltage\ Range}{Pressure\ Range}$$

(Equation 123) $$V_{Minimum} = 4PSIG * \frac{10\ VDC}{15\ PSIG} = 2.7\ VDC$$

(Equation 124) $$V_{Maximum} = P_{Max} * \frac{Voltage\ Range}{Pressure\ Range}$$

(Equation 125) $$V_{Maximum} = 8PSIG * \frac{10\ VDC}{15\ PSIG} = 5.3\ VDC$$

If this analog output calibration procedure for pneumatic actuators is not performed, it typically results in poor system performance. PID loops cannot maintain the process variable at setpoint when its output signal does not produce a change in the output device (damper, valve, or inlet guide vanes) position. It makes no sense for the control pressure to modulate from 0 PSIG to 15 PSIG if the actuator only moves when the applied pressure range is between 4.5 PSIG to 7.5 PSIG. Under certain conditions, the PID loop may be able to achieve satisfactory control of the process variable with a 0-15 PSIG signal. However, its performance will generally be poor because the PID loop's calculated output signal (valve or damper actuation) is only effective for a small portion of the pressure range. When there is no response to the previous change in the PID loop output signal, the PID loop makes more frequent and larger signal changes. Eventually, the control voltage reaches a point at which the control device produces a change in the process variable, but by this time the calculated output signal is too large and results in a large change in the process variable (temperature, pressure, etc.) resulting in overshooting/undershooting of the setpoint.

40.2 Applications

1. Modulating Damper/Valve Control. Modulating dampers and valves can be controlled by an analog output signal from a BAS controller, an EPT, and a solenoid air valve (if required) to maintain a process variable at setpoint.

2. Modulating Inlet Guide Vane Control. Inlet Guide Vanes (IGV) may be encountered in older air-handling units. IGVs are a mechanical means of airflow modulation that was prevalent in variable-air-volume systems before Variable Frequency Drives. It essentially blocks the fan inlet resulting in a reduction in flow capacity. IGVs consist of a set of blades each in the shape of pieces of pie or pizza. Each blade is mounted to a shaft whose axis is oriented in the radial direction at fixed clock positions. The blades turn in unison when actuated to either allow airflow or block airflow. A pneumatic actuator is used to control the airflow or supply duct static pressure by controlling the IGV position.

40.3 Typical Control Wiring

The following diagram is an example of a pneumatically actuated heating coil control valve that is controlled by the BAS controller through an EPT to maintain the space/discharge air temperature at setpoint. In this example, the auxiliary contacts of the supply fan contactor are closed to energize the solenoid air valve which allows the passage of control air signal to the pneumatic valve actuator. Upon a loss of power or actuation of a safety device, the supply fan's contactor is disabled which de-energizes the solenoid air valve resulting in the venting of the control air pressure to the pneumatic actuator EPT causing them to return to their fail-safe position.

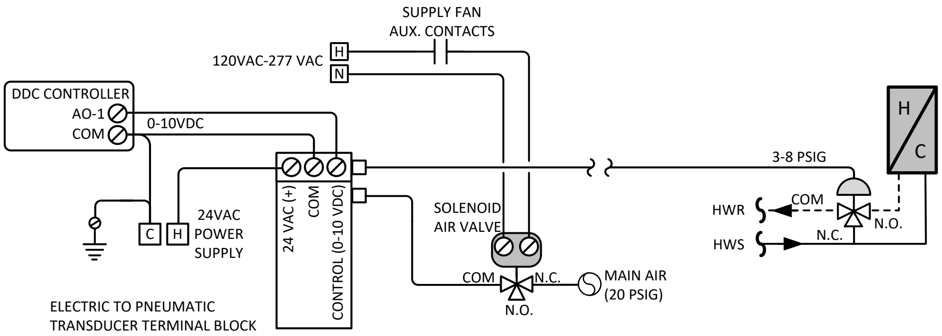


Figure 298 - Hot Water Coil Control with an EPT and Solenoid Air Valve

The next example illustrates the use of pneumatically actuated dampers in an air-handling unit that is controlled by the BAS controller through an EPT to maintain the process variable (mixed-air, discharge air, or space temperature) at setpoint. The solenoid air valve vents the control air pressure to the atmosphere upon a loss of power or actuation of a safety device causing the dampers to return to their fail-safe positions.

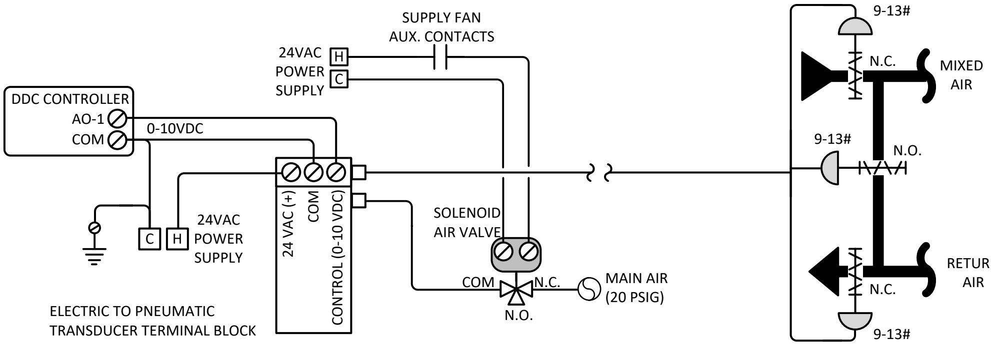


Figure 299 - Damper Control with an EPT and Solenoid Air Valve

40.4 Analog Output Testing and Verification

The general test procedures for Modulating Pneumatic Actuators include the following:

1. Verify that the modulating pneumatic actuator(s), EPT, and solenoid air valve have the capabilities, capacity, and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The operating voltage, mounting, EPT pressure range, EPT signal range, actuator pressure range, fail-safe position, and wiring requirements are some of the features that should be verified. The control damper and valves and their actuators must be properly matched to provide the required action and fail-safe positioning.
2. Review the sequences of operation to verify the fail-safe position (open or closed) of the damper or valve actuator. In the absence of the BAS control signal, as could happen if the power to the BAS control panel should fail, the actuator assumes its fail-safe position if they are equipped with the spring return option.

3. Verify that the modulating pneumatic actuator, EPT, and solenoid air valve have been installed in the correct or optimum location.
4. Verify that the modulating pneumatic actuator, EPT, and solenoid air valve have been installed per the manufacturer's installation recommendations. The base of the pneumatic actuator is securely mounted to the anchor points as well as to the driven damper or valve. The mechanical connections between the pneumatic actuator and damper/valve should be secure. Dampers often require jackshafts to redirect the torque or adjust the length of the stroke applied to the damper. Adjustments may be required to ensure that the fully closed and fully open positions can be attained by the stroke of the actuator. There should not be any looseness in the connections as this can affect the actual range of motion. Excess play will prevent the damper or valve from fully opening and/or closing. Also, check for the presence of binding or jerky motion as the stroke progresses. Valve actuators may either require a rotational or linear motion to actuate the valve stem depending on the control valve type. If the shaft of the damper actuator is not marked by the factory, then a mark should be made on the end of the damper's jackshaft with a permanent marker so that quick visual verification of the damper's position is possible. All actuators should be firmly mounted to prevent movement and disconnection upon actuation.
5. Measure and document the pressure of the main compressed air system at the point of use and at the source. If the EPT is remotely located from the compressed air plant, the measured pressure could be substantially different. The available compressed air pressure must be high enough to fully actuate the pneumatic actuator throughout its entire range.
6. Verify whether the compressed system is equipped with an operable air dryer. Moisture (water and oil) in pneumatic lines can be very problematic. To check for moisture, disconnect the main compressed air line and vent the compressed air toward a large piece of white paper which allows you to see what is discharged with the compressed air.
7. Verify that pneumatic tubing connections between the pneumatic actuator, EPT, and solenoid air valve have been correctly connected. Review the pneumatic actuator, EPT, and solenoid air valve literature. Also, review the ladder logic diagrams typically included in the control submittal. If none exist, drawings or sketches are typically best for documenting the wiring strategies used. Pressure gauges on the main and branch lines of the EPT are recommended. They provide quick indications of the current control pressures. Pressure gauges are also recommended on the pneumatic line at the controlled pneumatic damper or valve actuator. Verify that the pneumatic tubing connections are tight and fully seated. An ultrasonic leak detector is very good at identifying compressed air leaks because this device detects sound waves in the ultrasonic range.
8. Verify that the BAS controller, EPT, and solenoid valve have been correctly wired. This will involve reviewing the wiring between the BAS controller and EPT. In addition, a review of the solenoid air valve and its connection to the motor starter or air-handling unit fan safety alarm circuit may be required. Drawings or sketches are typically best for documenting the wiring strategies used.
9. Verify and document how all hardware interlocks associated with the analog output are implemented. When a safety device of an air-handling unit trips, the compressed air pressure supplied to the pneumatic valve and damper actuator through the EPT is vented and they assume their fail-safe or normal positions. This causes the damper or valve to return to its fail-safe or normal positions. Update the control logic ladder diagram that is typically included with the controls submittal.
10. Verify that pneumatic tubing connections between the pneumatic actuator, EPT, and solenoid air valve have been correctly connected. Review the pneumatic actuator, EPT, and solenoid air valve literature. Also, review the ladder logic diagrams typically included in the control submittal. If none exist, drawings or sketches are typically best for documenting the wiring strategies used. Pressure gauges on the main and branch lines of the EPT are recommended. They provide quick indications of the current control pressures. Pressure gauges are also recommended on the pneumatic line at the controlled pneumatic damper or valve actuator. Verify that the pneumatic tubing connections are tight and fully seated. An ultrasonic leak detector is very good at identifying compressed air leaks because this device detects sound waves in the ultrasonic range.
11. Verify that the EPT, solenoid air valve, and actuator have been labeled to indicate what analog output data point (AO-X) and what equipment, system, or component they are associated with. For example, an air-handing unit minimum outdoor air damper may be marked or labeled with the following information: AO-1/EPT-1/OAD. If the model number and operating pressure range of the pneumatic actuator is not visible in its final installed location, it is typically a good idea to indicate the model number and pressure range on the actuator body where it is visible.
12. Verify that the facets of the analog output signal that controls the modulating pneumatic actuator are correctly

displayed. Most analog output signals that control damper and valve actuators use the percent sign (%) to indicate the percentage open. The BAS graphics are easy to understand when the facets for all damper and valve positions are consistent. Using both "% Open" as well as "% Closed" is not recommended as it causes confusion. If face-and-bypass dampers are displayed, I have found that there is less confusion if both the face and bypass commands are displayed. Displaying only one percentage can invite confusion especially if the data tag is placed where it is not clear to which damper it represents.

13. Verify that the solenoid air valve is enabled and disabled per the sequences of operations. The solenoid air valve must be enabled to allow the compressed air to reach the controlled actuators via the EPT. When the solenoid air valve is disabled, the air to the EPT and actuator is vented to the atmosphere which causes the actuator to return to its fail-safe position. The solenoid air valve is typically interlocked with auxiliary contacts from the supply fan contactor, an interlocking isolation relay, or controlled by the BAS controller.
14. Review the current configuration of the BAS controller's analog output control signal. They would have been based on the spring range (9-13 PSIG range to actuate it from 0-100% open) of the pneumatic actuator.

	Actuator Position (%)	Actuator Pressure (PSIG)	EPT Voltage (VDC)
Minimum	0	9	6.0
Maximum	100	13	8.66

Table 179 - Initial Analog Input Configuration

The current control signal range would have been determined as follows:

(Equation 126) $V_{Minimum} = 9.0PSIG * \frac{10\,VDC}{15\,PSIG} = 6.0\,VDC$

(Equation 127) $V_{Maximum} = 13.0PSIG * \frac{10\,VDC}{15\,PSIG} = 8.66\,VD$

If the output configuration is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs.

Volts (DCV)	% Output
6.00	0
8.66	100

Calculated Scale= 37.59
Calculated Offset= -225.56

Table 180 - Initial Scale-Offset Calculation for Analog Output Configuration

15. Determine the actual minimum and maximum pressures required to stroke the damper/valve actuator from the fail-safe position to the fully-actuated position (fully-closed or fully-open) by applying test pressure to the actuator while connected to the damper/valve under normal operating conditions. The goal is to determine the pressure at which the damper/valve just starts to move and the pressure when it reaches the opposite, full-stroke position. Without testing of the pneumatic actuator, it is typically initially configured based on the rated pressure range which is typically stamped or indicated on the actuator label.

	Actuator Position (%)	Actuator Pressure (PSIG)
Minimum	0	9
Maximum	100	13.5

Table 181 - Pneumatic Actuator Pressure Test Results

16. Verify the BAS controller's analog output control signal range required to produce the minimum and maximum actuator pressures with the EPT. This will require knowledge of the available compressed air pressure, the EPT pressure range, EPT signal range, and the pneumatic actuator pressure range. Analog outputs are typically configured to use their entire control signal range (0-10 VDC). However, the pneumatic actuator only needs a small portion of the 0-15 PSIG range to actuate the pneumatic actuator from 0-100% open. If the pneumatic actuator has a 9-13.5 PSIG range to actuate it from 0-100% open, the actuator pressure range is set to 8.5-14 PSIG (Adding 0.5 PSIG to the upper and lower end of the range). The control signal range is calculated as follows:

(Equation 128) $V_{Minimum} = 8.5PSIG * \frac{10\,VDC}{15\,PSIG} = 5.67\,VDC$

(Equation 129) $$V_{Maximum} = 14PSIG * \frac{10\,VDC}{15\,PSIG} = 9.33\,VDC$$

The two voltages calculated above define the minimum and maximum control signals that the analog output should be configured to provide. With this signal range, the EPT will output the required pneumatic signal to the pneumatic actuator. If the pneumatic signal was provided to multiple actuators, then the pressure signal range should be selected to provide the "best" performance and ensure that all actuators stroke as commanded.

	Actuator Position (%)	Actuator Pressure (PSIG)	BAS Control Signal (VDC)
Minimum	0	8.5	5.67
Maximum	100	14.0	9.33

Table 182 - Updated Analog Input Configuration

If the output configuration is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs.

Volts (DCV)	% Output
5.67	0
9.33	100

Calculated Scale=	27.32
Calculated Offset=	-154.92

Table 183 - Updated Scale-Offset Calculation for Analog Output Configuration

17. Using the damper/valve command data point (not the BAS graphics), verify that the modulating pneumatic actuator actuates on command. Override the pneumatic control damper/valve to 0%, 25%, 50%, 75%, and 100% open and verify that the actuator assumes the commanded positions. At each increment of commanded output, record the commanded position, the damper/valve position. Also, measure and record the voltage signal (VDC) at the terminals of the EPT and the BAS controller and the pressure applied to the pneumatic actuator. Verify that the damper or valve fully opens and closes without binding or large jumps. The stroke should be linear and proportional to the control signal. Problems typically exist at the extremes of the stroke. Either it does not fully open or it does not fully close. Dampers, especially old ones, are notorious for having a nonlinear stroke because of the wear and tear of service, friction, and looseness in the linkages. They may also require cleaning and lubrication (even replacement) to achieve satisfactory performance. If the control signal provided by the BAS controller is provided to multiple actuators, verify that each damper or valve actuator follows the position commands. Air-handling unit dampers (outdoor air, return air, and relief) are typically controlled by a common control signal. Recall that the return air damper stroke is inversely proportional to the outdoor air and exhaust (or relief) damper command. If it does not, adjust the control signal range, linkages, connections, and stops, as required, to provide the required damper or valve stroke.

Field Measurements				
Command (% Open)	Solenoid Air Valve Voltage (VAC)	Observed Position (% Open)	BAS Controller Output (VDC)	EPT Output Signal (PSIG)
0%	119.5	0%	5.67	8.5
25%	119.5	25%	6.59	9.8
50%	119.5	50%	7.5	11.3
75%	119.5	75%	8.42	12.6
100%	119.5	100%	9.33	14.0
Fail-Safe	0	0	0	0

Table 184 - Pneumatic Actuator Observations versus Output Command

18. As the position command is overridden, verify and document that the corresponding data point bound to the BAS graphics also changes. Also, verify that the damper/valve position command data points bound to the graphic change color to indicate that they have been overridden. The color change provides a visual notification on the BAS graphics that this point has been overridden. While the damper/valve command is overridden, the programmed control logic no longer controls the analog output and they will remain in the overridden state until the overrides are released.
19. Verify that the fail-safe position of the pneumatic dampers and/or valve actuators. The easiest way to do this is to disconnect the 24 VAC power to the BAS controller, solenoid air valve, and EPT. All connected damper and valve actuators will be affected, so it is typically more time-efficient to verify the fail-safe positions of all affected damper and valve actuators. If the damper or valve does not go to the required fail-safe position, verify that the correct actuators are provided, they are properly mounted, tubing connections are properly terminated, wiring is properly

connected, and that mechanical linkages are properly configured.

20. Using the damper/valve command field bound to the BAS graphics (not the analog output data point), verify that the pneumatic modulating actuator assumes the commanded positions. Override the analog output data point to other values and verify that the controlled modulating pneumatic actuator follows the commanded positions. Also verify that the BAS graphic provides a visual indication that these analog output points are currently overridden.
21. If the status of the controlled pneumatic modulating actuator is monitored by a status monitoring device (position feedback signal or position switch), this is an ideal time to test and adjust that device as well.
22. Verify that the analog output controls the modulating, pneumatic actuator over time by reviewing the associated trend data. Numeric interval trend extensions are used to collect trend data at the programmed time intervals. If the analog output can be verified by monitoring other sensors, trend those points as well. For example, if an air-handling unit chilled water control valve position command is trended, also trend the supply air temperature. Trending the position command only does not confirm that the position command was followed.
23. Document the results of all testing. Screenshots of the analog output point data as well as the BAS graphics are useful for documenting the ability of the BAS to control the analog output device.

40.5 Review

1. True or False: When no pressure is applied to a pneumatic valve actuator with spring return it assumes its normal or fail-safe position. Answer: ________
2. The following are advantages of pneumatic actuators:
    - A. Fast actuation speed
    - B. Explosion-proof
    - C. High power for the size
    - D. All of the above
3. True or False: If a control valve strokes between full open and full closed when the applied pressure varies between 3 PSIG and 8 PSIG, it is acceptable to control it with an EPT configured for a minimum and maximum pressures of 0 PSIG and 20 PSIG, respectively. Answer: ________
4. If a pneumatic actuator does not stroke when test pressure is applied, the most likely root cause is______________.
    - A. No air pressure
    - B. Disconnected pneumatic line
    - C. Failed diaphragm
    - D. Failed EPT
5. How many EPTs are required to control the outdoor air, return air, and relief air dampers of a typical air-handling unit? Answer: ________
6. True or False: In air-handling units, a solenoid air valve is typically interlocked with the supply fan motor starter control circuit such that control air is provided to the pneumatic dampers as long as the supply fan is energized and the safety devices (freezestat and/or smoke detector) are in their normal state. Answer: ________

Chapter 41 - Modulating Electric Resistance Heating Coils (AO)

41.1 Description

Electric resistance heaters are typically manufactured for stepped or staged capacity control. In some applications, increased levels of capacity control are required. For these situations, electric resistance heaters equipped with Silicon Controlled Rectifier (SCR) controllers are required. This type of electric resistance heating coil has a higher cost than conventional staged electric resistance heating coils because of the additional circuitry required to implement the high-speed switching of the electrical circuits that allow modulating capacity control. SCR heating coils have a significantly longer service life than staged heaters because of the much lower thermal shock and stress experienced by the heating element. Comfort is improved because the temperature variations are kept to a minimum resulting in a more stable space/discharge air temperature. Capacity control is achieved by varying the time that the heater is energized. Electric heaters are also used in hydronic systems, but this chapter focuses on air heating applications.


Photo 380 - Slip-In SCR Electric Finned-Tubular Duct Heater

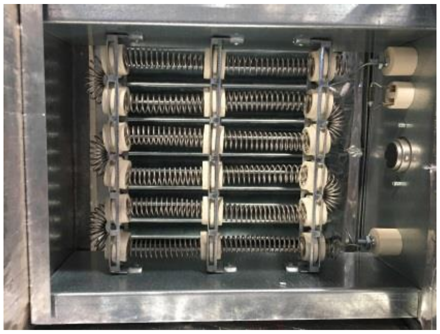


Photo 381 - Slip-in Open-Coil SCR Electric Duct Heater

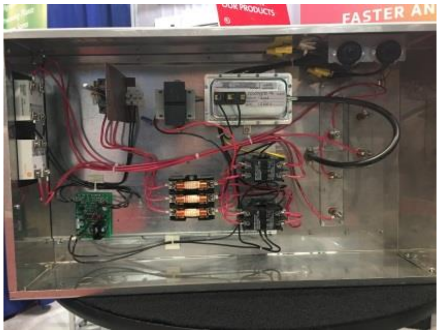


Photo 382 - Typical Control Panel of an SCR Electric Duct Heater

Electric resistance heating coils with SCR allow the heating capacity to modulate from its minimum to its maximum output by control of an analog signal from a BAS controller. It functions very much like a Variable Frequency Drive (VFD) for electrical motors. SCR controlled electric heaters typically have a noticeable heat sink on the outside of the electrical enclosure to dissipate the heat from the controller's transistors. With conventional electric resistance heating coils the entire capacity of each stage is energized when power is applied until the space temperature is satisfied. This type of control results in varying levels of over and undershooting of the space temperature setpoint. However, with SCR electric resistance heating coils, the output capacity is modulated by varying the amount of time that the heater is energized. This form of capacity control saves energy and improves comfort.

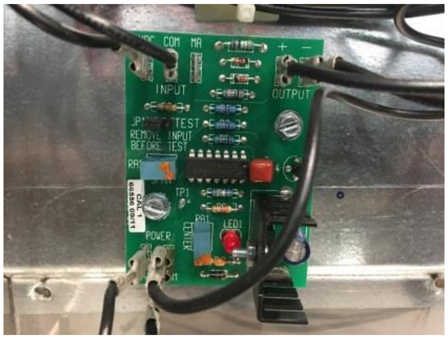


Photo 383 - SCR Control Board


Photo 384 - SCR Transistors

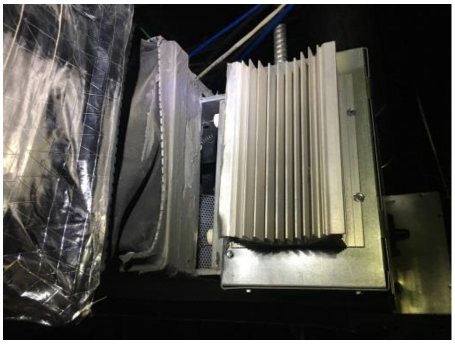


Photo 385 - SCR Heat Sink

SCR controlled electric resistance heaters typically utilize either the Zero Voltage Switching or Phase-Angled Firing to vary the heating capacity of electric resistance heating coils. These are two distinct methods of high-speed electrical switching. Zero voltage switching enables a percentage of the power cycles that occur during the time basis depending on the output command. The heater coil is enabled at the beginning of the waveform where it crosses the voltage axis (zero voltage)-thus the name. Recall that the incoming alternating current waveform is based on 60 Hertz or cycles per second. If the time basis is a half-second (0.5 seconds), then 30 cycles occur during this time. For a 50% output command, the heater coil may be enabled for 15 cycles and disabled for 15 cycles. If the time basis was one second (1.0-Second), then the heater would be enabled for 30 of the 60 cycles for each second. For 75% output, 45 of the 60 cycles are enabled for each second. The following diagram provides a graphical example of an SCR electric resistance heater coil commanded to 50% output as indicated by the waveform that shows the coil is enabled for two complete cycles and is disabled for the following two complete cycles.

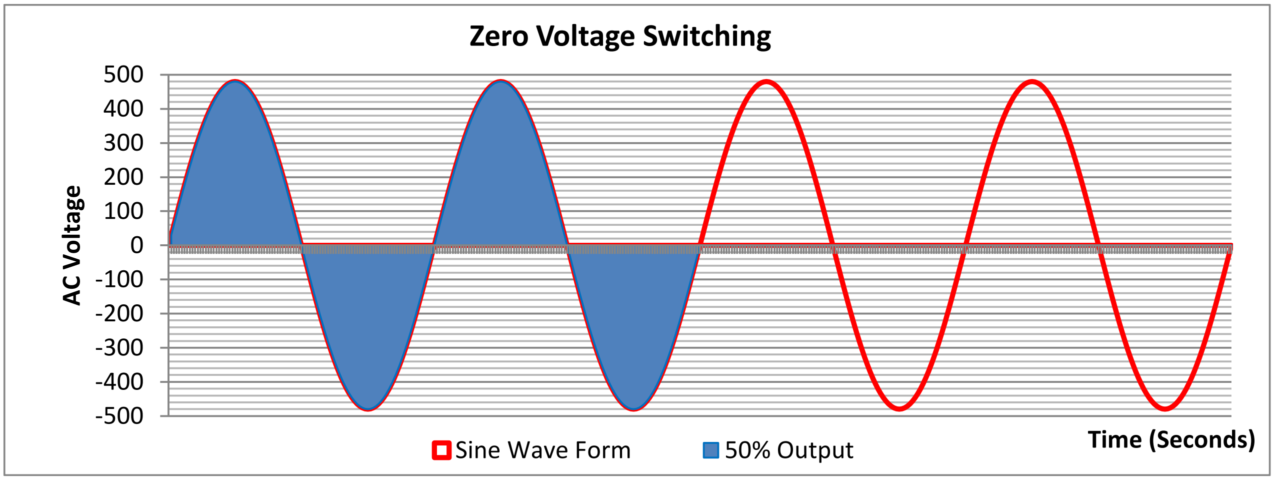


Figure 300 - Zero Voltage Switching Waveform Example

The Phase-angle fired method of capacity control enables the electric resistance heater coil at phase-angles of each half power cycle of the alternating current waveform. Therefore, the electric resistance heater coil is energized with maximum frequency which minimizes thermal stress and maximizes the service life. This form of capacity control delays the enabling of the heater coil until a percentage of each half cycle is achieved. The phase-angle delay is dependent on the required output capacity. At 100% output command, there is no delay and the heater coil is enabled at the beginning of the phase angle (at or near the zero crossing) and is energized for the entire cycle. If the output command were 50%, then the enabling of the heater coil would be delayed until phase angle reaches 50% (90-Degrees) of each half cycle of the waveform. The following diagram provides a graphical example of an SCR electric resistance heater coil commanded to 50% output. If the output command were 25%, then firing of the heater coil would be delayed until phase angle reaches 75% (135-Degrees) of each half cycle of the waveform. This method of capacity control is preferred with low-mass electric resistance heater coils because it ensures that it is energized with maximum frequency which minimizes thermal shock.

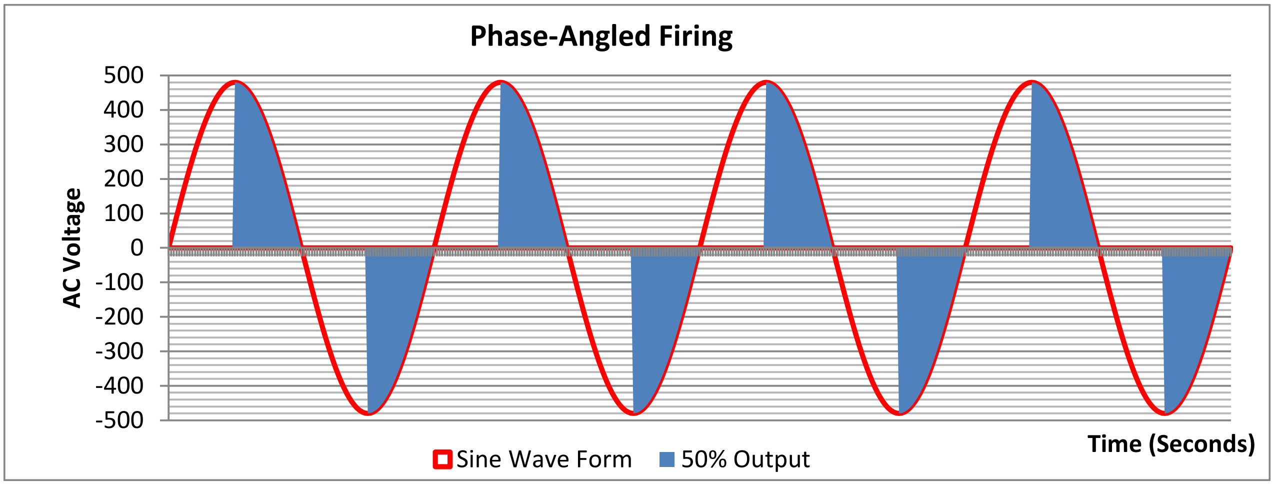


Figure 301 - Phase-Angled Firing Waveform Example

41.2 Applications

1. **Air-Handling Unit Space/Discharge Air Temperature Control**. SCR electric resistance heating coils may be installed in air-handling units or may be duct-mounted to provide heating capacity. The heat output is modulated to control the space or discharge air temperature to setpoint. SCR-controlled electric heating coils are a very good option

when tighter temperature tolerances are required.

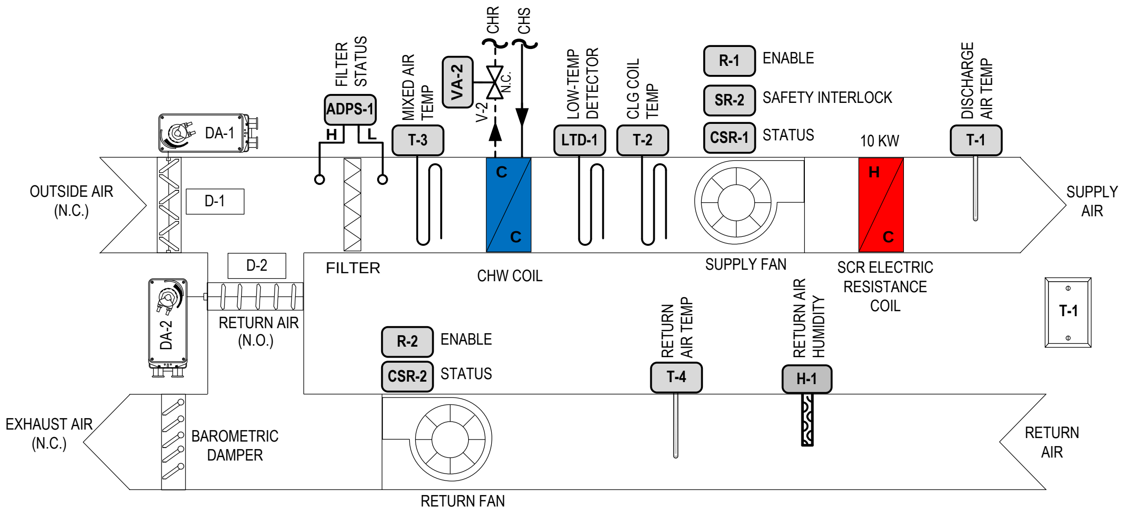


Figure 302 - SCR Electric Heating Coil in an Air-Handling Unit

2. **Terminal Unit Space/Discharge Air Temperature Control**. The following example is a variable-air-volume terminal unit equipped with a single SCR electric heating coil. The primary airflow typically reduces to the minimum airflow setpoint before the heat capacity is energized. The airflow rate at the minimum airflow setting should be verified to ensure that the minimum velocity/airflow rate recommended by the manufacturer is provided to the electric resistance heating coil. Occasionally, the air-proving switch will not make at the low airflow setpoint. This will require an increase in the minimum airflow setpoint until the air-proving switch makes and allows operation of the electric resistance heating circuits.

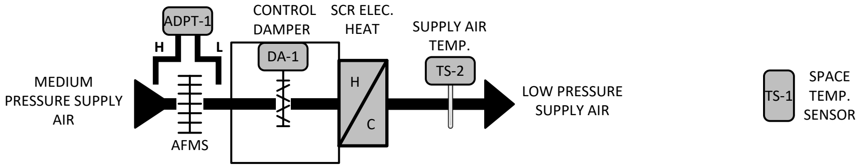


Figure 303 - SCR Electric Heating Coil in a Pressure-Independent Terminal Unit

3. **Supply Duct Reheat Coil**. SCR electric resistance heating coils are often duct-mounted to provide heating capacity for specific rooms and zones. The heat capacity is modulated to control the space temperature to setpoint. These units come in slip-in or flanged designs.

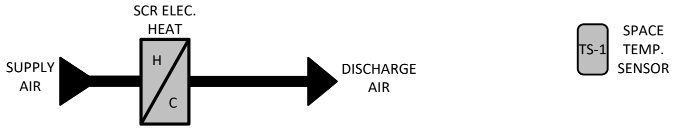


Figure 304 - Duct-Mounted SCR Electric Heating Coil

41.3 Typical Control Wiring

The following diagram is an example of the wiring strategy typically employed with SCR electric heaters. Verify the control signal requirements with the manufacturer.

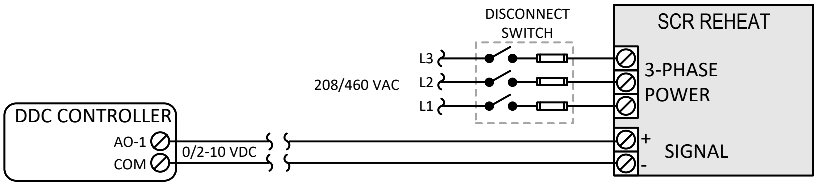


Figure 305 - SCR Controller Wiring (Voltage Control Signal)

41.4 Analog Output Testing and Verification

Testing and verification of SCR electric resistance heaters may pose an electrical hazard because of the potential exposure to high-voltage (120 VAC and higher) electrical conductors. De-energize the electrical power whenever possible. Use the appropriate personal protective equipment to ensure your safety and those around you when access to live electrical enclosures is required. The general test procedures for SCR Electric Resistance Heating Coils include the following:

1. Verify that the SCR electric resistance heater has the capabilities, capacity, and accessories required by the project contract documents (design drawings and specifications) and/or controls submittal. The operating voltage, mounting, wiring requirements contacts, coil type, control signals are some of the features that should be verified.
2. Verify that the airflow through the electric resistance heater has been tested, adjusted, and balanced to the design airflows. Proper airflow is required to fully evaluate the operation and performance of electric resistance heaters. Temperature rise is an important performance metric that must be evaluated, but this evaluation must be based on the correct airflow through the coil. Terminal units may require adjustment of either the airflow setpoint or the air-proving switch setpoint to allow the electric resistance heat to energize.
3. As applicable, posture the HVAC system or the required components to prevent unwanted system changes during the sensor/transmitter calibration. Testing of electric resistance heating coils requires supply air at the design conditions (typically 55°F) and the supply airflow rate at the minimum heating airflow rate. Verify that the supply air temperature is stable. Also, verify that the supply airflow indication is stable with only minimal variation. The resultant temperature rise when the electric resistance heat is energized is dependent on the supply air temperature and airflow being correct. Document these values because they will be used in the following steps.
4. Verify that the SCR electric resistance heater has been installed in the correct or optimum location.
5. Verify that the SCR electric resistance heater has been installed per the manufacturer's installation recommendations. Be sure that slip-in electric resistance heaters are secured to the duct.
6. Verify that the analog output for the SCR electric resistance heater has been correctly wired. The SCR electric resistance heater may have multiple contacts which must be properly landed and coordinated to provide the desired control signal. Verify and document how all hardware interlocks are implemented. Drawings or sketches are typically best for documenting the wiring strategies used.
7. Verify and document how all hardware interlocks associated with the SCR electric heater are implemented. Electric resistance heaters are typically interlocked with a thermal cutout switch (also referred to as a high temperature switch) and airflow proving switch. The thermal cutout switch disables power to the heating elements if its temperature setpoint is exceeded. The airflow proving switch is typically either a sail switch or an air differential pressure switch. The setpoints of these devices are initially set by the factory and should only be tested and adjusted if the field test results indicate that there may be an issue with the current setpoints. Use the manufacturer's instructions when making adjustments. The electric resistance heat must be disabled when the airflow is insufficient because catastrophic damage will result.
8. Verify that the control signal terminals of the SCR electric resistance heater are connected to the correct BAS controller analog output. This step is typically performed by overriding the heater output command and measuring the analog output signal at the BAS controller and the SCR heater signal terminals and by verifying that the SCR heater responds correctly to the analog output signal.
9. Verify that the wires that transmit the analog control signals have been labeled to indicate what data point and what system, equipment, or component it is associated with.
10. Verify that the facets of the analog output signal that controls the SCR electric resistance heater are correctly displayed. Electric resistance heaters with modulating output use "%" or "% Output" as the facets.
11. Verify that the precision of the analog output reading for the SCR electric resistance heater is appropriately set. Setpoints should be whole numbers and the precision of the heater output command should be no more than one decimal place for most applications.
12. Review the current configuration of the BAS controller's analog output control signal. This is required because the initial control signal range may be incorrectly set.

	Output (%)	Volts (VDC)
Minimum	0	2
Maximum	100	10

Table 185 - Initial Analog Input Configuration

If the output configuration is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs.

Volts (DCV)	% Output
2	0
10	100

Calculated Scale= 12.5000
Calculated Offset= -25.00

Table 186 - Initial Scale-Offset Calculation for Analog Output Configuration

13. Verify that the BAS controller's analog output point has been properly configured to transmit the commanded SCR electric resistance heater output. This data is typically provided on the nameplate or in the equipment submittals. In this example, the electric resistance heater was determined to require a 0-10 VDC signal instead of the 2-10 VDC signal range that was initially programmed.

	Output (%)	Volts (VDC)
Minimum	0	0
Maximum	100	10

Table 187 - Final Analog Input Configuration

If the output configuration is based on scale and offset factors, calculate them as explained in Chapter 3: BAS Inputs and Outputs.

Volts (DCV)	% Output
0	0
10.00	100

Calculated Scale= 10.00
Calculated Offset= 0.00

Table 188 - Updated Scale-Offset Calculation for Analog Output Configuration

14. Override the output signal to 0%, 25%, 50%, 75%, and 100% and verify that the SCR electric resistance heater assumes the commanded output. If it does not function as commanded, review the configuration of the analog output, the wiring, and terminals of the electric resistance heater. At each increment of commanded output, record the control signal (VDC), discharge air temperature, heater voltage, and heater amperage at the terminals of the electric resistance heater. This step verifies that the voltage and amperage readings are within the manufacturer's specifications. The voltage and amperage measurements are typically taken on the line side of the SCR controller. The following table is based on a 15 KW SCR electric heater with a flow of 2,400 CFM.

Field Measurements							
Output	**Command Signal (VDC)**	**Discharge Temp. Rise (°F)**	**Voltage by Phase (VAC)**	**Current by Phase (Amps)**	**Total Current (Amps)**	**Output Power (KW)**	**Thermal Output (MBH)**
0%	0.0	0	476/474/475	0/0.1/0	0.1	0	0
25%	2.5	4.9	476/474/475	4.5/4.6/4.7	4.6	3.8	12.7
50%	5.0	9.9	476/474/475	9.0/9.1/9.0	9.1	7.5	25.7
75%	7.5	14.8	476/474/475	13.6/13.5/13.6	13.6	11.2	38.4
100%	10.0	19.2	476/474/475	18.2/18.3/18.2	18.2	14.9	49.8

Table 189 - Electric Resistance Heater Performance

If the electric resistance heater voltage and/or amperage readings do not match the manufacturer's rating, have a qualified electrician review and verify that the wiring, connections, switches, contactors, etc. are properly installed and that the electrical power supplying the electric heaters are at the proper voltage and current. The furthest supply air diffuser typically provides the most representative reference temperature reading because it will be fully mixed. This data may be documented in a table similar to that shown in the above table. Equipment summary screens (Figure 8) and overrides of the heating command are very effective at reducing the time required to test SCR electric heaters when there are large quantities to test and calibrate. If the discharge air temperature exceeds ~20˚F of the desired space temperature, consider adding maximum discharge air temperature limits in the control logic.

15. As the BAS controller analog output is overridden, verify and document that the corresponding data point bound to the BAS graphics also changes as the SCR electric heater output changes. Also, verify that the analog output data points bound to the graphic change color to indicate that they have been overridden. The color change provides a visual notification on the BAS graphics that this point has been overridden. While the analog output is overridden, the programmed control logic no longer controls the analog output and they will remain in the overridden state until

the overrides are released.

16. Using the analog output field bound to the BAS graphics (not the analog output data point) verify that the SCR electric heater output changes on command. Override the analog output data point to other values and verify that the SCR electric heater follows the commanded outputs. Also, verify that the BAS graphic provides a visual indication that this analog output point is currently overridden.
17. If the status of the SCR electric heater is monitored by a status monitoring device (current-sensing relay, current transmitter, or discharge temperature sensor), this is an ideal time to test and adjust that device as well.
18. Release all overrides used to posture the system for testing and calibration.
19. Verify control of the SCR electric heater over time by reviewing trend data. Numeric interval trend extensions are used to collect trend data at the programmed time intervals. If the analog output can be verified by monitoring other sensors (discharge air or space temperature), trend those points as well. For example, if an air-handling unit SCR heater coil output is trended, also trend the electric resistance heater current. Trending the output command only does not confirm that the command was followed.
20. Document the results of all testing. Screenshots of the analog output point data as well as the BAS graphics are useful for documenting the ability of the BAS to control the analog output device.

41.5 Review

1. True or False: The control signal of terminal unit electric resistance heating elements should be limited to prevent the discharge temperature from exceeding 90°F-95°F to prevent temperature stratification. Answer: ________
2. ____________________ switching controls the percentage of cycles within the time base in which the heater coil is enabled based on the heater output command signal.
3. ____________________ are preferred for low-mass electric resistance heating coils because its operation minimizes thermal shock.
4. SCR electric heaters utilize ____________________ to switch the heater on and off at high speeds.
5. If the output command were 25%, then firing of the heater coil would be delayed until phase angle reaches 75% or ____________Degrees of each half cycle of the waveform.

41.6 References

1. https://www.avatarinstruments.com/wp-content/uploads/2015/08/Understanding-SCRs-by-Paul-Evalds-President-Avatar-Instruments.pdf
2. https://ccipower.com/sites/default/files/what_you_should_know.pdf
3. https://www.chromalox.com/-/media/files/training-manuals/en-us/tm-pk501-scr-power.pdf

Section 6: Miscellaneous

Chapter 42 - Variable Frequency Drives

42.1 Description

Variable Frequency Drives (VFDs) are electrical appliances that allow the speed of induction motors to be modulated by controlling the frequency and voltage supplied to the motor. VFDs are also referred to as Variable Speed Drives (VSD), Adjustable Speed Drives (ASDs), or simply "Drives." VFDs are typically used in variable-flow systems (air, water, refrigerant) because the speed of the induction motors driving the fans, pumps, and compressors is constantly varying. They are also used in constant-flow applications for soft starting as well as for system balancing.

Photo 386 - Cooling Tower Fan Speed Control

Photo 387 - Dual-Temperature Pump Speed Control

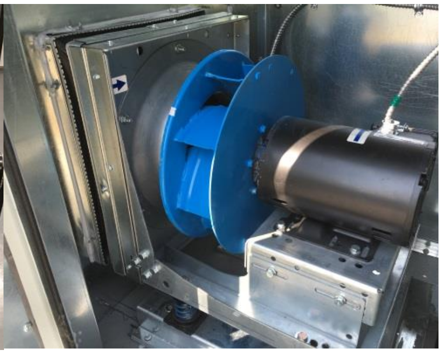


Photo 388 - Direct Drive Supply Fan Speed Control

Speed modulation in electrical motors provides the opportunity to significantly reduce electrical consumption and operating costs. VFDs also substantially reduce mechanical stresses on the driven system components (fan, pump, compressor, belts, sheaves, couplings, drives, bearings, gears, etc.) because of the gradual ramp up to normal speeds and reduced operating speeds. The cost of VFDs used to be very high compared to motor-starters, but their expanding use and increasing number of suppliers have brought the costs down substantially. As a result, they are very widely used today. The following table below provides a summary of common applications of VFDs in typical HVAC systems.

System	Controlled Component	VFD Modulates	Controlled Variable
Air-handling Unit	Supply Fan	Fan Speed	Supply Duct Static Pressure
Air-handling Unit	Return Fan	Fan Speed	Supply Fan speed Signal Tracking
Air-handling Unit	Return Fan	Fan Speed	Return Fan Flow (Fan Tracking)
Air-handling Unit	Supply Fan	Fan Speed	Space Temperature
Exhaust	Exhaust Fan	Fan Speed	Exhaust Duct Static Pressure
Air-handling Unit	Compressor	Compressor Speed	Head Pressure
Chilled Water	Pump	Pump Speed	Differential Pressure
Hot Water	Pump	Pump Speed	Differential Pressure
Condenser Water	Pump	Pump Speed	Differential Pressure
Air-Cooled Chiller	Compressor	Compressor Speed	Chilled Water Supply Temperature
Water-Cooled Chiller	Compressor	Compressor Speed	Chilled Water Supply Temperature
Condensing Unit	Condenser Fans	Fan Speed	Head Pressure
Condenser Water	Cooling Tower Fan	Fan Speed	Condenser Water Supply Temp.

Table 190 - Typical HVAC VFD Applications

VFDs use various electrical components (transistors, capacitors, diodes, etc.) which allow the voltage and frequency of the outgoing power to be controlled by a remote speed signal. The description that follows summarizes the traditional VFD concept that uses rectifiers, capacitors, and inverters to provide speed control. Incoming 60 Hertz three-phase power first enters the rectifier which converts Alternating Current (AC) to Direct Current (DC) through the use of diodes which only allow current flow in only one direction. The arrangement of the diodes flips the negative portion of the current waveform to the top producing a rough direct current profile. This newly constituted direct current passes through filters and capacitors that clean and smooth this waveform. The clean direct current then enters the inverter which uses Insulated Gate Bipolar Transistors (IGBTs) to reproduce the AC waveform in the required voltage and frequency. IGBTs are high-speed switches that open and close using Pulse Width Modulation (PWM) to simulate the AC current waveform at the frequency required by the load. The BAS controller provides a speed setpoint through a 0/2-10 VDC signal which the VFD interprets through its configuration and adjusts the PWM to provide the requested speed command in terms of Hertz.

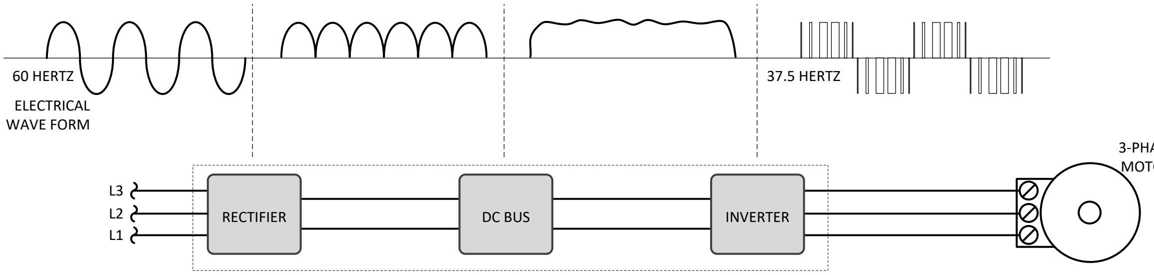


Figure 306 - VFD Power Conversion Concept (Single Phase Waveform Shown)

Manufacturers are always pushing the design envelope of VFDs to make them more efficient and to correct their only disadvantage – Harmonics. Harmonics are not a problem for the VFD, but they can produce a variety of issues with the driven induction motor (if not designed for VFDs) and electrical system to which the VFD is connected. Harmonics are caused by current pulses in the rectifier and DC bus. Harmonics are distorted signals that lower the efficiency of the electrical system. Yaskawa has developed the revolutionary Matrix VFD design that directly converts the 60 Hertz AC power to the required frequency without ever converting it to DC power. It uses an array or "matrix" of nine bi-directional IGBTs to directly convert the 60 Hertz power to the frequency required by the load through PWM. This vastly simplifies the design, reduces the VFD power requirement, allows much smaller VFD enclosure sizes, and drastically reduces harmonics.

Unlike most other analog input and output devices which require a single set of two or three conductor wires to connect them to the BAS controller, VFDs typically require several sets of wires. Chillers, boilers, humidifiers, electric resistance heaters, and space sensors (with optional occupancy override and setpoint adjustment) may also require multiple input/output points depending on project requirements. VFDs are typically provided with at least the following hard-wire control points: Start/Stop (BO), Speed Command (AO), Operating Status (BI), and VFD Fault status (BI). Several other parameters could also be monitored (amps, speed feedback, voltage, power, etc.), but these are typically the minimum data points that most projects require. VFDs have configurable outputs that can be modified to provide a variety of additional binary and analog feedback signals.

Photo 389 - Yaskawa VFD User Interface

Photo 390 - ABB VFD User Interface

Photo 391 - Danfoss VFD User Interface

VFDs typically have multiple terminal boards and options, so having the correct documentation is critical to landing the control and monitoring wires correctly. The VFD terminals are only labeled with numbers, so knowing the terminal assignments is the key to successfully controlling and monitoring a VFD. When a VFD has the bypass option this adds another level of difficulty to the task because additional terminals are available. Even with the necessary documentation, it can be difficult to get the VFD configured to accept and properly use the control signals. As with any input or output device, the inputs and outputs of the VFD must be configured to match the signals provided and received by the BAS controller. The speed reference signal is typically a 0-10 VDC and the polarity must be correct or the VFD will not increase beyond its programmed minimum speed.

It is worth noting that the "VFD status" contacts of the VFD indicate the VFD's operating status, not the operating status of the driven pump, fan, or compressor. These are not the same data points. We are typically more interested monitoring the operating status of the driven load. If the coupling or belt that connects the induction motor to the fan, pump, or compressor were to fail, the BAS would continue to receive the positive VFD operating status. Typically, a separate input device (air differential pressure switch, flow switch, current sensing relay, current transmitter, etc.) is used to monitor the operating status of the driven load. It is common to see a separate current sensing relay installed either on the load side or the line side of the VFD power conductors.

The unit described above is an example of a VFD with hard-wired control and monitoring points. Each point has a set (2 or 3) of wires that conducts specific control and monitoring data to/from the BAS controller. VFDs typically have an option to communicate their operating and control data through a physical communication link like RS-485 or Ethernet. BACnet, Lon, or Modbus protocols may be utilized to communicate data to and from the VFD. If a VFD communicates with the BACnet protocol, then its wiring must fully and completely conform to the BACnet specifications. It also requires that the VFD be in constant communication with the BAS supervisory controller (JACE). If this communication bus is ever broken, then the control signals provided by the BAS controller and the feedback data signals provided by the VFD will be lost. It's all or nothing with VFD integrations. Communication issues and unexplained behaviors seem to be typical of integrated equipment. VFD integrations also reduce the ability of the local building staff to test and troubleshoot VFDs when there is a communication or operational issue. The optimal VFD configuration for long-term stability, local troubleshooting, and reliability is to utilize hard-wired control and monitoring points through the BAS controller and have the integrated VFD data available as supplemental information – not primary control.

We must also be aware of how a VFD functions, so that the correct CSR or current transmitter is selected and it is properly located to provide the required status or load indications. On the line-side (upstream) of the VFD, voltage and frequency remain constant while the current varies proportionally with changes in load/operating speed in a very predictable fashion. Therefore, a current transmitter on the line side of the VFD would provide a good indication of operating load. On the load-side (downstream) of the VFD, voltage, frequency, and current are changing due to the operation of the VFD. The voltage supplied to the motor is proportional to the operating speed. The current flow is inversely proportional to the voltage at a given power output. Therefore, current is not proportional to the load/operating speed on the load-side of the VFD. A current sensing relay is able to provide an operating status indication on either the line-side or load-side of the VFD. The following table summarizes the characteristics of the voltage, frequency, and current signals on the line-side and load-side of VFD. The final installed location depends on the choice of status monitoring device. Review the Chapter 11: Current Sensing Relays (BI) and Chapter 23: Current Transmitters for more information.

Parameter	VFD	
	Line-Side	Load-Side
Voltage (VAC)	Constant	Varies with Load
Frequency (Hertz)	Constant	Varies with Load
Current (Amps)	Varies with Load	Varies with Voltage

Table 191 - Line-Side/Load-Side Characteristics of Motor starters and VFDs

VFDs have internal and external faults that disable its operation should a fault condition be detected. VFDs monitor many performance parameters which indicate various fault conditions (Over/under-voltage, Over-current, VFD High Temperature, Phase Loss, Back-EMF, Ground fault, Motor Overload, etc.) which, if left undetected, could catastrophically damage the VFD and/or driven motor. These are examples of internal conditions that may generate internal VFD faults. VFDs are typically equipped with a set of contacts that are dedicated to electrically interlocking external safety devices (Low-temperature detectors, smoke detectors, fire alarm relay modules, etc.) to the VFD. As long as the status indications of the included safety devices are normal, the interlocking safety relay contacts will be closed and electrically continuous allowing the VFD to operate. Should the status of the external safety devices change to the alarm state, the status contacts open thereby disabling the VFD until the safety devices are restored to their normal status. At the same time, the BAS controller will detect the change in status through the VFD fault status contacts. This is an example of an external fault implemented by hard-wired interlocking (no BAS input). Photographs 391 and 393 show actual External Faults. Safety devices are typically interlocked to these VFD safety contacts either directly or indirectly through an interlocking safety relay. Refer to Chapter 6: Wiring Practices for Safety Devices for more information. When internal or external fault conditions are detected, the VFD is disabled and it displays the appropriate fault code on its user interface. To interpret the fault code displayed by the VFD, its operating manual must be reviewed. It is recommended that the VFD manual be kept either at the VFD in a water-proof bag or folder or nearby in a safe, dry, and accessible location. To restore normal VFD functions after fault activation, it must either be reset or its power cycled depending on the VFD manufacturer and its settings.

Photo 392 - ABB VFD External Fault Code

Photo 393 - ABB VFD Overcurrent Fault Code

Photo 394 - Yaskawa External Fault Code

There are two types of binary signals that disable a VFD. The first is the fault (internal and external) condition that was discussed in the previous paragraph. The run-permissive signal is implemented through two contacts on the VFD terminal board that monitor for continuity and may be labeled as "Enable" depending on the VFD manufacturer. When there is continuity across these terminals, it allows or enables the VFD to operate. This signal typically will not cause a fault or alarm notification or disabling of the VFD operation. A position feedback switch or auxiliary contacts of an electric actuator for a smoke isolation damper might provide a run-permissive signal for a VFD. These contacts would typically prove that the smoke isolation dampers are fully open before allowing the VFD to energize. If the dampers ever fail to prove their wide-open status, the VFD will be disabled. If there are no smoke dampers or other devices providing the run-permissive signal, a jumper wire is installed across these contacts.

VFDs with the bypass option present a challenge when utilized on air-handling units. VFDs are typically connected to the BAS with hard-wired connections to enable, control its speed, monitor its operating status, and monitor its faults. The VFD is typically interlocked with the status of the safety devices either directly or indirectly through the fan safety alarm circuit. When the VFD is set to bypass mode, the safety device status may not disable the fan motor. Therefore, should a smoke detector or low-temperature detector activate, the supply fan will continue to operate. The safety devices should always disable the supply fan whether it is operating through the VFD or the bypass. To avoid this issue, it is recommended that the VFD manufacturer be required to wire the VFD and bypass motor starter to disable if a common safety status circuit indicates an alarm condition with any of the included external safety devices. Alternatively, an additional safety interlock relay can be installed in the bypass contactor control circuit to disable it should a safety device activate.

Electrical induction motors are equipped with an integral fan that provides cooling of the motor windings. A minimum operating speed is required to provide adequate cooling. Extensive low-speed operation can significantly shorten the motor life because of insulation failure by overheating. The minimum VFD operating speed setpoint is typically set between 12 Hertz and 15 Hertz. The motor manufacturer should be consulted to determine the appropriate minimum motor operating speed. Whatever the minimum VFD operating speed setting, it is recommended that the Controls Contractor configure the PID loop that controls the VFD speed to have a minimum output signal (30% for example) that is higher than the VFD minimum speed setting to avoid motor damage and maximize its service life.

Until recent years, the maximum VFD speeds in most HVAC applications had typically been 60 Hertz. Operating the VFD at 60 Hertz typically meant that the motor was operating at its maximum nameplate speed. It is becoming more and more typical to see VFDs operating above the 60 Hertz threshold. For example, airflow readings of a direct-drive Dedicated Outside Air Supply (DOAS) unit were found to be well below the design airflow rate while operating at 60 Hertz. When the manufacturer of the DOAS units was consulted, they advised that the VFD speed needed to be increased beyond 60 Hertz to achieve the required airflow. The maximum speed of the supply fan was increased to 92 Hertz to achieve the required supply airflow rate. Therefore, the supply fan motor with a nameplate operating speed of 1,750 RPM was operating at a speed of 2,718 RPM while still operating below the nameplate amperage rating. This exemplifies the ever-changing VFD and motor technology that keeps us all on our toes. The jury is still out on the long-term effect that operation beyond the nameplate motor speed rating will have on its motor life. Operation beyond 60 Hertz should be confirmed with the equipment manufacturer to avoid any issues with warranties.

There is often confusion on construction sites when it comes to the setup and configuration of VFDs. Typically, when an air-handling unit is factory-assembled and shipped to the job site, the VFD settings typically have been preconfigured. However, there are always exceptions. Whoever provided and installed the VFD or the equipment which contains the VFD is typically responsible for ensuring that the VFDs parameters are properly set. The Controls Contractor must then review the VFD, its configuration, its documentation, contract documents, and the controls submittal to determine how it should be monitored, controlled, and interlocked. VFDs may require hard-wired control wiring and conduit, communication bus wiring, or both depending on the required control and wiring strategy. Most Control Technicians are familiar with accessing and reviewing the VFD control parameters because they are often required to do so to verify the control signal range and other settings. In addition, they typically will be familiar with the wiring conventions of the most frequently encountered VFDs.

Reading	Typical Range	
	Minimum	Maximum
Motor HP	Motor Nameplate	
Motor Voltage	Motor Nameplate	
Motor FLA	Motor Nameplate	
Motor RPM	Motor Nameplate	
Motor Frequency (Hertz)	Motor Nameplate	
Speed Reference Signal (VDC)	0 or 2	10
Minimum Speed/Frequency	12 -15 Hertz	60 Hertz or Higher
Maximum Speed/Frequency	Determined by TAB Contractor	
Acceleration Time (Seconds)	30	120
Deceleration Time (Seconds)	30	120

Table 192 - Typical Configuration of VFDs for HVAC Applications

42.2 Typical Control Wiring

The control wiring strategy employed for VFDs depends on whether the VFD control and monitoring points are hard-wired or established through integration with the VFD. Figure 307 shows a typical VFD wiring schematic that shows the various hard-wired connections. Each set of terminals provide a specific piece of information. Isolation relays are typically located at the VFD. One is used to enable the VFD through the BAS controller's binary output. The other isolation relay is used to interlock the status of the fan safety alarm circuit or safety device to the operation of the VFD. The VFD provides a status point, but it is important to realize that this is a "VFD Status" point that indicates that the VFD is operational, not that the driven fan, pump, or compressor is operational. A separate CSR or current transmitter is used to provide the operational status of the driven equipment.

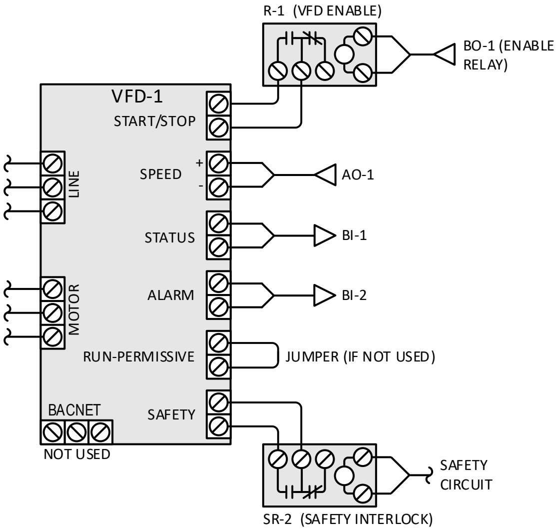


Figure 307 - Typical Hard-Wired VFD Connections

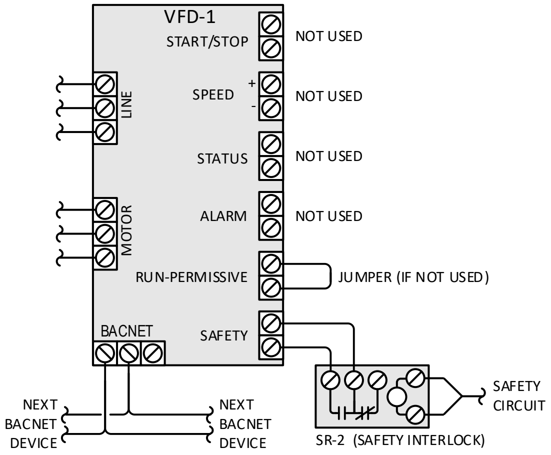


Figure 308 - Typical Integrated VFD Connections

Figure 308 illustrates the same VFD, but this one communicates its control and monitoring data through the BACnet protocol over the MS/TP (Master-Slave/Token-Passing) data link. Once the BACnet link is established, a list of BACnet points is provided. After the points are selected, they are added to the list of proxy points which are constantly updated with live data. **Writable** points are those which can be overwritten through the BAS and **Readable** points can only be read and not changed. The enable and speed commands are writable. Monitoring points (status, alarms, faults, amps, speed, etc.) are not writable. The logic that controls the enabling and speed of the VFD is linked to the proxy points and the VFD follows those commands as long as the communication bus is operational. The VFD must be configured so that it uses either the hard-wired data or the integrated data points for control. Conflicts typically arise when the control source is not clearly defined. In many installations, the VFDs are controlled by hard-wired connections to BAS controllers and supplemented with the wealth of operating data provided by the integration.

When a fan, pump, or compressor is driven by an integrated VFD, that operating status may be derived through logic rather than a hardware (CSR or current transmitter). Through control logic, comparisons of select VFD data points (current, speed, VFD status, output voltage, etc.) to field determined values may be used to determine the equipment operating status. This operating status indication is only valid while the communication trunk is functioning properly. If the motor drives equipment equipped with a belt, detection of operating status will be a bit more challenging. There are many strategies for monitoring operating status. Some Control Contractors monitor the current flow with a current transmitter and BAS controller to have a status indication whether the motor is driven by the VFD or the bypass.

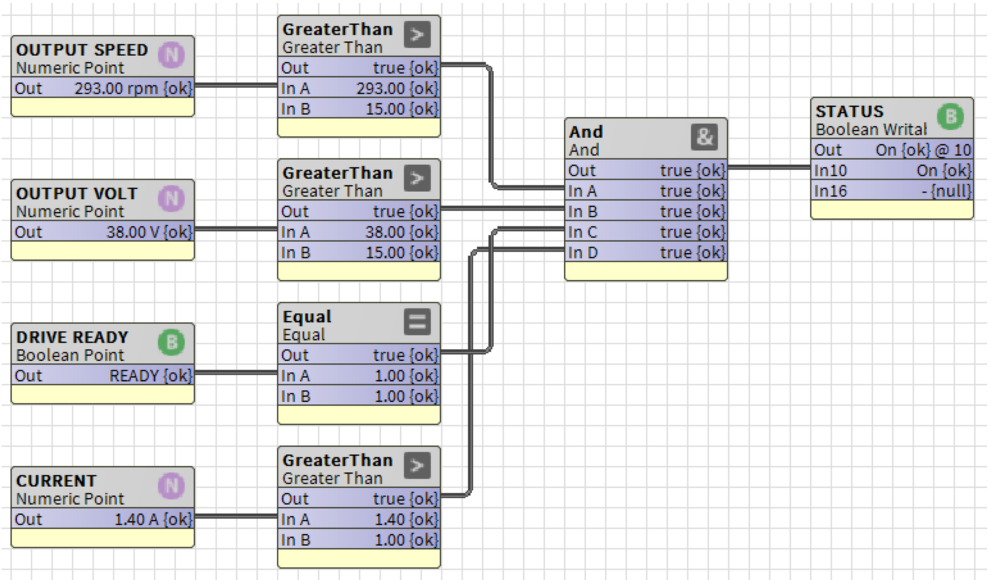


Figure 309 - Fan Status Logic for an Integrated VFD

42.3 VFD Testing and Verification

Testing and verification of VFDs may pose an electrical hazard because of the potential exposure to high-voltage (120 VAC and higher) electrical conductors and capacitors. De-energize the electrical power whenever possible. Use the appropriate personal protective equipment to ensure your safety and those around you when access to live electrical enclosures is required.

One of the first things you will want to verify is that the VFD is properly sized. This will require a comparison between the VFD capacity and the ratings of driven load. Next, the VFD configuration is reviewed to verify that the correct parameters have been entered. Typically, the installing contractor would have started the VFD and verified the programmed settings. If they are not correctly entered, the VFD may not function at all or may function incorrectly. The programmed settings are typically reviewed by the Controls Contractor to ensure that the signals received by and sent from the VFD are properly configured.

After the ratings of the VFD are verified, we then check that the driven motor turns in the correct direction. A fan or pump turning in the wrong direction will have no chance of reaching its design capacity. A bump test is typically performed to determine the direction it is currently configured to turn. The manual operating mode is selected and the speed command is ramped up to get the motor turning. Observe the motor shaft or the driven fan or pump to determine the current direction of spin. If it turns in the wrong direction, it is typically easiest to change any two of the line-side or load-side electrical leads. De-energize the power before performing this step. This will reverse the direction in which the motor turns. Some VFDs have internal software switches that provide this same function. The motor rotation should also be verified while the VFD operates in the Automatic mode.

VFD testing and verification are quite different from most BAS input/output devices because VFDs typically require several control and monitoring points. VFDs are remotely enabled and disabled through a binary output from a BAS controller. Their speed is modulated by a remote speed reference signal (analog output) provided by a BAS controller. It is also possible that the VFD operates in a constant-volume air or hydronic system. Therefore, it has no speed reference signal and is used as a soft-starter providing a smooth ramp up to full speed. This precludes the stresses, noise, and high inrush currents of typical across-the-line starts. When it comes to setting the total airflow, it is much easier to change the maximum speed of the VFD than to change the pitch of adjustable sheaves or replace sheaves and belts. The Owners and operators typically want to know that the driven fan, pump, or compressor is functional, so a separate status monitoring device such as a CSR, current transmitter, ADPS, or ADPT is typically utilized to provide operating status indications. VFD faults may also be monitored by the BAS so that the operator knows why the VFD is not operating.

In addition to the control and monitoring points mentioned above, there are a plethora of optional data points which could also be specified by your project's construction documents. To avoid unnecessary repetition of testing and verification procedures and to utilize to the fullest potential the testing and verification protocols already described in previous chapters, the following table has been provided. These reference testing and verification procedures may not exactly match the VFD, but they provide a firm base from which to test the VFD functions.

VFD Point	Chapter	Chapter Description
VFD Status (BI)	11	Current Sensing Relays
VFD Fault/Alarm Status (BI)	11	Current Sensing Relays
Current Feedback (AI)	23	Current Transmitters
Enable (BO)	32	Equipment Remote Enable
Speed Command (AO)	36	Equipment Setpoint/Capacity Adjustment

Table 193 - VFD Testing and Verification Reference

42.4 Review

1. True or False: VFDs that have been integrated to the BAS through BACnet use the same number of wires as a hard-wired VFD. Answer: ________
2. In a cooling tower, the __________________ speed is modulated to maintain the condenser water supply temperature at setpoint.
3. __________________ are generated by the VFDs and can cause power efficiency issues in the building electrical system where it is installed.
4. The DC power enters the inverter which uses ______________________________ to reproduce the AC power in the required frequency.
5. Low-temperature detectors, smoke detectors, high-static safety switches, etc. of air-handling units are typically interlocked with the ___________________ contacts of the VFD.
6. Yaskawa produces a revolutionary VFD called the ____________________ which provides variable speed motor operation with very low levels of harmonics.

42.5 References

4. https://www.yaskawa.com/
5. https://new.abb.com/drives
6. https://www.danfoss.com/en-us/about-danfoss/our-businesses/drives/
7. https://www.eaton.com/us/en-us/products/controls-drives-automation-sensors/variable-frequency-drives/variable-frequency-drives.html
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9. https://dam-assets.fluke.com/s3fs-public/3850210_6003_ENG_B_W.PDF

Chapter 43 - Answers to Review Questions

43.1 Chapter 1

1. Mechanical Contractor
2. Java Application and Control Engine
3. State Table
4. Summary screen
5. True
6. Input and Output Modules
7. False
8. Lowest first cost

43.2 Chapter 2

1. Characteristic Curve
2. Parallel
3. Span
4. False
5. Accuracy
6. Slope
7. Error
8. 39.8 PSIG to 40.2 PSIG
9. 24.5 PSIG to 25.5 PSIG
10. Calibration
11. Nonlinear
12. False
13. 77.0°F
14. Reset Schedules
15. Design Error
16. Selection Error

43.3 Chapter 3

1. PID Loops
2. Local Control Panel (LCP)
3. Binary
4. Isolation Relays
5. Binary Triac
6. Floating
7. Loop-Powered
8. Reverse
9. 1 VDC and 5 VDC
10. 80%

43.4 Chapter 4

1. Facets
2. Signal Generator
3. Input and Output Devices
4. Decade Resistance Box or Variable Resistor
5. Red
6. Zero
7. One
8. False
9. False
10. True

43.5 Chapter 5

1. Electromagnet
2. Relay in a Box
3. Heaters
4. Auxiliary
5. Hand
6. Relay Logic Diagrams or Ladder Diagrams

43.6 Chapter 6

1. Normally-Closed
2. Four (One per safety device and one master)
3. Two
4. False
5. True
6. BACnet
7. C. Electrical Multimeter
8. E. All of the above.

43.7 Chapter 7

1. 15 PSIG
2. Six
3. Four

4. De-energized
5. Ground Fault Current Interrupter
6. Wire Pig Tail
7. True
8. True

43.8 Chapter 8

1. True
2. False
3. True
4. B. Downstream of the pre-heat coil
5. False
6. 96 (12x8x1)

43.9 Chapter 9

1. True
2. True
3. Light Scattering
4. True
5. Fan Safety Alarm Circuit (FSAC)
6. Relay Module
7. 2000 CFM
8. D. All of the above

43.10 Chapter 10

1. False. It is typically located at the entrance
2. Fan Safety Alarm Circuit
3. 90A
4. Isolation Relays
5. Cover
6. B. Normally closed

43.11 Chapter 11

1. Adjustable
2. True
3. False
4. Status Alarms
5. True
6. No-load and Normal-load
7. 41.2 Amps (@80%)
8. False
9. True
10. D (B and C)
11. 15 (5/0.35+1)
12. B. Load is de-energized
13. D. A and B
14. PPE

43.12 Chapter 12

1. True
2. Binary
3. False
4. False
5. True
6. Clean/Dirty
7. Probes or Pickups
8. Fan Safety Alarm Circuit (FSAC)

43.13 Chapter 13

1. False
2. Five
3. False (Both are required for differential pressure monitoring)
4. Isolation relay
5. Isolation valves
6. Calibration pump

43.14 Chapter 14

1. Ultrasonic
2. False
3. Bushing
4. Low-flow
5. Two
6. D. All of the above

43.15 Chapter 15

1. Ultrasonic
2. Heat
3. Dual-Technology
4. Change-of-State
5. Doppler

43.16 Chapter 16

1. Closed/Opened
2. True
3. Enable
4. Binary

43.17 Chapter 17

1. True
2. Gravity
3. True (Depending on contact ratings)
4. Supply Fan
5. Open

43.18 Chapter 18

1. False
2. True
3. True
4. Electricity
5. False
6. Mineral Deposits

43.19 Chapter 19

1. A. Negative
2. Calibration
3. Coanda
4. C. Within
5. E. All of the above
6. False
7. False
8. Temperature Stratification
9. North
10. 2 ([5x4x1]/12 = 1.7)
11. D. All of the Above
12. D. Both 2 & 3

43.20 Chapter 20

1. Space Temperature Sensors
2. Resistance
3. Scale= 0.002 °F/Ohm Offset=59°F
4. Low or No
5. D. None

43.21 Chapter 21

1. False. Immersion provides better temperature indication.
2. Drain
3. True
4. Thermal Conductive Paste
5. Pressure/Temperature (P/T) Ports
6. B. Well downstream of the mixing point

43.22 Chapter 22

1. Sunlight
2. False. It will be lower
3. Scale= 12.5 %RH/VDC Offset= -25 %RH
4. 40%RH and 60 %RH

43.23 Chapter 23

1. Split-core
2. C. Equal
3. Line-side
4. Current Switch (Current Sensing Relay)
5. E. Both B and D
6. C. Drops to the NLA
7. B. Two
8. Scale= 25 Amps/VDC Offset= 0 Amps

43.24 Chapter 24

1. False. It decreases installation costs. There are fewer wire runs down the wall, fewer holes in the wall.
2. True
3. Rural
4. 62.1 (Ventilation for Indoor Air Quality-Commercial)
5. 2000
6. 350-450 PPM

43.25 Chapter 25

1. False
2. True
3. B. Outside air condition
4. B. Outside air condition
5. 2.03 Inches W.C.

6. Inches W.C.
7. Probes or Pickups
8. Positive

43.26 Chapter 26

1. False
2. C. 2/3 to 3 /4 don the longest pipe run
3. 27.88 PSIG
4. Condenser Water
5. Scale= 6.25 PSIG/VDC Offset= -12.5 PSIG
6. Conduction
7. Bypass Valve
8. 500 FT (216.55 PSIG*2.31FT HD/PSIG)

43.27 Chapter 27

1. 4,005 FPM
2. False. The VAV controller will not read the true velocity pressure without the caps.
3. False. The tubing connections affect the sensed velocity pressure.
4. Turbulence
5. Straighteners

43.28 Chapter 28

1. K-factor
2. False
3. Low-flow hunting
4. False
5. True
6. B. Hard Duct Extension
7. B. Turbulence

43.29 Chapter 29

1. Gain and Offset
2. Temperature
3. False
4. D. All of the above
5. Power
6. B. Equal to

43.30 Chapter 30

1. False
2. True
3. Pulsed
4. B. Turbine
5. Deduct
6. Energy

43.31 Chapter 31

1. 35.63% Open
2. B

43.32 Chapter 32

1. False
2. RIBU1C
3. LED
4. RIB relay
5. 2
6. Normally closed

43.33 Chapter 33

1. Inrush current
2. Ladder logic diagram
3. Thermal overloads
4. D. All of the above
5. 24 VAC
6. 15
7. RIBU1C
8. B. Not recommended

43.34 Chapter 34

1. False. They can be flipped.
2. B. De-energize the actuator power supply
3. C. Electromagnet
4. D. A & B
5. B. 120 VDC

43.35 Chapter 35

1. Fail-safe
2. Common
3. Pressure gauge
4. B. Restrictor
5. Air Dryer
6. Diaphragm or Bladder

7. Isolation Relay

43.36 Chapter 36

1. False
2. 15°F
3. Current-Sensing Relay (also called a Current-Operated Switch)
4. Thermal cutout
5. Airflow
6. B. Binary output

43.37 Chapter 37

1. True
2. 18.0 Hertz
3. True
4. Stratification
5. Analog output
6. Signal generator
7. C. Signal wires are not correctly landed

43.38 Chapter 38

1. True
2. False
3. 5.0 VDC
4. False

43.39 Chapter 39

1. PID (Proportional, Integral, and Derivative)
2. D. Two binary outputs
3. Time/timing
4. Tri-state
5. False
6. D. A and C

43.40 Chapter 40

1. True
2. D. All of the above
3. False. 2.5-8.5 would be closer to the correct range.
4. C. Failed diaphragm
5. One
6. True

43.41 Chapter 41

1. True
2. Zero crossing
3. Phase angled switching
4. IGBTs (Insulated Gate Bipolar Transistors)
5. 135

43.42 Chapter 42

1. False
2. Fan
3. Harmonics
4. Pulse Width Modulation
5. Safety or external fault
6. Matrix

Chapter 44 - Abbreviations

A	Amps
A	Area (Square feet)
AC	Alternating Current
ADC	Analog to Digital Converter
ADPS	Air Differential Pressure Switch
ADPT	Air Differential Pressure Transmitter
AFMS	Airflow Measuring Station
AHJ	Authority Having Jurisdiction
AHU	Air-Handling Unit
AI	Analog Input
ANSI	American National Standards Institute, Inc.
AO	Analog Output
ASD	Adjustable Speed Drive
ASHP	Air-Source Heat Pump
ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ATC	Automatic Temperature Control
B-	Boiler X
BAS	Building Automation System
BD	Barometric Damper
BI	Binary Input
BMS	Building Management System
BO	Binary Output
BP-	Boiler Pump X
BTU	British Thermal Unit
°C	Degrees Celsius
C/C	Cooling Coil
CAV	Constant-Air-Volume
CF	Correction Factor
CFM	Cubic Feet per Minute
CFR	Code of Federal Regulations
CH-	Chiller X
CHR	Chilled Water Return
CHS	Chilled Water Supply

CLG	Cooling
CO2	Carbon Dioxide
COM	Common
COR	Current-Operated Relay
CRAC	Computer Room Air Conditioning
CSD	Controls and Safety Devices
CSR-	Current Sensing Relay
CT	Current Transmitter
C_V	Valve Flow Coefficient. Flow rate at 1 PSIG pressure drop across the valve.
CWR	Condenser Water Return
CWS	Condenser Water Supply
ΔT	Delta T (temperature change)
DA-	Damper Actuator X
DAC	Digital to Analog Converter
DAT	Discharge Air Temperature
DB	Dry Bulb
DC	Direct Current
DCA	Direct-Coupled Actuator
DCV	Demand-Controlled Ventilation
DCW	Domestic Cold Water
DDC	Direct Digital Control
DHW	Domestic Hot Water
DI	Digital Input
DIN	Deutsches Institut für Normung
DOAS	Dedicated Outdoor Air System
DP	Differential Pressure
DRGs	Diffusers, Registers, and Grills
D:S	Distance to Spot
DUT	Device Under Test
DTR	Dual-Temperature Return
DTS	Dual-Temperature Supply
EA	Exhaust Air
EC	Electronically Commutated
EAD	Exhaust Air Damper
EF-	Exhaust Fan X
EMF	Electromotive Force
EMI	Electromagnetic Interference

ε	Emissivity
EPO	Emergency Power Off
EPT	Electric to Pneumatic Transducer
ERU	Energy Recovery Unit
ERV	Energy Recovery Ventilator
ESD	Emergency Shutdown
ESS	Emergency Shutdown Switch
Estop	Emergency Stop
FACP	Fire Alarm and Control Panel
FBD	Face and Bypass Damper
FCU	Fan Coil Unit
FLA	Full Load Amps
FM	Flow Meter
FPM	Feet per Minute
FPS	Feet per Second
FSAC	Fan Safety Alarm Circuit
%FS	Percent Full Scale
FT	Feet
FZ-	Freezestat X
°F	Degrees Fahrenheit
GFCI	Ground Fault Current Interrupter
GPM	Gallons per Minute
GUI	Graphical User Interface
H	Humidity
H/C	Heating Coil
HDPS	Hydronic Differential Pressure Switch
HDPT	Hydronic Differential Pressure Transmitter
HFS	Hydronic Flow Switch
%RH	Percent Relative Humidity
H-O-A	Hand Off Auto
HP	Horsepower
HRU	Heat Recovery Unit
HRV	Heat Recovery Ventilator
HS-	Humidity Sensor
HSS-	High Static Safety X
HTG	Heating
HVAC	Heating, Ventilating, and Air-Conditioning

HWR	Hot Water Return
HWS	Hot Water Supply
HZ	Hertz
I	Input
IGV	Inlet Guide Vanes
IN	Inches
IP	Internet Protocol
IR	Infrared
IT	Information Technology
JACE	Java Application and Control Engine
K	1000
K	K-factor. Airflow rate at 1 inch pressure drop across the flow pickup.
KBS	Kilobits per Second
KW	Kilowatt
LCP	Local Control Panel
LPC	Low-Pressure Condensate
LSS	Low-Pressure Steam
LED	Light Emitting Diode
LOTO	Lock-out Tag-out
LRA	Locked Rotor Amps
LSS-	Low Static Safety X
LTD-	Low Temperature Detector
LVT	Low-Voltage Transformer
mA	Milliamps
MA	Mixed Air
MAT	Mixed Air Temperature
MBH	1000 British Thermal Units
MBS	Megabytes per Second
MS/TP	Master-Slave/Token-Passing
N.C.	Normally Closed
NDIR	Non-Dispersive Infrared
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NIC	Not Included in Contract
NIST	Institute of Standards and Technology
NLA	No Load Amps
N.O.	Normally Open

NTC	Negative Temperature Coefficient
O	Output
OA	Outdoor Air
OAD	Outdoor Air Damper
OAT	Outdoor Air Temperature
OCC	Occupied
OED	Open End Duct
Ω	Ohm
OSHA	Occupational Health and Safety Administration
Ø	Phase
ϱ	Density
PC	Personal Computer
PCHP-	Primary Chilled Water Pump X
PFS	Position Feedback Switch
PID	Proportional, Integral, Derivative
PIR	Passive Infrared
PPE	Personal Protective Equipment
PPM	Parts per Million
PRV	Pressure Reducing Valve
PS-	Power Supply X
PSIG	Pounds per Square Inch Gauge
PTC	Positive Temperature Coefficient
PVC	Polyvinyl Chloride
P/T	Pressure/Temperature
Q	Heat Transfer (BTU/h)
R-	Relay X
RA	Return Air
RAD	Return Air Damper
RAF	Return Air Fan
RAH	Return Air Humidity
RAT	Return Air Temperature
RLA	Run Load Amps
RMS	Root Mean Square
RPM	Revolutions per Minute
RTD	Resistance Temperature Detector
RTT	Resistance Temperature Table
RTU	Rooftop Unit

%RD	Percent Reading
SA	Supply Air
SAD	Supply Air Damper
SAF	Supply Air Fan
SAT	Supply Air Temperature
SCHP-	Primary Chilled Water Pump X
SCR	Silicon Controlled Rectifier
SD-	Smoke Detector #
SF-	Supply Fan X
SP	Static Pressure
SR-	Safety Relay X
SPP	Static Pressure Profile
T	Temperature
TAB	Testing, Adjusting, and Balancing
TD	Thermal Dispersion
TIA	Telecommunications Industry Association
TP	Total Pressure
TS-	Temperature Sensor X
TU	Terminal Unit
UDT	Ultrasonic Diagnostic Tool
UFM	Ultrasonic Flow Meter
UL	Underwriters Laboratory
UV	Unit Ventilator
Unocc	Unoccupied
UI-	Universal Input X
UL	Underwriters Laboratory
UUT	Unit Under Test
V	Velocity
V-	Valve X
VA	Volts-Amps
VA-	Valve Actuator X
VAC	Volts Alternating Current
VAV	Variable Air Volume
VDC	Volts Direct Current
VFD	Variable Frequency Drive
VP	Velocity Pressure
VPN	Virtual Private Network

WB	Wet Bulb
W.C.	Water Column
W.G.	Water Gauge
WLC	Water Level Controller
WSHP	Water-Source Heat Pump