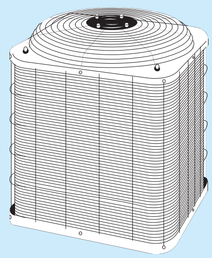
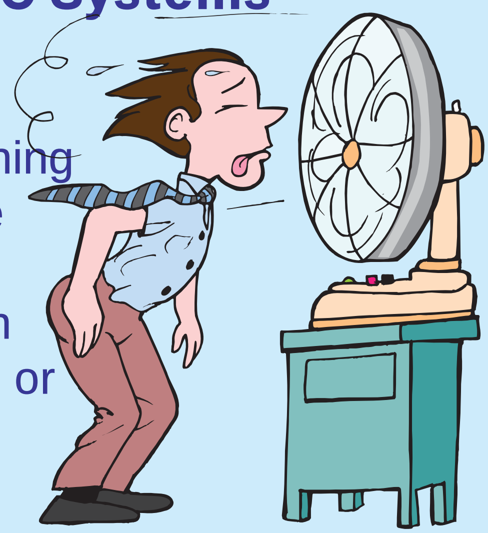
HVAC Basics and HVAC System Efficiency Improvement



Introduction

- HVAC systems – or Heating, Ventilating and Air-Conditioning systems – control the environment for people and equipment in our facilities.
- They account for about 13% of the electrical energy use in a typical residential building; and about 20% in a typical commercial or institutional building. HVAC use in an office building might be as high as 30 – 50%.
- HVAC systems and chillers are also significant energy consumers in many manufacturing facilities.

Functions of HVAC Systems

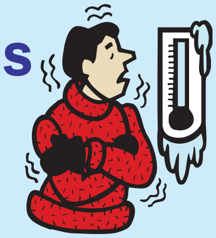


- The purpose of a Heating, Ventilating and Air Conditioning (HVAC) system is to provide and maintain a comfortable and safe environment within a building for the occupants or for the process being conducted.
- Many HVAC systems were not designed with energy efficiency as one of the design factors

Environmental Control Factors

- An HVAC system functions to provide an environment in which these three factors are maintained within desired ranges. Typical design conditions are:
- 75 degrees F temperature (dry bulb)
- 40 - 60% relative humidity
- ASHRAE 62.1 – 2007/2010 Ventilation Standard
    - 17 CFM outside air per person, or
    - CO2 less than 1000 PPM

Temperature Control Strategies



- Vary the temperature of the supply air to the space while keeping the air flow rate constant. This is the *constant volume*, variable temperature approach.
- Vary the air flow rate while keeping the supply air temperature constant. This is the variable volume, constant temperature approach. VAV – variable air volume system.
- Vary the supply air temperature and the flow rate, as in a variable volume reheat system.

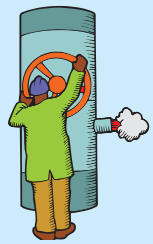
Relative Humidity Control

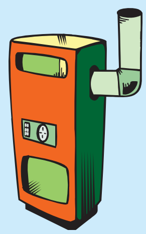
- Humidification - The air is too dry and water vapor must be added for comfort.
- Dehumidification - The air is too wet and water vapor must be removed for comfort.

- AC systems typically over-cool the air to remove water vapor, and then may have to heat the air back up - this is called reheat, and requires additional energy.
- Either way, energy required is around 1000 Btu per pound of water.

Primary Equipment

- Chillers
- Direct expansion (DX) systems
- Boilers
- Furnaces





Secondary Systems

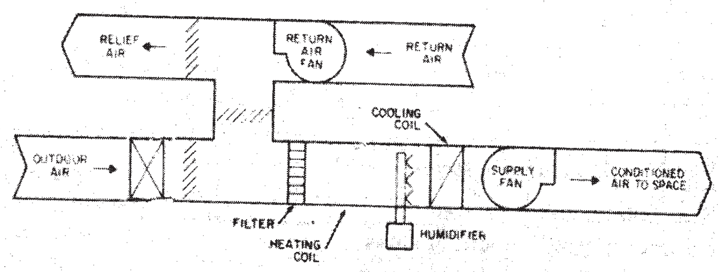
- Single duct, single zone system
- Single duct, terminal reheat system
- Multizone system
- Dual duct system
- Single duct, variable air volume system
  – This is the most common system going in to large commercial buildings
- Fan coil system

HVAC Systems

The summary below illustrates the types of systems frequently encountered in heating and air-conditioning systems.

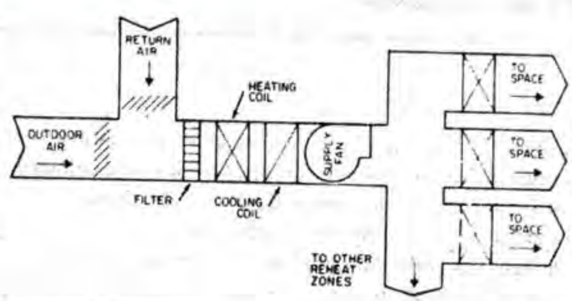
Single Zone System

Single zone systems consist of a mixing, conditioning and fan section. The conditioning section may have heating, cooling, humidifying or a combination of capabilities. Single zone systems can be factory assembled roof-top units or built up from individual components and may or may not have distributing duct work.



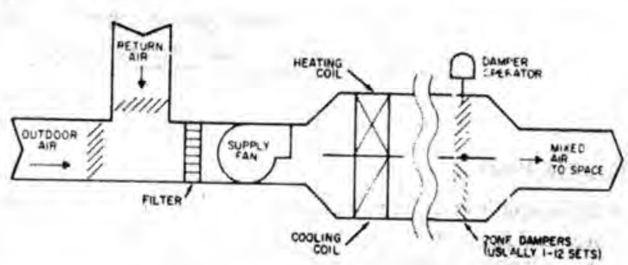
Terminal Reheat System

Reheat systems are modifications of single zone systems. Fixed cold temperature air is supplied by the central conditioning system and reheated in the terminal units when the space cooling load is less than maximum. The reheat is controlled by thermostats located in each conditioned space.

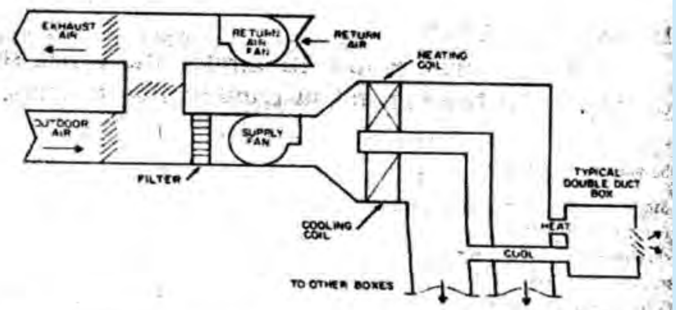


Multizone Systems

Multizone systems condition all air at the central system and mix heated and cooled air at the unit to satisfy various zone loads as sensed by zone thermostats. These systems may be packaged roof-top units or field-fabricated systems.

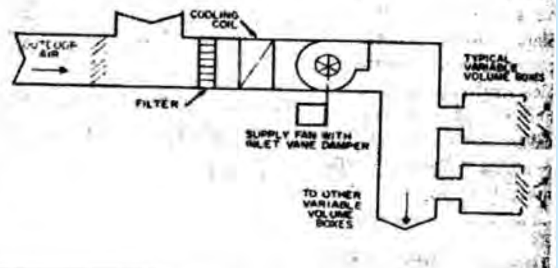


Dual duct systems are similar to multizone systems except heated and cooled air is ducted to the conditioned spaces and mixed as required in terminal mixing boxes.



Variable Air Volume Systems

A variable air volume system delivers a varying amount of air as required by the conditioned spaces. The volume control may be by fan inlet (vortex) damper, discharge damper or fan speed control. Terminal sections may be single duct variable volume units with or without reheat, controlled by space thermostats.



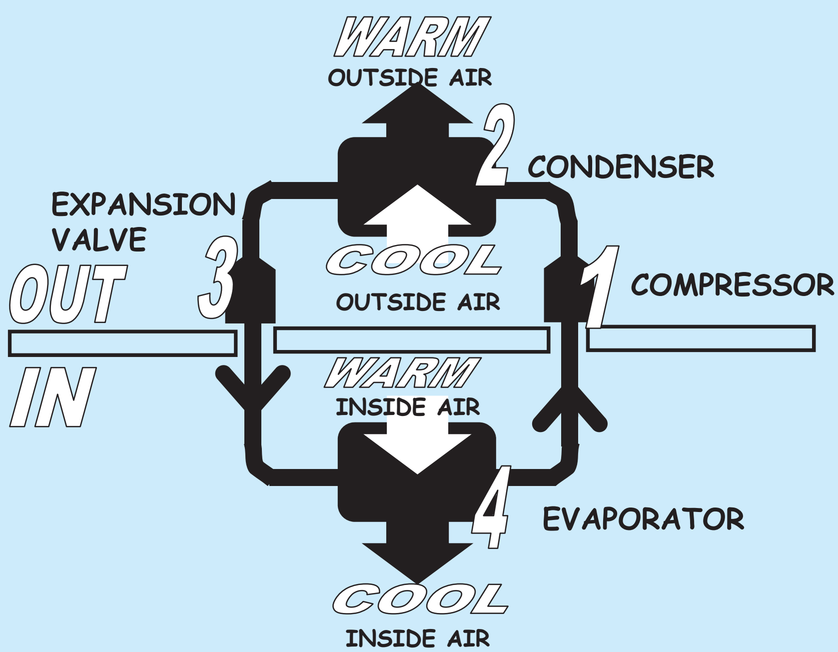
VAV HVAC Systems

- Most common new system going in to large commercial buildings.
- High efficiency because of use of variable speed drive on the supply air fan. For example, cutting air flow from full rate to 80% of full rate, cuts the fan power almost in half!
- Fan is controlled most often to keep a constant static pressure in the supply duct. Temperature is controlled by a local terminal box in the zone.

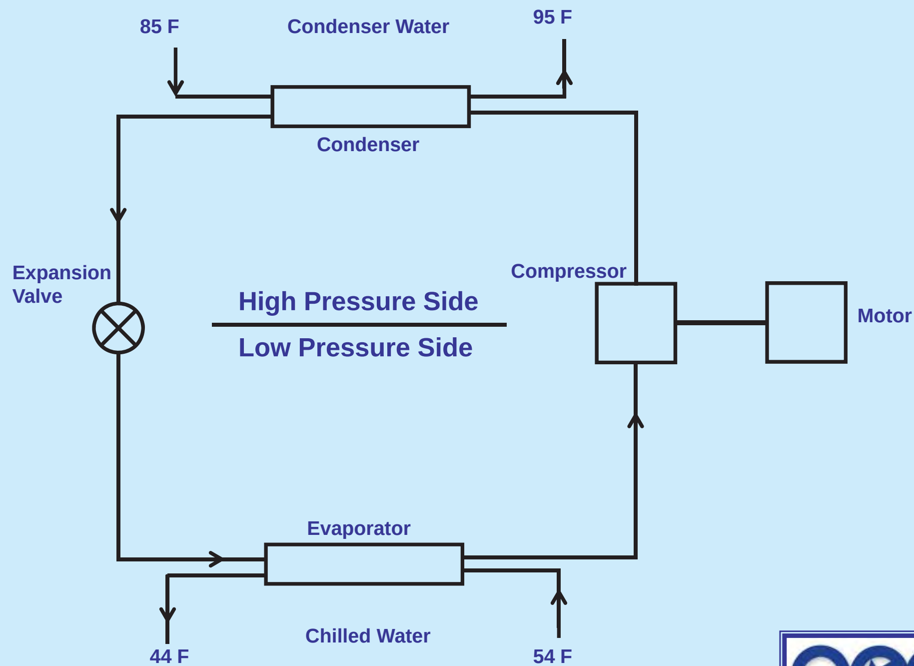
Power and Energy in Air Conditioning

- One ton of A/C = 12,000 Btu/hour
  - A ton is a measure of A/C power, and is used when sizing systems, or when determining electrical demand.
- One ton-hour of A/C = 12,000 Btu
  - A ton-hour is a measure of A/C energy, and is used when sizing storage tanks for thermal energy storage (TES) systems, or when determining electrical energy consumption.

Vapor Compression Cycle



Chiller Diagram



HVAC System Performance Measures

Energy Efficiency Ratio (EER)

$$EER = \frac{\text{Btu of cooling output}}{\text{Wh of electric input}} = \frac{\text{Btu/h of cooling output}}{\text{W of electric power input}}$$

Coefficient of Performance (COP)

$$COP = \frac{\text{Energy or heat output (total)}}{\text{Energy or heat input (external only)}} = \text{EER / 3.412 Btu/Wh}$$

Some Magic Numbers for EER and COP

$$EER = \frac{\text{Btu/h of cooling output}}{\text{W of electric power input}}$$

$$COP = EER\ /3.412\ \text{Btu/Wh}$$

$$\frac{X\ kW}{Ton} = \frac{12}{EER}$$

Sensible and Latent Heat

- Sensible heat - The heat associated with a temperature change of a substance at a constant moisture level.
- Latent heat - The heat associated with the phase change of a substance.
- Enthalpy - Total heat content of a substance, including both sensible heat plus latent heat.

System Improvement Options

- Make building envelope improvements to reduce HVAC load
  - insulation, high performance windows and roofs
- Replace old HVAC units and chillers with more efficient models
- Possibly downsize units and chiller
  - Energy Star says chillers are oversized 60%

- Consider multiple chillers
- Consider a chiller with a variable speed drive
- Consider installing a small chiller or separate HVAC system for 24/7 loads
- Use VSDs on pumps, cooling towers
- Replace constant volume systems with VAV - variable air volume systems

- Consider adding a gas engine driven chiller with heat recovery for hot water
- Retrofit to DDC controls
- Use cooling towers where possible

Absorption Chillers

- Absorption chillers can produce large quantities of chilled water using very little electric power and energy. Their prime energy source is heat from hot water or steam.
- Absorption chillers have no CFCs. Most absorption cycles use either ammonia and water or lithium bromide and water.
- Absorption chillers are not very efficient.
  - Single stage -- COPs about 0.6 - 0.8
  - Two-stage -- COPs about 1.0 - 1.2

CEM Review Problems

1. In a vapor compression cycle air conditioner, the refrigerant is always in the vapor state.
   A) True B) False
2. A roof top air conditioner has an EER of 9.2. What is its COP?
3. Reheat may still be needed in an HVAC system even if the outside temperature is very high.
   A) True B) False

4. A roof top air conditioner has an EER of 13.5. What is its kW/ton rating?

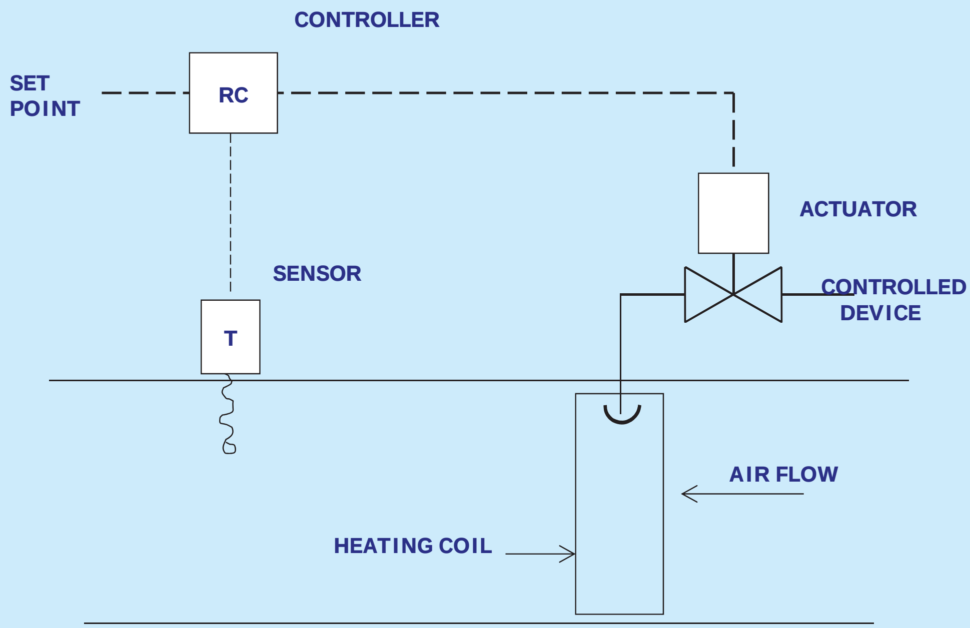
Controls and BAS

- **Controls**
  - Basic Types
  - Inputs & Outputs
  - Technologies
    - Pneumatic
    - Electric
    - DDC
  - Terminology
  - PID Controls
  - Review
- **Building Automation Systems for Energy Management**
  - Basic Functions
  - Programs
  - Review

Basic Types

- **Manual**
  Switches
  Dimmers
- **Open Loop Automatic**
  Timer
- **Closed Loop Automatic**
  Thermostat
  Humidistat
  Dimmable Ballast w/Photosensor

Basic Feedback Control System



Basic Types

- **Two Position (binary)**
  - The system is either OFF or ON (*gas furnace*).
  - Accomplished with a relay whose contacts are either open or closed, or a valve whose stem position is either open or closed.
- **Proportional**
  - A variation from the set point produces a proportional movement in the actuator.
  - Pneumatic controls vary the air pressure.
  - Electric controls use a potentiometer (a type of variable resistor).

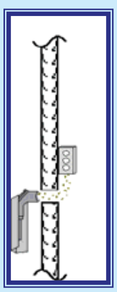
Basic Inputs & Outputs

- **Digital (D) (~ binary)**
  - Signal with two states or positions which can be incremental (*on-off, day-night, open-closed, occupied-unoccupied, series of 1's & 0's*)

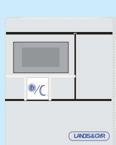
- **Analog (A)**
  - Signal can be monitored or controlled through a range of positions or values (*0 to 120ºF, 3 to 5 PSI, 0 to 10 VDC,4 to 20 milliamps*)

Input Examples

Analog

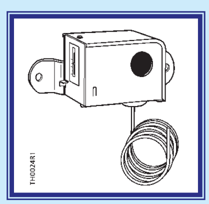


Outside Air Temp. Sensor
Analog Input

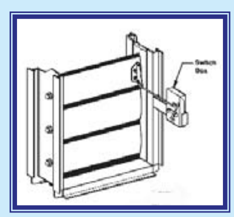


Room Temperature Sensor
Analog Input

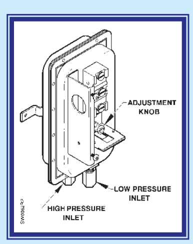
Digital



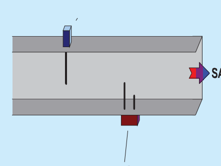
Low Temp. Detector
Digital Input



End Switch
Digital Input



High Pressure Detector
Digital Input



Duct Smoke Detector
Digital Input

Inputs & Outputs

Input Points

Temperature **AI**

Flow **AI / DI**

Status or Proof **AI / DI**

Relative Humidity **AI**

Pressure **AI**

Air Quality **AI**

Output Points

Motors for Pumps / Fans **DO**

Lights **DO**

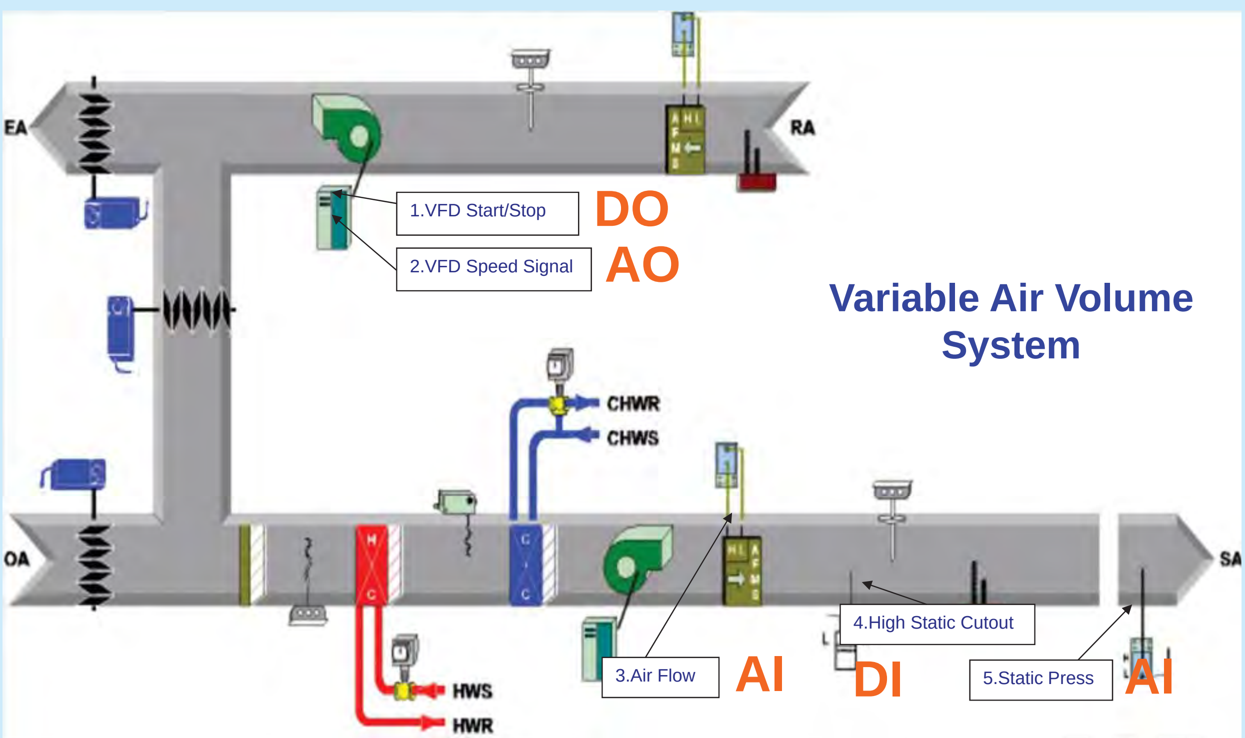
Variable Speed Drives **AO** (or digital)

Valves **AO**

Dampers **AO**

Lighting Contactors **DO**

Inputs & Outputs

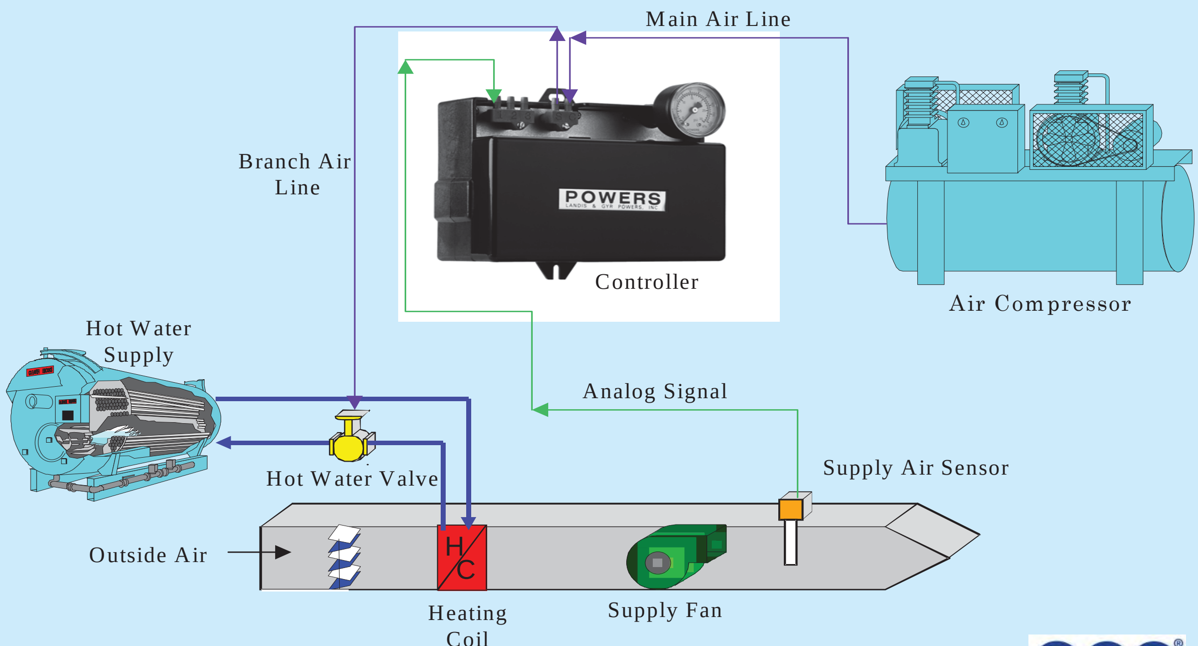


Basic Technologies

- Pneumatic
- Electric
- Direct Digital Control (DDC)

Pneumatic Controls

- Use clean, dry, oil-free **compressed air** to operate the control system.
- Have been used in many HVAC applications.



Pneumatic Controls

Advantages
- Are well understood by many designers and most maintenance people.
- Are inherently proportional and very reliable.
- Were relatively inexpensive in the past.

Disadvantages
- Not very precise.
- Typically required frequent calibration.
- Pneumatic control algorithms are hard to change. (*typically pre-set by manufacturer*)

Electric Controls

- Can be analog electric or electronic controls.
- Use a variable, but continuous, **electrical voltage or current** to operate the control system.
- Transmit signals quickly and accurately.

Electric Controls

Advantages

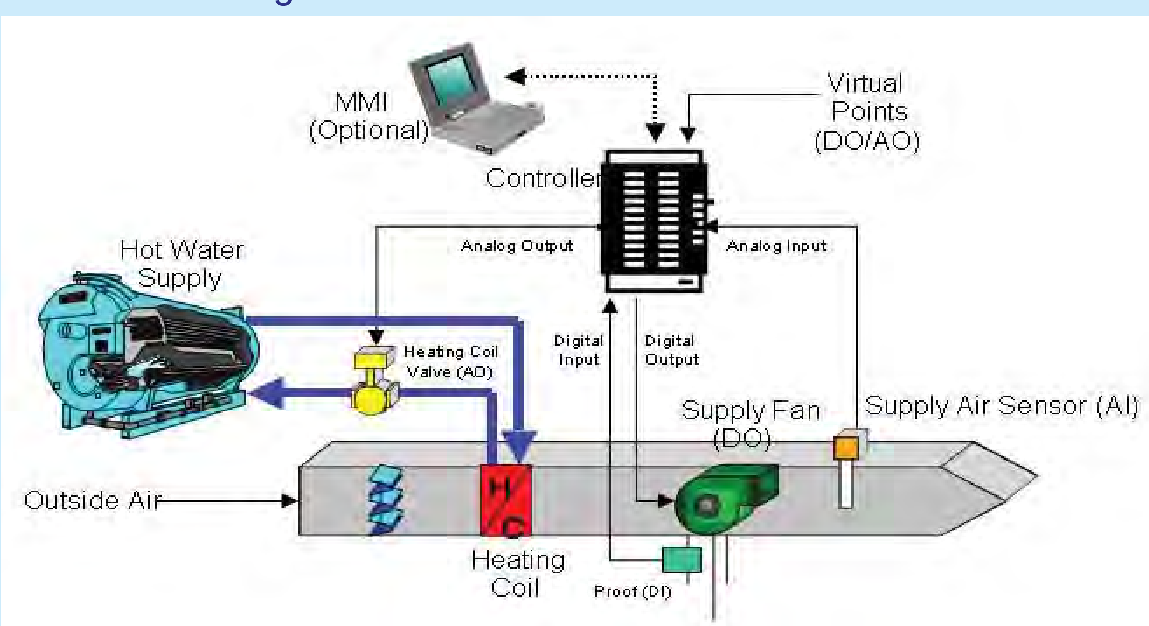
- Can be very accurate and very stable.
- Do not require field calibration, and are drift-free, if good quality sensors are used.
- Relatively easy to implement proportional plus integral (PI) control electronically.

Disadvantages

- Difficult to interchange parts easily because of the many different systems.
- Do not interface directly with our digital computers

Digital Controls

- Use **electrical pulses** to send signals.
- Interface directly with microprocessors, directly &/or via the internet using TCP/IP.



Digital Controls

Advantages

- Algorithms can be adjusted relatively easily after installation
- Precise
- No controller drift, recalibration is normally not necessary
- Cost effective (*similar to electronics market*)

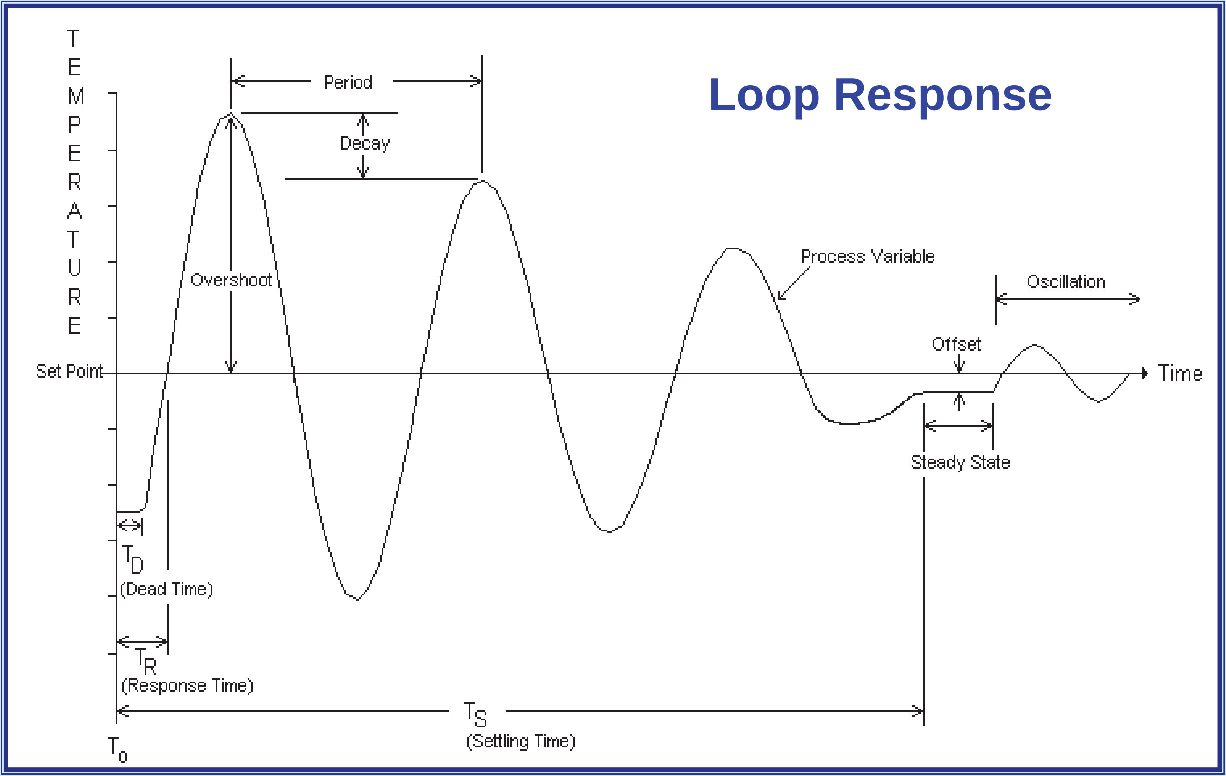
Disadvantages

- Possibly not well understood by O&M staff
- Different communication protocols, interface standards, and internal logic are typically complex (*BACNET-ASHRAE 135-2004; and Lonworks – Lonmark Corporation; are both addressing these interface problems*)

Control Algorithms

- PID Controls
  - P is proportional
  - I is integral
  - D is derivative
- Controls are usually P, PI or PID
- PID is considered the best of this group
- Newer control algorithms are:
  - Fuzzy logic
  - Learning systems
  - Self-optimizing systems

PID Controls



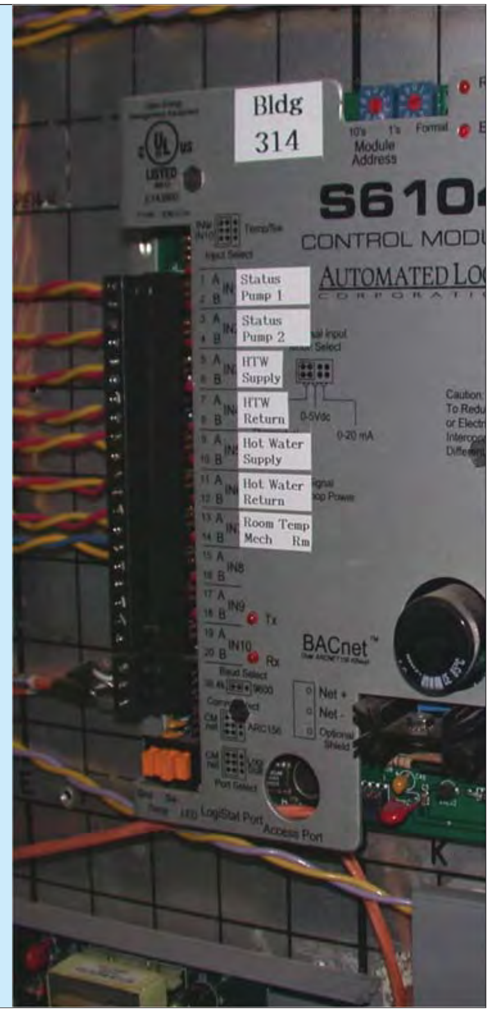
PID Controls

Summary Of Gains

CONTROL MODE	PURPOSE	ERROR DETECTIONS
PG	Reacts to Change	Detects **SIZE** of Error
IG	Reduces/Eliminates Offset	Averages Error over **TIME**
DG	Senses High Rate Load	Detects **RATE** of change of error

$$CV\ (adjustable) = \left\{ \left(\frac{PG}{1000} \times error\ * action \right) + \left(\frac{IG}{1000} \int error\ dt\ * action \right) + \left(\frac{DG}{1000} \times \frac{d\,(error)}{dt} * action \right) \right\} + bias$$

Building Automation Systems (BAS)

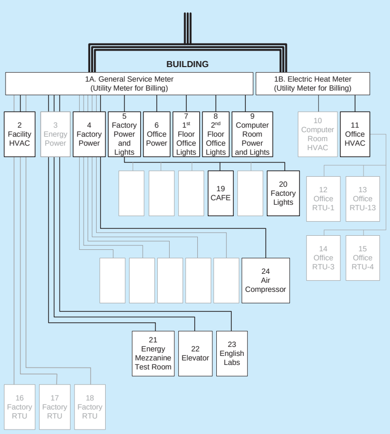


Session 9.19

Basic Functions

1. Monitoring/Surveillance

- Building Conditions
- Equipment Status
- Utility Submetering
- Climatic Data
- Fire & Security



Session 9.20

Basic Functions

2. Demand Limiting

- Load shedding
- Duty cycling

3. Maintenance

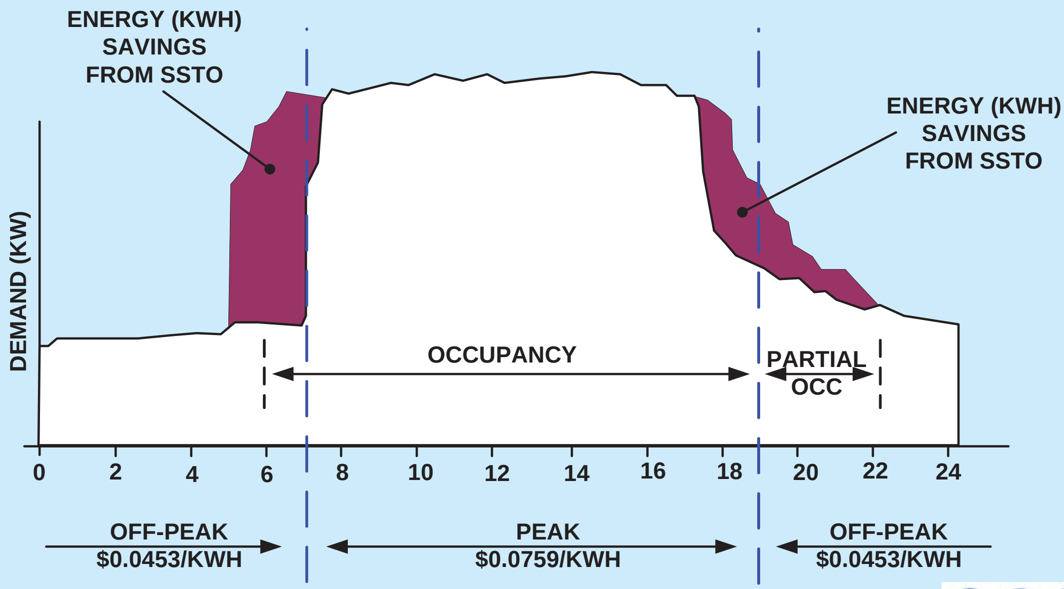
- Remote operation and control of equipment
- Generation of maintenance schedules
- Diagnosing breakdowns

4. Record Generation

- Trends and operation logs
- Utility demand profile (“baseline”)
- Modification/replacement analysis
- Energy conservation documentation

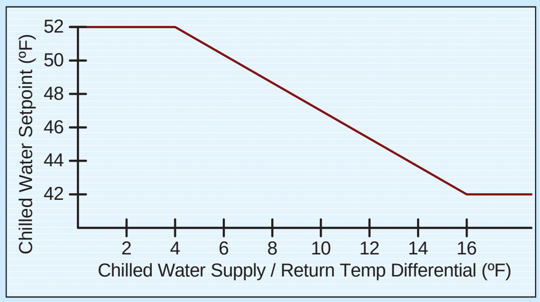
Start-Stop Optimization

- **How It Works**
  - Start the equipment at the latest possible time
  - Stop at the earliest possible time



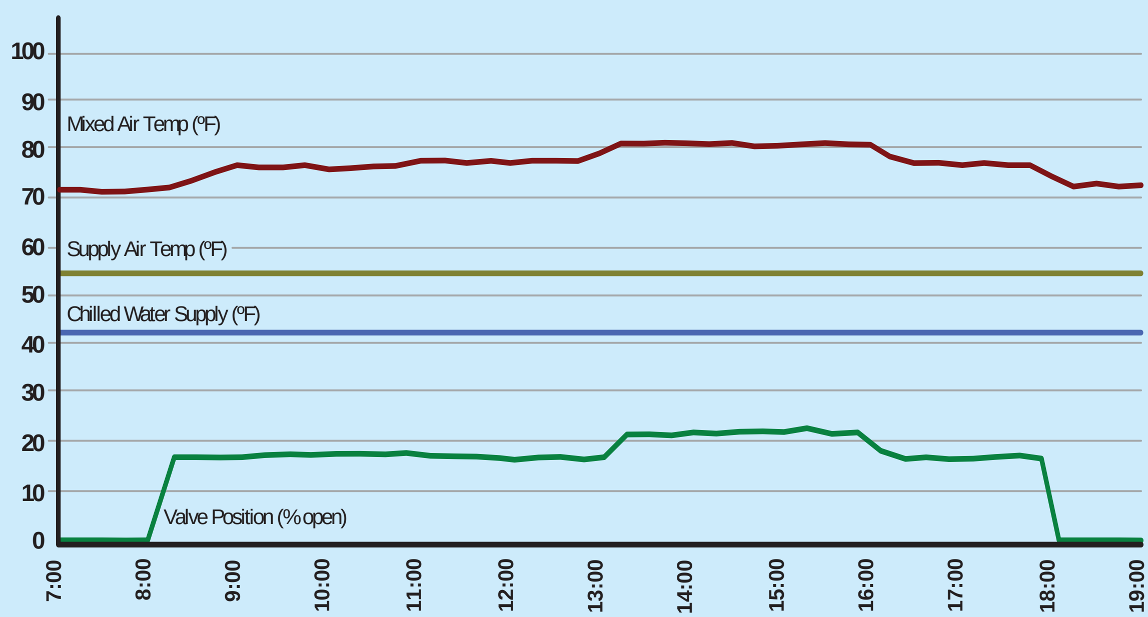
Chilled Water Reset

- **Introduction**
  - Many buildings' chilled water setting is designed for the heaviest anticipated cooling load.
  - Significant cost savings can result from resetting chilled water temperatures in anticipation of cooling load
- **How It Works**
  - When the load, chilled water ΔT, or return chilled water temperature increases, the chilled water setpoint is lowered, and vice versa



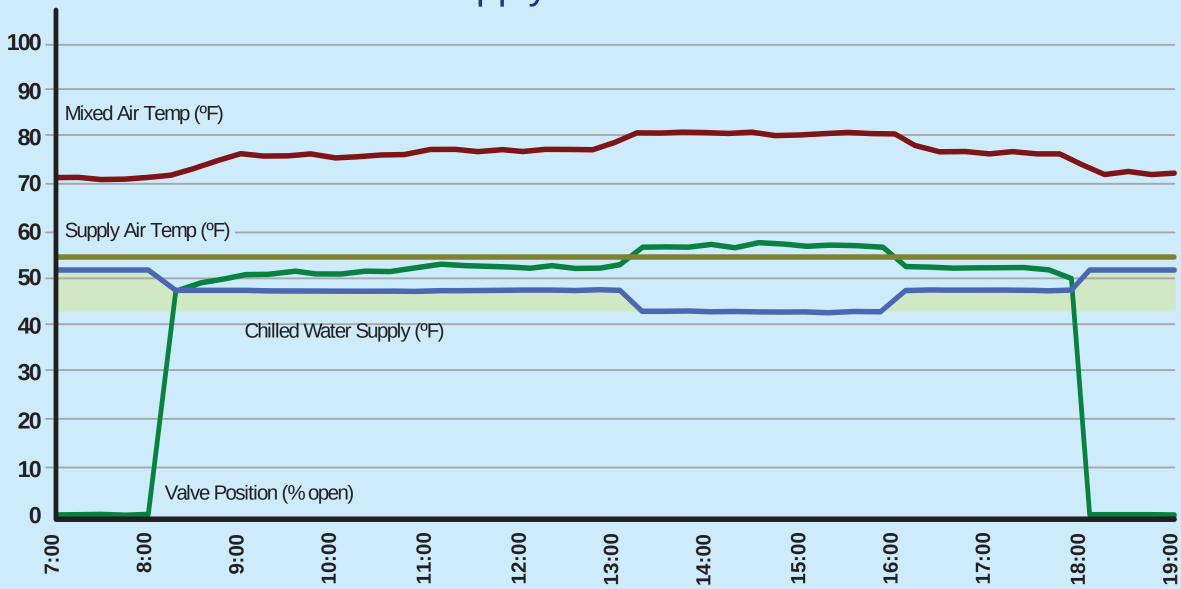
Chilled Water Reset

- **Proof of Performance**
  - Constant CHW Supply Temp Scenario:



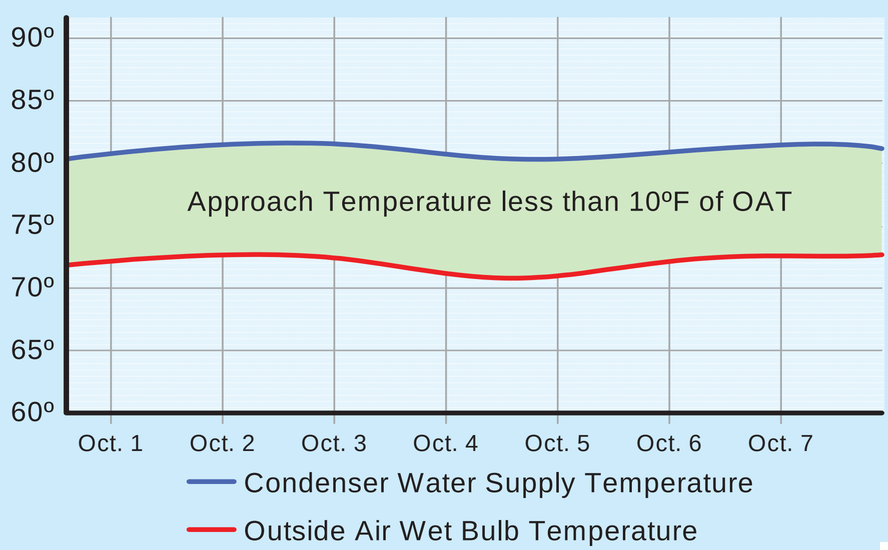
Chilled Water Reset

- **Proof of Performance**
  - As the outside air temperature decreases, the temperature of the chilled water supply can be allowed to increase



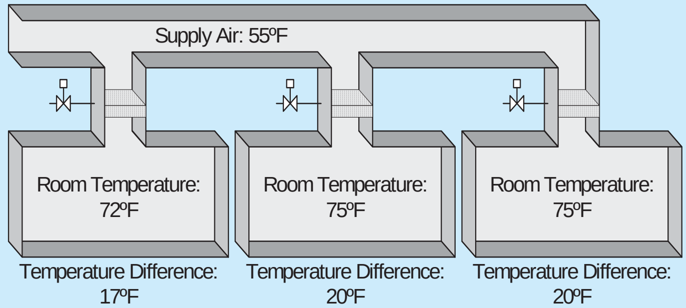
Condenser Water Reset

- **Proof of Performance**
  - This trend shows the cooling tower approach temperature
  - Trend points at a fixed time interval to ensure operation (*Approach Temp, Cond Wtr Return Temp & Cond Wtr Supply Temp*)

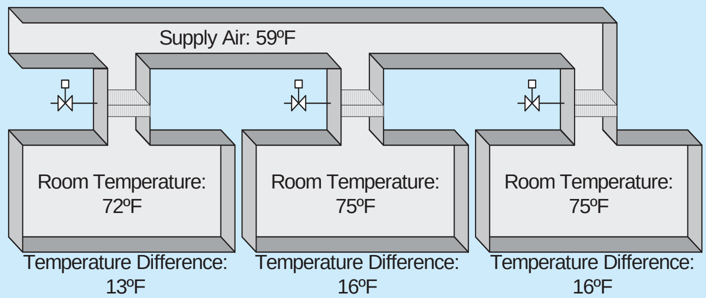


Supply Air Reset

- **Introduction**
  - When supply air temperature is set to 55ºF, rooms must mechanical reheat

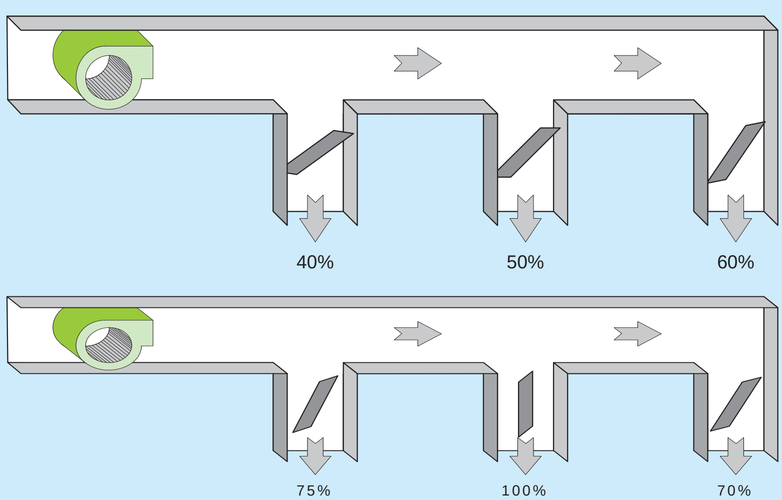


  - When supply air temperature is reset to 58ºF, rooms require less mechanical reheat



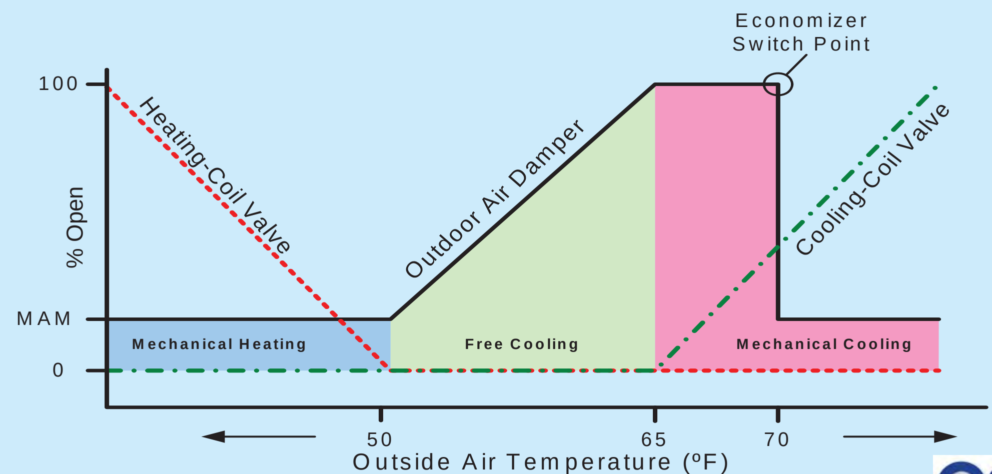
Static Pressure Resets

- **How It Works**
  - The DDC system monitors the VAV static pressure and lowers the pressure until only one damper is completely open
  - The Static Pressure and VFD control sensors must be located on the same DDC control panel



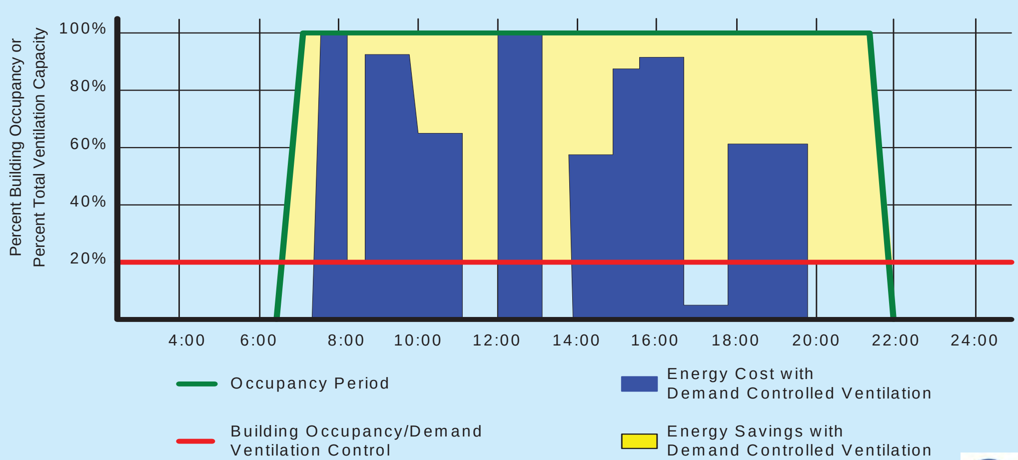
Economizer

- **How It Works**
  - Reduce cooling & heating energy by optimizing mixed air temp
  - As the outside air allows, the outdoor air damper opens more
  - Free heating/cooling occurs when occupant comfort is maintained without using mechanical heating or cooling



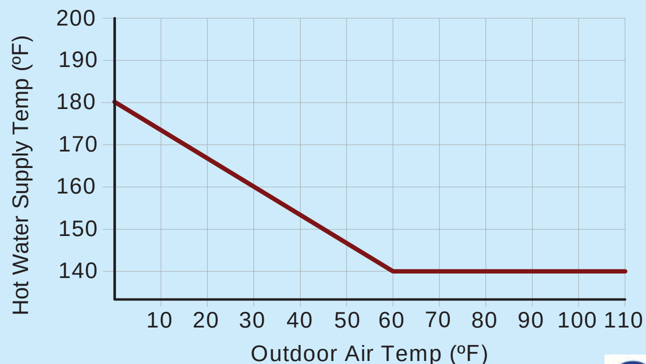
Demand Control Ventilation

- **How It Works**
  - DCV provides just the right amount of outside needed by occupants
  - Modulates ventilation to main target cfm/person ventilation based on actual occupancy
    - Less than 700 ppm above outside CO_2 concentration



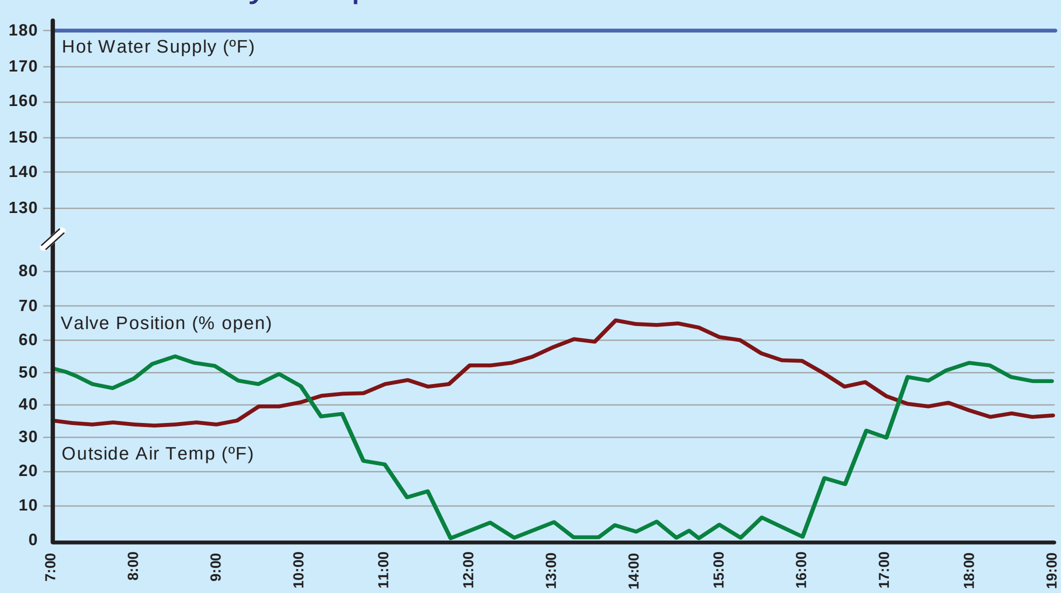
Hot Water Reset - How It Works

- Hot water boilers are very efficient at partial load
  - Distribution losses are less when temperature is reduced
  - Hot water reset conserves energy by reducing the boiler's operating temperature
  - Hot water reset reduces thermal shock because it does not involve drastic temperature fluctuations
  - To minimize flue gas corrosion, do not reset lower than 140ºF



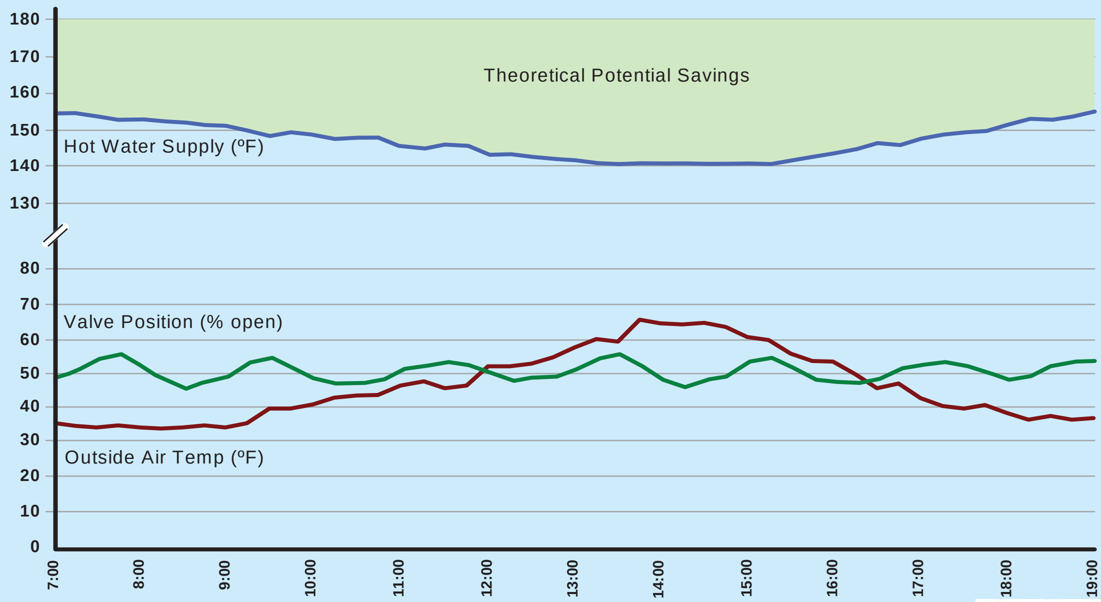
Hot Water Reset

- **Proof of Performance**
  - Maintaining 180ºF water temperature forces the heating valves to cycle open and closed



Hot Water Reset

- **Proof of Performance**
  - Resetting the hot water temperature allows heating valves to operate in more efficient mid-actuation positions



Other EMS Programs

1. ***Scheduled Start/Stop*** – Starting and stopping equipment based upon the time of day, and the day of the week.
2. ***Duty Cycling*** – Shutting down equipment for predetermined short periods of time during normal operating hours.
3. ***Demand Limiting*** – Temporarily shedding electrical loads to prevent exceeding a peak value.
4. ***Unoccupied Setback*** – Lowering the space heating setpoint or raising the space cooling setpoint during unoccupied hours.

5. ***Warm Up/Cool Down Ventilation & Recirculation*** – Controls operation of the OA dampers when the introduction of OA would impose an additional thermal laod during warm-up or cool-down cycles prior to occupancy of a building.
6. ***Hot Deck/Cold Deck Temperature Reset*** - Selects the zone/area with the greater heating and cooling requirements, and establishes the minimum hot and cold deck temperature differential which will meet the requirements.
7. ***Steam Boiler Optimization*** – Implemented in heating plants with multiple boilers. Boiler plant optimization is accomplishes through the selection of the most efficient boiler to satisfy the space temperature requirements during the building occupied period.
8. ***Reheat Coil/Reset*** – Selects the zone/area with the greatest need for reheat, and establishes the minimum temperature of the heating hot water so that it is just hot enough to meet the reheat needs for that time period.

9. ***Chiller &/or Boiler Optimization*** – For facilities with multiple chillers &/or boilers, the most efficient chiller(s) &/or boiler(s) are selected to meet the existing load with minimum demand and or energy.
10. ***Chiller Demand Limiting*** – The chiller electrical load is reduced at certain times to meet a maximum pre-specified chiller kW load.
11. ***Lighting Control*** – Turns lighting off and on according to a pre-set time schedule.
12. ***Remote Boiler Monitoring and Supervision*** – Uses sensors at the boiler to provide inputs to the EMCS for automatic central reporting of alarms, critical operating parameters, and remote shutdown of boilers.
13. ***Maintenance Management*** – Provides a maintenance schedule for utility plants, mechanical and electrical equipment based on run time, calendar time, or physical parameters.

Review: BAS/EMS

1. Distinguish between analog and digital control.

2. Devices using 4-20 mA current loops are using digital data transmission.

   (A) True *(B) False*

3. A facility is heated and cooled by multizone units using hot water pumped from a central boiler system. List some EMS controls that could reduce the facility energy costs.

4. List some maintenance aids that could be provided by an EMS.

5. An optimum start device is a control function that:

(A) *Shuts off the outside ventilation air during start up of the building.*

(B) *Shuts off equipment for duty cycling purpose.*

(C) *Senses outdoor and indoor temperatures to determine the minimum time needed to heat up or cool down a building.*

(D) *Compares the enthalpy of outdoor and return air and determines the optimum mix of the two streams.*

Maintenance and Commissioning

Importance of Maintenance Programs

Good maintenance saves energy costs

Major problems in maintenance

- Lack of adequate management attention
- Lack of adequate maintenance training
- Poor reporting of problems
- Lack of work order systems
- Poor analysis of problems
- Poor preventive maintenance efforts
- Poor control of maintenance activities

Successful Maintenance Programs

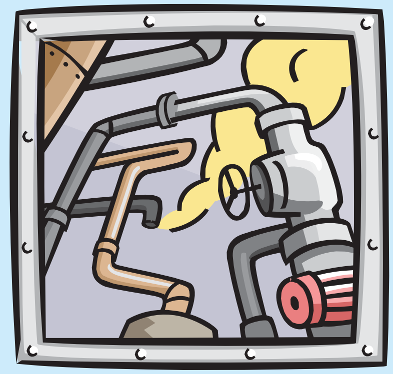
- Require adequate funding and training
- Do not defer maintenance
- Use new Maintenance Management Systems

Maintenance Management Systems

- MMS bring high tech to the maintenance area.
- MMS provide capability for inputs from sensors such as differential pressure across filters, equipment temperatures, and vibration.
- MMS provide data analysis, data summaries, generation of maintenance orders, and performance records on equipment.

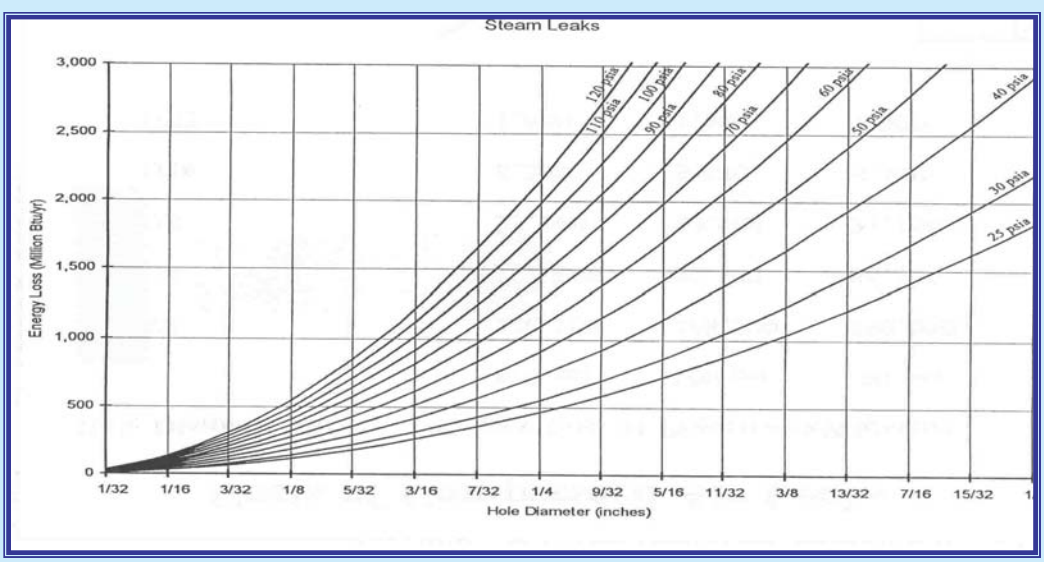
Costs of Poor Maintenance

- Steam leaks
- Steam trap failures
- Compressed air leaks
- Uninsulated pipes
- Boiler scale



Energy Loss of Steam Leak Chart

in PSIA, and for 8760 h/yr operation



Air Leaks

Table in PSIG, and for 8760 h/yr operation

Costs of Compressed Air Leaks

Hole Diameter (in)	Energy Loss at Pressure (kWh/year)		
	110 psi	100 psi	90 psi
3/8	226,100	208,100	190,000
1/4	100,500	92,500	86,300
1/8	25,100	23,100	21,100
1/16	6,300	5,800	5,300
1/32	1,600	1,400	1,300

Compressed Air Leaks

Recall from Section M:

- Quantifying air leaks
  - Apply the following formula to find standard cubic feet per minute (SCFM) lost

$$R = \frac{V\,(P_1 - P_2)}{(\Delta T)\ 14.7\,\text{lb/in}^2}$$

A standard cubic foot of air is one cubic foot of air at 14.7 lb/in^2.

R = average leakage rate (Scfm)

V = system volume (ft^3)

P_1 = initial pressure (psig)

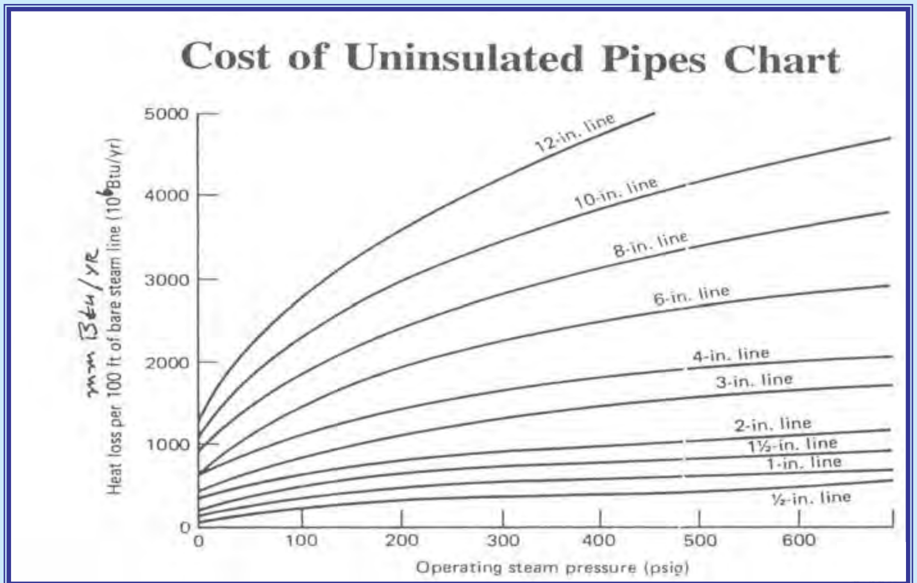
P_2 = final pressure (psig)

ΔT = time interval over which leaks are measured (minutes)

If V=200 ft^3, P_1 - P_2 = 10 psig and ΔT = 12 min, compute R.

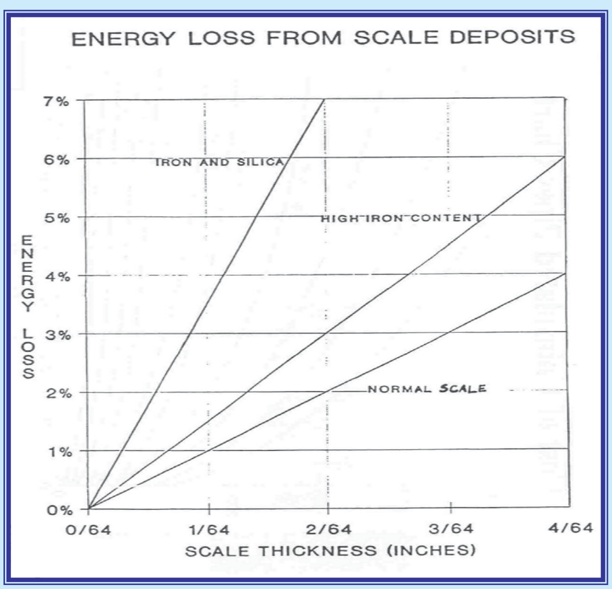
Cost of Uninsulated Steam Pipes

in PSIG, and for 8760 h/yr operation, per 100 feet



Cost of Boiler Scale Chart

percent loss from factory clean



Maintenance Help from Interesting Technologies

Infrared Photography
And
Vibration Analysis

Infrared Photography

- Family of non-destructive testing techniques
- Produces images of heat usually invisible to the human eye
- Heat in some mechanical situations can be a sign of impending malfunctions
- Heat in some electrical wiring can be a sign of bad connections and/or phase problems
- Heat anomalies in steam systems (e.g. traps)
- Heat loss through building envelope

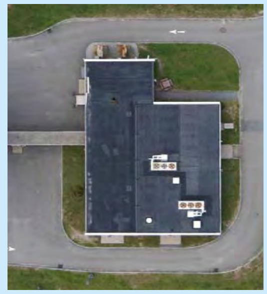
Infrared Photography Cont.

- Averted problems can be significant in nature (e.G. Primary transformer fires, etc.)
- IR operator needs some level of expertise
  - Attend training
  - Contract service
- One major malfunction discovered and infrared program just paid for itself

Example IR Photos

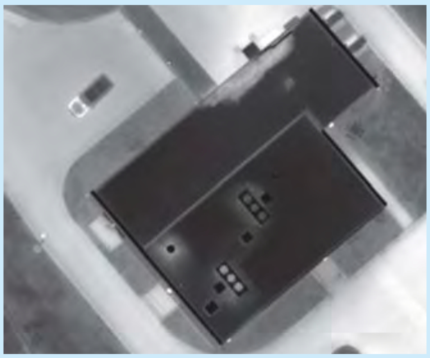
- **Example IR photo of bad electrical connection – FLIR Systems Inc.**

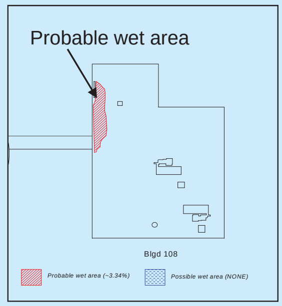
Aerial example of thermal image, visible image and CAD drawing



PHOTOGRAPH

THERMOGRAPH



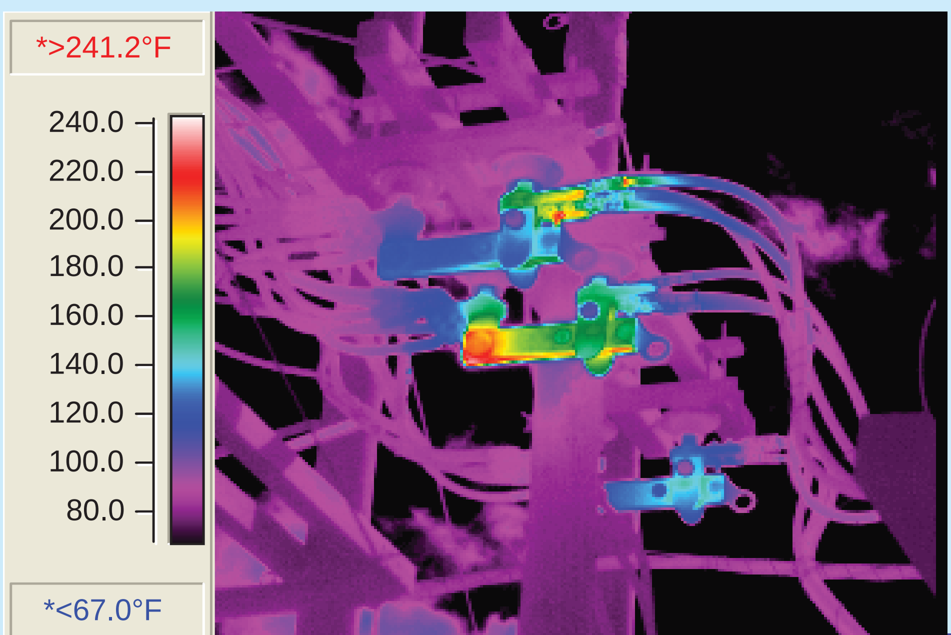


CAD DRAWING

CAD OVERLAY

Session 10.15

Electrical P/PM



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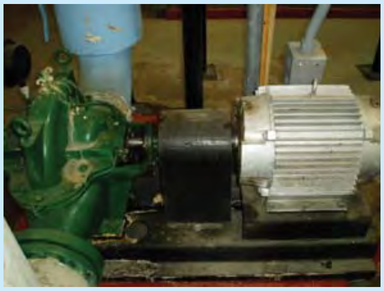
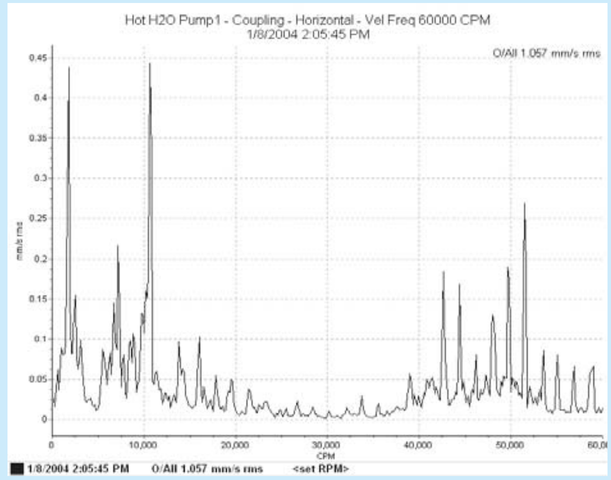
Vibration Analysis

- Another powerful member of the family of non-destructive testing techniques
- Measures vibration signatures of machinery (usually rotating)
- Two Main Diagnostic Methods
  1. Vibration Signatures (Snap-Shot)
  2. Trending (Observation Over Time)

Vibration Analysis Cont.

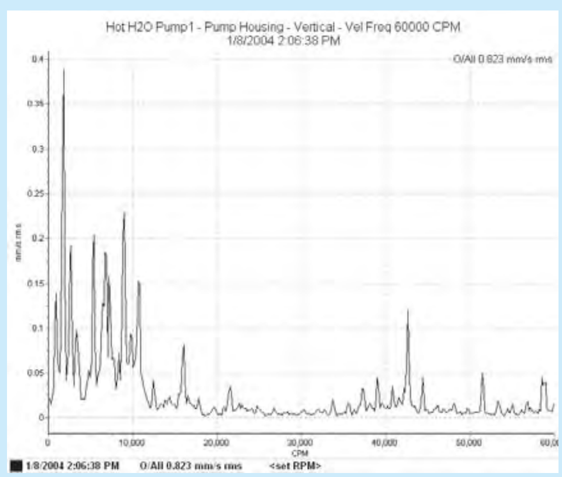
- Even more so than infrared photography, training is mandatory (this is a science ***and*** an art)
- Trending vibration levels over time can remove some of the uncertainty of problems
- Technique used to spot:
  - Bad Bearings
  - Bad Gears
  - Loose Machine Mountings





Problem was later localized to the motor coupling. Repair was initiated to avoid catastrophic failure.

Vibration Analysis Examples



Water pump with suspicious (noise-floor) vibrations. Attempts to localize problem began. (**Okla. State IAC**)

Maintenance Review Problems

1. Five bucket steam traps are stuck open in your facility. They all exhaust to the drain. If gas costs $7.00/MCF and your steam system is 78% efficient, what is the cost of these malfunctioning steam traps per year? Each trap has a 1/8 inch orifice. The steam line pressure is 110 psia.

2. In problem 1, what else do you really need to explore?

Maintenance Review Problems Cont.

3. You run a compressed air check in your facility and find the following leaks -- one 1/4 inch and one 1/8 inch. What is the annual cost to your facility if your system has 100 psig air and you are paying $.05 per kWh for electricity?

Commissioning

Session 10.23

23

CBECS DATA

	Energy Use (kBtu/sq.ft.yr)	Energy Cost ($/sq.ft.yr.)
Energy Star (2000)	48.9	1.12
Average Buildings (1995 CBECCS*)	107.1	2.07
Efficient Buildings (Top 25% 1995 CBECS*)	51.4	1.25

* Commercial Buildings Energy Consumption Survey (US DOE)

Source: Energy Performance Pitfalls., Building Operations Management, p.43, March 2000

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CBECS DATA

	Energy Star 2000	1995 CBECS (Top 25%)	1995 CBECS (Bottom 25%)
Economizers	70%	30%	75%
VSDs	55%	20%	45%
VAV	70%	35%	65%
EMS	80%	25%	55%
Motion Sensors*	60%	10%	20%
* More Data Given - Not Presented Here			

Source: Energy Performance Pitfalls., Building Operations Management, p43, March 2000

Lack of Commissioning Examples

- Air side economizers: 50% of the time do not function properly (ASHRAE says 70%)
- Chilled water pumps directly connected to CW return lines
- Parallel pumps with some connected backward
- Air handling units (AHU) with belts completely absent (motor still running)
- One study found 650 such discrepancies

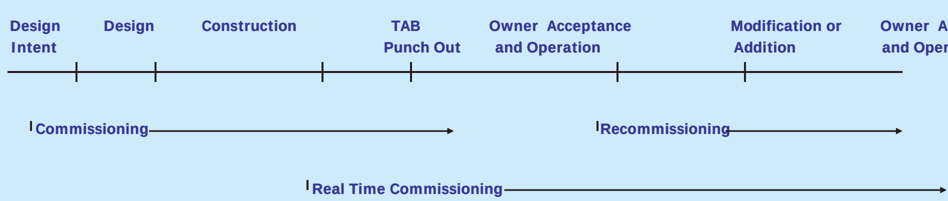
Do It Right The First Time And Keep It There

Commissioning

The process of ensuring that systems are designed, installed, functionally tested, and capable of being operated and maintained to perform in conformity with the design intent .... begins with planning and includes design, construction, start-up, acceptance and training, and can be applied throughout the life of the building (ASHRAE guideline 1-1996)

Time Line

The chart depicted below is the author's concept of how these fit together. There is nothing accurate about the actual placement of these activities on the time line; the chart is intended to convey thought only.



Note: Modification also includes design intent, design, construction, etc. This has been simplified.

Commissioning: General

1. Design intent is important (know what you want and express it).

2. Commissioning experience and training is important. Get someone with experience to help the first time(s) and obtain proper training. This process can be extremely cost effective; do it right.

Commissioning: General

3. Facility staff should be involved in the process as soon as possible. This is especially critical in the formal commissioning activities (systems try out and tuning).

4. Commissioning is not a "quick fix" or a "one time activity". It is a rather dramatic change in philosophy and an on-going activity. Management will be doing some phase of commissioning for the entire life of the facility. Remember, it is cost effective.

Commissioning: General

5. Commissioning is not implicit in construction. Management must make it happen.

6. Commissioning almost guarantees a smooth transition.

7. Commissioning must include training, systems manuals, maintenance manuals, and other documentation as needed.

Real Time Commissioning

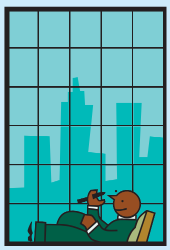
A Texas A&M study started Continuous Commissioning ™ on 80 campus buildings in 1995. By 1999, more than $2,000,000 was spent for metering and another $2,000,000 was spent for analysis and implementation of recommendations. Cumulative savings over the same time period were more than $10,000,000.

Commissioning: Where To From Here?

- Check Building Commissioning Association site and publications
- Check ASHRAE course and Guideline 1
- Check AEE course and certification

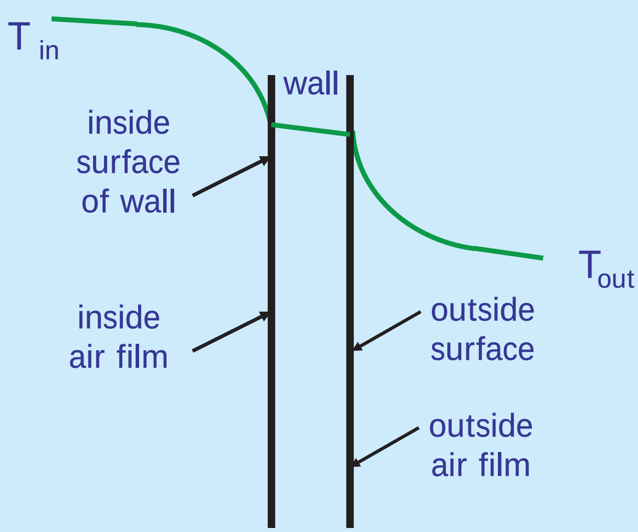
Building Envelope

Fast Track CEM



Heat Loss and Gain

- Heat is lost and gained through walls and ceilings.
- Consider a three-quarter inch plywood wall.



Basic Heat Flow Equations

- Conduction heat losses through walls and ceilings

$$q = \frac{A \times \Delta T}{\Sigma R} \quad \left[\frac{Btu}{hr}\right]$$

- Heat loss is proportional to the area A and the temperature difference ΔT between inside and outside.
- ΣR is the sum of the resistances of everything that resists heat flow.

$$\Sigma R = R_{\text{inside air film}} + R_{\text{plywood}} + R_{\text{outside air film}} \quad \left[\frac{hr \cdot ft^2 \cdot {}^\circ F}{Btu}\right]$$

Basic Heat Flow Equations

- The equation often is written

$$q = U \times A \times \Delta T \quad \left[\frac{Btu}{hr}\right]$$

- where U is the overall thermal conductance.

$$U = \frac{1}{\Sigma R} = \frac{1}{R_{\text{Total}}} \quad \left[\frac{Btu}{hr \cdot ft^2 \cdot {}^\circ F}\right]$$

Surface Air Film Resistance (Buildings)*

Wall or roof position	Direction of heat flow	R_s (hr·ft^2·°F/Btu)
Still air		
horizontal	up	0.61
horizontal	down	0.92
vertical	horizontal	0.68
Moving air		
15 mph (winter)	All	0.17
7.5 mph (summer)	All	0.25

*Data from 2001 ASHRAE Fundamentals Handbook, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia. p. 25.2.

Wall and Insulation Resistances

- R can be obtained from the conductance C, given for a specified thickness of material,

$$R = \frac{1}{C}$$

- If the conductivity k is given, R can be calculated knowing k and the material thickness t.

$$R = \frac{t}{k}$$

Conductances and Conductivities

Table 11-2.

Material	Description	Conductivity K^a	Conductance $C^{b,c}$
Building boards	Asbestos-cement board	4.0	
	Gypsum or plaster board...1/2 in.		2.25
	Plywood	0.80	
	Plywood...3/4 in.		1.07
	Sheathing (impregnated or coated)	0.38	
	Sheathing (impregnated or coated) 25/32 in.		0.49
	Wood fiber—hardboard type	1.40	
Insulating materials	Blanket and Batt:		
	Mineral wool fibers (rock, slag, or glass)	0.27	
	Wood fiber	0.25	
	Boards and slabs:		
	Cellular glass	0.39	
	Corkboard	0.27	
	Glass fiber	0.25	
	Insulating roof deck...2 in.		0.18
Masonry materials	Loose fill:		
	Mineral wool (glass, slag, or rock)	0.27	
	Vermiculite (expanded)	0.46	
	Concrete:		
	Cement mortar	5.0	
	Lightweight aggregates, expanded shale, clay, slate, slags; cinder; pumice; perlite; vermiculite	1.7	
	Sand and gravel or stone aggregate	12.0	
	Stucco	5.0	
	Brick, tile, block, and stone:		
	Brick, common	5.0	
	Brick, face	9.0	
	Tile, hollow clay, 1 cell deep, 4 in.		0.90
	Tile, hollow clay, 2 cells, 6 in.		0.54

Table 11-2. *(Continued)*

Material	Description	Conductivity K^a	Conductance $C^{b,c}$
Masonry materials (cont'd)	Block, concrete, 3 oval core:		
	Sand & gravel aggregate ....4 in.		1.40
	Sand & gravel aggregate ....6 in.		0.90
	Cinder aggregate ....4 in.		0.90
	Cinder aggregate ....6 in.		0.58
	Stone, lime or sand	12.50	
Plastering materials	Cement plaster, sand aggregate	5.0	
	Gypsum plaster:		
	Lightweight aggregate...1/2 in.		3.12
	Lt. wt. agg. on metal lath...3/4 in.		2.13
	Perlite aggregate	1.5	
	Sand aggregate	5.6	
	Sand aggregate on metal lath 3/4 in.		7.70
	Vermiculite aggregate	1.7	
Roofing	Asphalt roll roofing		6.50
	Built-up roofing...3/8 in.		3.00
Siding materials	Asbestos-cement, 1/4 in. lapped		4.76
	Asphalt insulating (1/2 in. board)		0.69
	Wood, bevel, 1/2 × 6, lapped		1.23
Woods	Maple, oak, and similar hardwoods	1.10	
	Fir, pine, and similar softwoods	0.80	
	Fir, pine & sim. softwoods 25/32 in.		1.02

[c]Same as *U* value.
[a]Conductivity given in Btu•in./h•ft^2•°F
[b]Conductance given in Btu/h•ft^2•°F
Source: Extracted with permission from *ASHRAE Guide and Data Book*, 1965. Reprinted with permission from the Trane Co., La Crosse, WI.

B. L. Capehart *et. al.*, Guide to Energy Management, 4th ed., Fairmont Press, 2003, pp. 386-387.

Basic Heat Flow Problem

- What is the rate of heat loss through a three-quarter inch plywood wall if the inside temperature is 60°F and the outside temperature is 30°F? The area of the wall is 100 square feet. Include surface films.

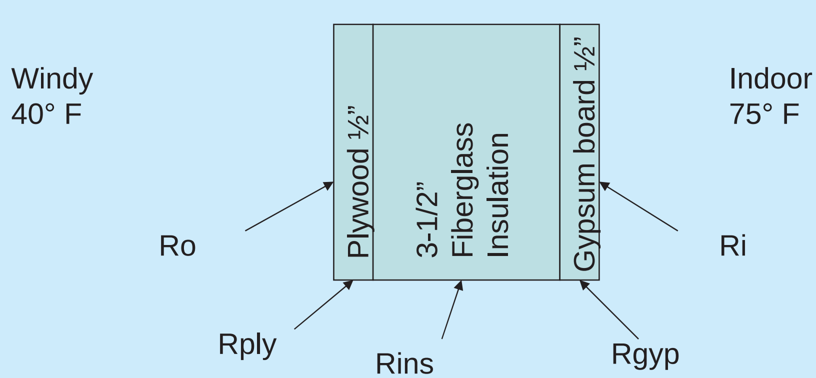
Basic Heat Flow Equations

- How could we reduce the heat flow?
- Often the answer is insulation—a simple and inexpensive way of adding more resistance to the denominator of the equation

$$q = \frac{A \times \Delta T}{\Sigma R} \left[\frac{Btu}{h} \right]$$

Composite Wall Example

A 160 ft^2 wall is exposed to an inside temperature of 75 °F and an outside winter temperature of 40 °F in windy weather. The wall consists of ½” plywood, 3 ½” of fiberglass insulation, and ½” gypsum board. How much heat is lost through the wall? Include surface films.



Basic Heat Flow Equations

- Temperature varies with time of day and season, so we often resort to this heat conduction equation

$$Q = U \times A \times DD \times 24 \quad \left[\frac{Btu}{yr}\right]$$

- where DD can be HDD or CDD. Annual units are $\dfrac{{}^\circ F \cdot d}{yr}$

- UxA is also known as the conduction part of the overall Building Load Coefficient BLC. Other parts include infiltration, ventilation, and slab-on-grade factor.

Air and Water Heat Flow Problems

$$q = \dot{m}\Delta h \quad \left[\frac{Btu}{h}\right] \quad \text{General}$$

$$= \dot{m}C_p\Delta T \quad \left[\frac{Btu}{h}\right] \quad \text{Sensible heat only}$$

$\dot{m}$ = Mass Flow Rate (lb/h)

Δh = Enthalpy Difference (Btu/lb)

C_p = Heat Capacity (Btu/lb·°F)

ΔT = Temperature Difference (°F)

Air and Water Heat Flow Problems

Air: ***Sensible Heat Only***

$$q = \left[CFM \times \frac{0.075\ lb}{ft^3} \times \frac{60\ min}{h} \right] \times \left[\frac{0.24\ Btu}{lb \cdot {}^\circ F} \right] \times \Delta T$$

$$q = CFM \times 1.08 \times \Delta T \qquad \left[\frac{Btu}{h} \right]$$

Sensible heat only

Air and Water Heat Flow Problems

Air: ***General***

$$q = \left[CFM \times \frac{0.075\ lb}{ft^3} \times \frac{60\ min}{h} \right] \times \Delta h$$

$$q = CFM \times 4.5 \times \Delta h \qquad \left[\frac{Btu}{h} \right]$$

Water: Sensible Heat only

$$q = \left(GPM \times \frac{8.34\,lb}{gal} \times \frac{60\,min}{h} \right) \times \left(\frac{1\,Btu}{lb \cdot {}^\circ F} \right) \times \Delta T$$

$$q = GPM \times 500 \times \Delta T \qquad \left[\frac{Btu}{h} \right]$$

Sensible heat only

Fan Laws - or Affinity Laws - Review

- **Flow and Speed**

$$\frac{CFM_2}{CFM_1} = \frac{RPM_2}{RPM_1}$$

- **Pressure (Head) and Speed**

$$\frac{P_2}{P_1} = \left(\frac{RPM_2}{RPM_1} \right)^2 = \left(\frac{CFM_2}{CFM_1} \right)^2$$

- **Power and Speed**

$$\frac{HP_2}{HP_1} = \left(\frac{CFM_2}{CFM_1} \right)^3$$

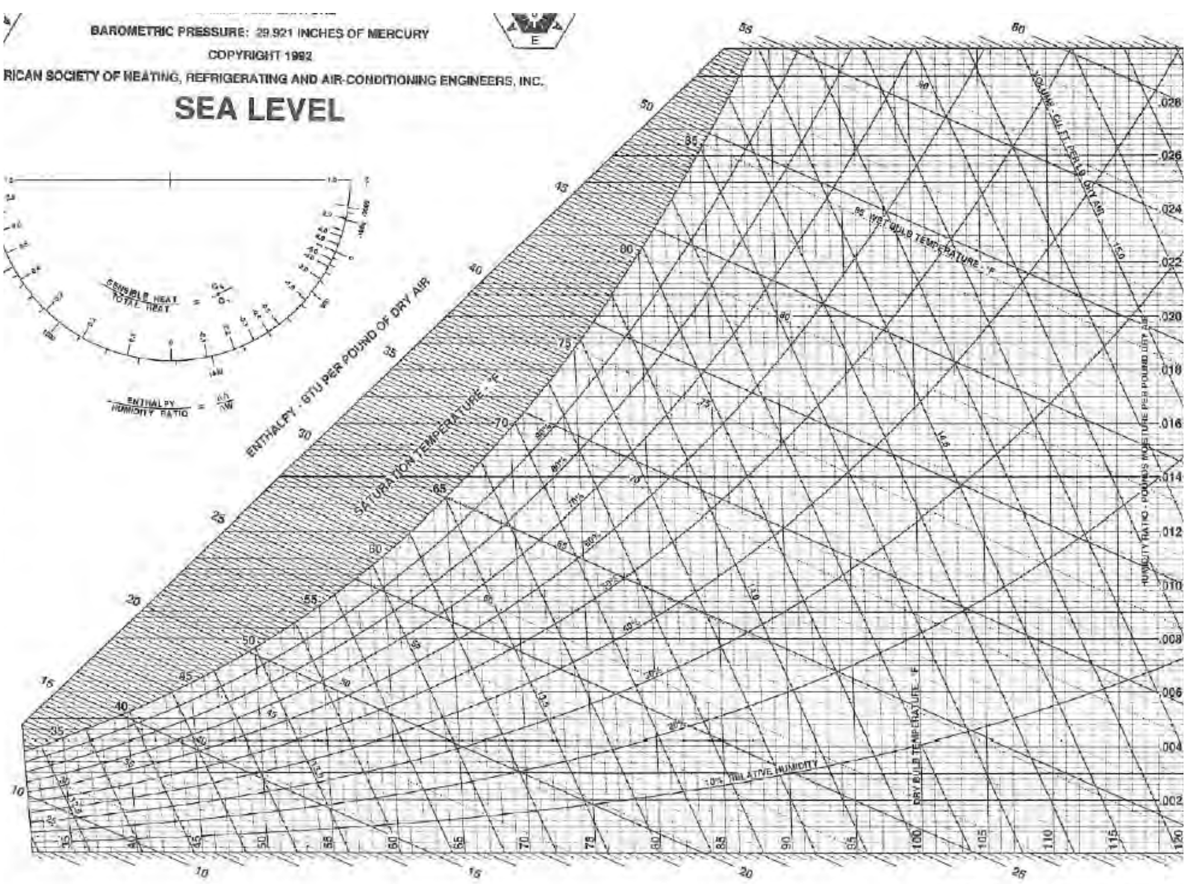
The Psychrometric Chart

The Psychrometric Chart graphically represents the steam tables for moisture in air at conditions we encounter in HVAC work.

The Psych Chart allows complex problems to be worked out easily, and provides a feel for common HVAC processes that we are interested in.

The standard ASHRAE Psych Chart has a horizontal axis for dry bulb temperature, and a vertical axis for humidity ratio in pounds of moisture per pound of dry air.

Other parameters on the chart are: relative humidity, wet bulb temperature, enthalpy, specific volume, and saturation temperature.



CEM Review Problems

An absorption chiller with a COP of 0.8 is powered by hot water that enters at 200°F and exits at 180°F at a rate of 25 gpm. The chilled water operates on a 10°F temperature difference. Calculate the chilled water flow rate. Solution of this problem does not require a knowledge of how absorption chillers work internally.

(A) 10 gpm
(B) 20 gpm
(C) 40 gpm
(D) 45 gpm
(E) 30 gpm

CEM Review Problems

The conduction part of the Building Load Coefficient (U*A) for a building is 5000 Btu/h per degree F. Estimate the seasonal energy consumption for heating if the heating season has 3,500 degree days. The heating unit efficiency is 80%.

(A) 625 MCF/yr
(B) 350 MCF/yr
(C) 420 MCF/yr
(D) 656 MCF/yr
(E) 525 MCF/yr

Example

A wall has an area of 100 ft^2 and has a thermal conductance of 0.25 Btu/ft^2·h·°F. If there are 3000 degree-days in the annual heating season, what is the total amount of heat that must be supplied by the heating system?

Duct Loss Example

10,000 cfm of air leaves an air handler at 50 °F. It is delivered to a room at 65 °F. There was no air volume loss due to duct air leaks. No moisture was added, or taken away from the air in the duct. How many Btu/h heat gain occurred because of heat transfer by conduction?

(A) 162,000 Btu/h

(B) 75,000 Btu/h

(C)126,000 Btu/h

(D) 256,000 Btu/h

(E) 10,000 Btu/h

Chilled Water Flow Example

A chiller supplies cold water with a ΔT of 10 °F.

How many GPM of this water is needed to provide one ton of air conditioning?

Practice Example

ACE Industries presently has a 5 hp ventilating fan that draws warm air from a production area. The motor recently failed, and they have determined the amount of ventilation can be reduced by one-third.

What size motor is needed now?

Answer: 1.48 HP

Psychrometric Heating Example

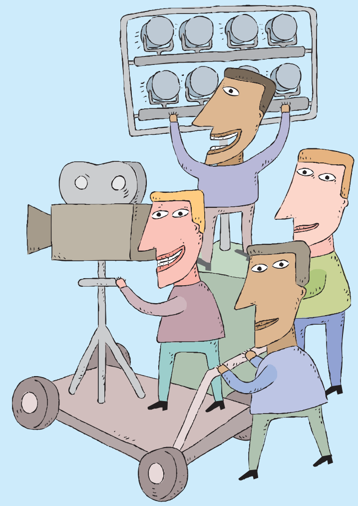
- For air, $q = CFM \times 4.5 \times \Delta h \quad \left[\frac{Btu}{h}\right]$
- Air at 69°F dry bulb and 50% relative humidity flows at 6750 cubic feet per minute and is heated to 90°F dry bulb and humidified to 40% RH. How many Btu/h is required in this process?

(A) 50,000 Btu/hr
(B) 100,000 Btu/hr
(C) 150,000 Btu/hr
(D) 300,000 Btu/hr

Psychrometric Cooling Example

- How many tons of air conditioning is required to cool 1000 CFM of air at 90 °F and 60 % relative humidity (RH) to 60 °F and 100 % RH?

Lighting Basics and Lighting System Improvements



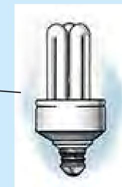
Session 12.1

Principles of Efficient Lighting Design

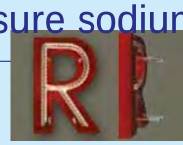
- Meet target light levels
- Efficiently produce light
- Efficiently deliver light
  - Balance efficiency with aesthetics, lighting quality, visual comfort
- Automatically control lighting operation

Session 12.2

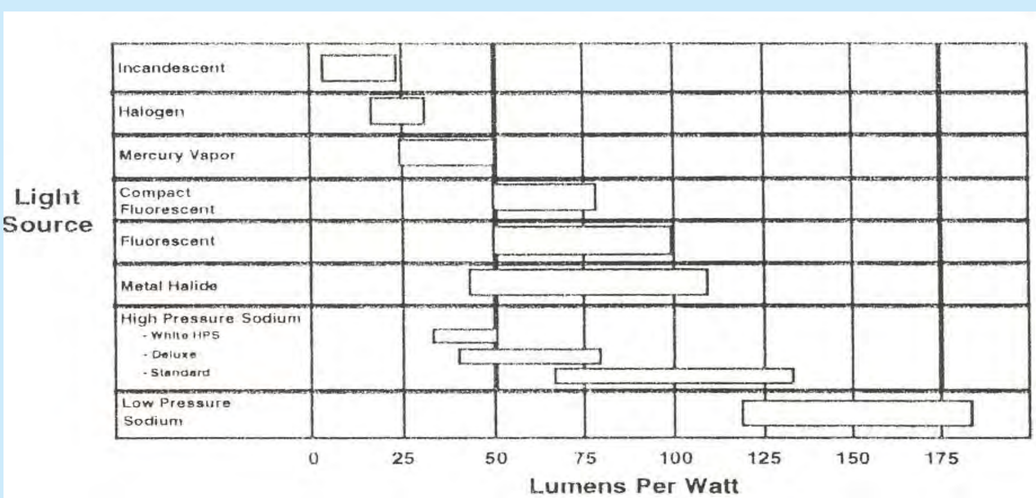
- **Types of Lamps** - Common types of lamps include:
  - incandescent
  - tungsten halogen (also incandescent)
  - compact fluorescent
  - full-size fluorescent
  - mercury vapor
  - metal halide
  - high-pressure sodium
  - low-pressure sodium
  - LED





Light Source Efficacy



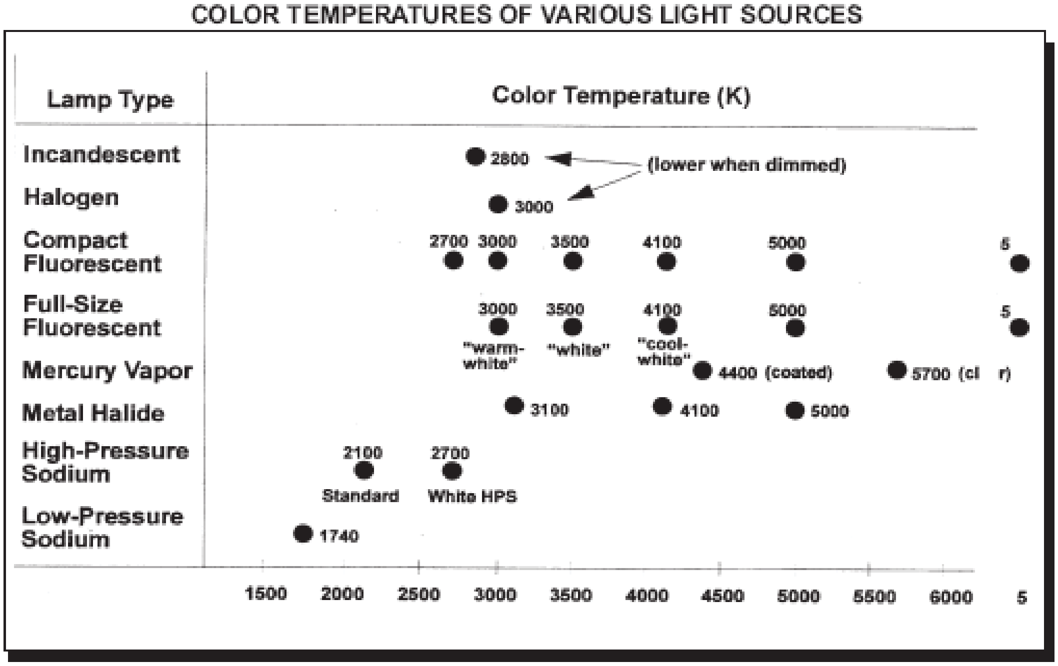
Note: Source efficacy values include ballast losses

Color Rendering Index (CRI)

EXHIBIT 3
TYPICAL CRI VALUES FOR SELECTED LIGHT SOURCES

Source	Typical CRI Value
Incandescent/Halogen	100
Fluorescent	
Cool White T12	62
Warm White T12	53
High Lumen T12	73-85
T8	75-85
T10	80-85
Compact	80-85
Mercury Vapor (clear/coated)	15/50
Metal Halide (clear/coated)	65/70
High-Pressure Sodium	
Standard	22
Deluxe	65
White HPS	85
Low-Pressure Sodium	0

EXHIBIT 5
COLOR TEMPERATURES OF VARIOUS LIGHT SOURCES



Amount of Light Required For Specific Applications

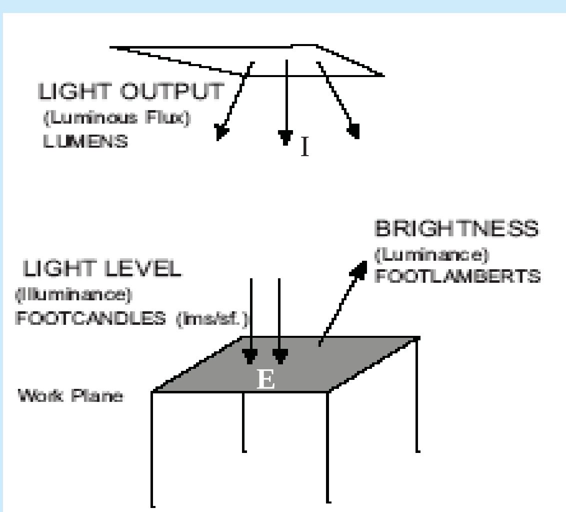
- We often use more light than is needed for many applications and tasks.
  - Light levels are measured in *footcandles (or lux, in SI units)* using an illuminance meter.

$$FC = lumens / ft^2$$

$$Lux = lumens / m^2$$

  - Consensus standards for light levels are set by the Illuminating Engineering Society of North America (IESNA.org).

Quantity of Illumination



Inverse Square Law

$$E = \frac{I}{d^2}$$

where d = distance from light source to surface of interest

RECOMMENDED LIGHT LEVELS
Source: IESNA

TYPE OF ACTIVITY	RANGE OF ILLUMINANCE
Public spaces with dark surroundings	2-3-5 fc
Simple orientation for short temporary visits (typical hallway)	5-7½-10 fc
Working spaces where visual tasks are only occasionally performed	10-15-20 fc
Ambient lighting for computer use	20-25-30 fc
Performance of visual tasks	
High contrast or large size (typical office)	20-30-50 fc
Medium contrast or small size	50-75-100 fc
Low contrast or very small size	100-150-200 fc
Low contrast and very small size over a prolonged period	200-300-500 fc
Performance of very prolonged and exacting visual tasks	500-750-1000 fc
Performance of very special visual tasks of extremely low contrast and small size	1000-1500-2000 fc

Some typical light levels needed are:

Parking lot	2 Footcandles
Hallways	10 Footcandles
Factory floor	30 Footcandles
Offices	50 Footcandles
Inspection	100 Footcandles
Operating room	1000 Footcandles

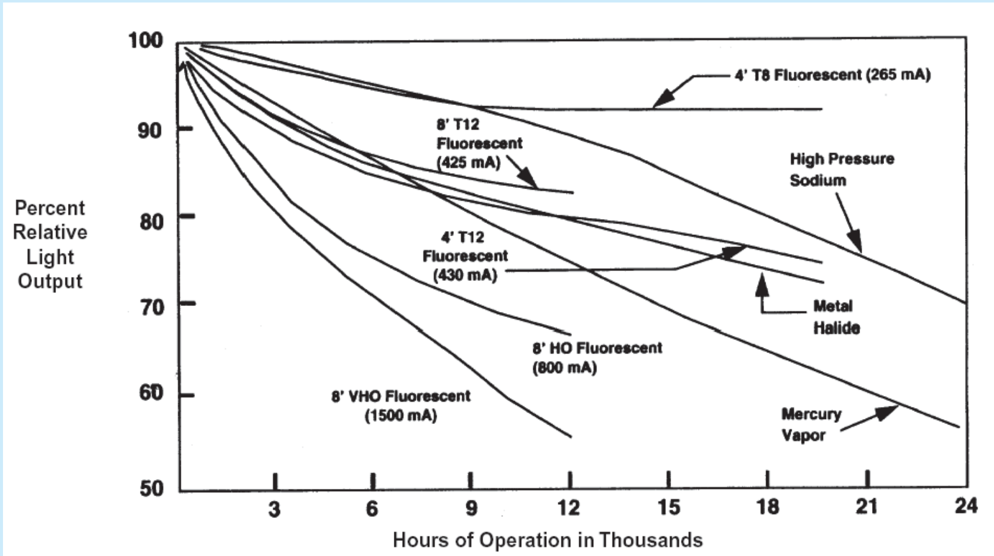
Average Rated Life

- Average rated life of a lamp is median value of life expectancy of a group of lamps
  - Time at which 50% have failed, 50% are surviving
  - Fluorescent lamps rated at 3 hours on, 20 minutes off per operating cycle
  - HID lamps rated at 10 hours on, one hour off per operating cycle
- Increased frequency of switching will decrease lamp life in hours, but typically increase useful calendar life
  - Energy savings more significant than lamp costs

Lighting Maintenance Principles

- Light output of all lighting systems decreases over time
- Lighting systems are over-designed to compensate for future light loss
- Improving maintenance practices can reduce light loss (depreciation) and can either:
  - allow reductions in energy consumption (redesign), or
  - improve light levels
- Group maintenance practices save money

Lamp Lumen Depreciation (LLD)



Source: US DOE

Lighting System Design Methods

1. **Lumen Method**
   - Assumes an equal footcandle level throughout the area.
   - This method has been used frequently since it is simple.
2. **Point by Point Method**
   - The current method of design based on the Fundamental Law of Illumination.
   - Requires a computer program and extensive computation.

Lumen Method Formula

$$N = \frac{F1 \times A}{Lu \times LLF \times Cu}$$

where

- N = the number of lamps required
- F1 = the required footcandle level at the task
- A = area of the room in square feet
- Lu = the lumen output per lamp
- Cu = the coefficient of utilization
- LLF = the combined light loss factor

Example of Lumen Method

Find the number of lamps required to provide a uniform 50 footcandles on the working surface in a 40 x 30 room. Assume two 3000 lumen lamps each per fixture, and assume that LLF is 0.65 and CU is 70%.

$$N = \frac{50 \times 1200}{3000 \times 0.65 \times 0.7} = 44$$

The number of two-lamp fixtures needed is 22.

The Coefficient of Utilization (CU)

The coefficient of utilization is a measure of how well the light coming out of the lamps and the fixture contributes to the useful light level at the work surface.

It may be given, or you may need to find it:

– Use Room Cavity Ratio (RCR) to incorporate room geometry

– Use Photometric Chart for specific lamp and fixture

Room Cavity Ratio (RCR)

RCR = 2.5 x h x (Room Perimeter)/(Room Area)

Where

L = room length

W = room width

h = height from lamp to top of working surface

Example

Find the RCR for a 30 by 40 rectangular room with lamps mounted on the ceiling at a height of 9.5 feet, and the work surface is a standard 30 inch desk.

$$h = 9.5 - 2.5$$
$$= 7 \text{ feet}$$

$$RCR = 2.5 \times h \times (2L+2W)/(L \times W)$$
$$= 2.5 \times 7 \times (60 + 80)/(30 \times 40)$$
$$= 35 \times 70/1200$$
$$= 2.04$$

Photometric Chart

Report LS1 1101
Lamp: 400 Watt Clear
Lumens: 50,000
Mounting Surface/Pendant

COEFFICIENTS OF UTILIZATION
Zonal Cavity Method
Effective Floor Cavity Reflectance 0.20

	RC	80			70			50		30	
	RW	70	50	30	70	50	30	50	30	50	30
RCR	1	94	91	89	91	88	86	83	81	78	77
	2	88	84	80	86	81	78	77	74	73	71
	3	83	77	72	80	75	70	71	67	67	65
	4	78	71	65	75	69	64	66	61	63	59
	5	73	65	59	70	63	58	60	56	58	54
	6	68	58	52	66	58	52	55	51	53	49
	7	63	54	48	61	53	47	51	46	49	44
	8	59	49	43	57	48	43	46	41	45	40
	9	55	45	39	53	44	38	42	37	41	36
	10	51	41	35	49	40	35	39	34	37	33

Example

Find the Coefficient of Utilization for a 30 by 40 rectangular room with a ceiling height of 9.5 feet, a ceiling reflectance of 70% and a wall reflectance of 50% using the photometric chart on the previous page.

The RCR from before was 2.04. Using RC = 70% and RW = 50%, the CU is found as CU = 0.81, or 81%

Fundamental Law of Illumination or Inverse Square Law

$$E = \frac{I}{d^2}$$

where

E = Illuminance in footcandles

I = Luminous intensity in lumens

d = Distance from light source to surface area of interest

One footcandle is equal to one lumen per square foot
(One lux is equal to one lumen per square meter)

Example

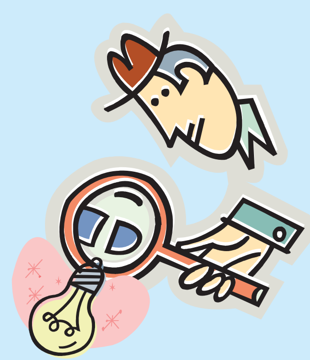
In a high bay facility, the lights are mounted on the ceiling which is 40 feet above the floor. The lighting level on the floor is 50 footcandles. No use is made of the space between 20 feet and 40 feet above the floor.

In a theoretical sense – that is, using the fundamental law of illuminance – what would be the light level in footcandles directly below a lamp if the lights were dropped to 20 feet?

$FC = 50(40^2/20^2) = 200$ footcandles

What to Look for in Lighting Audit

- Lighting Equipment Inventory
- Lighting Loads
- Room Dimensions
- Illumination Levels
- Hours of Use
- Lighting Circuit Voltage



Potential Lighting ECMs

- Fluorescent Upgrades
- Delamping
- Incandescent Upgrades
- HID Upgrades
- Controls Upgrades
- Daylight compensation

What Does a Ballast Do?

- A ballast does three things:
  - Conditions the lamp to start
  - Applies a high voltage spike to start the gas discharge process
  - Applies a current limiter to reduce the lamp current to a safe operating level
- Ballast factor
  - Normal light output (0.85-0.95)
  - Can specify reduced or increased light output in electronic ballasts with proportional reduction or increase in power

New Lighting Technology

- **Induction lamps**
  - Long life -- 100,000 hours for lamp & ballast
  - Phillips QL lamps in 55W, 85W and 165W
  - New application with reflector to replace metal halides as sign lights for road and commercial signs. Last four times as long

- OSRAM/Sylvania is the other maker of long life induction lamps
- Icetron in 70W, 100W and 150W sizes
- Also 100,000 hours
- Properties about same as QL lamp
  - Efficacy around 80 L/W (150 W ICE)
  - CRI 80
  - Instant start, and re-start
  - Operate in hot and cold environments

LED Lighting

- 80% of all new exit lights are LED lights
- But, there are some other interesting applications
  - **Traffic Signals**
    - Green 12" ball — 140 W to 13 W LED
    - Red 12" ball — 140 W to 11 W LED
    - Life — 1 year to 7 years for LED
    - Cost — $3 to $75 for LED
  - **Commercial Advertising Signs (Neon)**
    - Neon 15 mm tube — 3 W/ft
    - LED 15 mm replacement — 1.03 W/ft

T5HO and High Bays

High Bay & Fluorescent T5/HO (it's not just for HID anymore!)

Lamp	Lamp and Ballast * Maintained Light	Wattage
4 - T5/HO Lamps	19,000 Lumens	242 watts
1 - MVR250/U	13,500	293
1 - MVR250/Pulse	17,000	288
6 - T5/HO Lamps	28,500 Lumens	363 watts
1 - MVR400/U	23,500	458
1 - MVR400/Pulse	33,000	456

* (Impact of Fixture Design on Performance NOT included)

AND: Instant on, dimmable, choice of colors, no color shift...

Compare Lighting Power Density to ASHRAE/IES 90.1 Values

- **Example Whole Building Lighting Power Densities (W/ft2)**

	1989	1999	2003	2010
• Offices	1.63	1.30	1.0	0.9
• Education	1.79	1.50	1.2	0.99
• Retail	2.36	1.90	1.5	1.4
• Warehouse	0.53	1.20	0.8	0.66

Typical Lighting Operation

Building Type	Annual Hours of Operation
Assembly	2760
Avg. Non-Residential	3500
Education	2605
Food Sales	5200
Food Service	4580
Health Care	7630
Lodging	8025
Mercantile	3325
Office	2730
Warehouse	3295

Lighting Control Technologies

- On/off snap switch
- Timers and control systems
- Solid-state dimmers
- Dimming electronic ballasts
- Occupancy sensors
- Daylighting level sensors

Energy Savings Potential With Occupancy Sensors

Application	Energy Savings
Offices (Private)	25-50%
Offices (Open Spaces)	20-25%
Rest Rooms	30-75%
Corridors	30-40%
Storage Areas	45-65%
Meeting Rooms	45-65%
Conference Rooms	45-65%
Warehouses	50-75%

Lighting Appendix

AEE:CEM

CEM Exam Review Questions

1. The efficacy of a light source refers to the color rendering index of the lamp.
   A) True B) False

2. Increasing the coefficient of utilization of fixtures in a room will in many instances increase the number of lamps required.
   A) True B) False

3. Which HID lamp has the highest efficacy – for the same wattage?
   A) Mercury vapor
   B) Metal halide
   C) High pressure sodium

4. One disadvantage to metal halide lamps is a pronounced tendency to shift colors as the lamp ages.

A) True B) False

5. A 244,000 square foot high bay facility is presently lit with 800 twin 400 watt mercury vapor fixtures (455 watts per lamp including ballast). What are the annual savings of replacing the existing lighting system with 800 single 400-watt high-pressure sodium fixtures (465 watts per lamp

Including ballast)? Assume 8000 hours operation per year, an energy cost of $0.05 per kWh, and a demand cost of $6.00 per kW-month.

Solution

Solution

ΔkW = (800 fixtures)(.455 kW/lamp)(2 lamps) –
(800 fixtures)(.465 kW/fixture) = 356 kW

Demand $ savings = (356 kW)($6/kW-mo)(12 mo/yr) = $25,632/yr

Energy $ savings = (356 kW)(8000 hrs/yr))($0.05/kWh) = $142,400/yr

Total $ savings = ($25,632 + $142,400)/yr = $168,032/yr

Cost = (800 fixtures)($400/fixture) = $320,000 ??

7. The Light Switch Problem (Just for Fun)

You must determine which switch on a three switch panel on the first floor of a building controls a light on the fifth floor of the building.

- The other two switches are not connected to anything and there is no way to see any light from the fifth floor without going up stairs.
- You have no tools and you cannot take the switch cover off.
- You can only make one trip up the stairs to the light. How can you determine which switch operates the light?

Solution

Turn on the middle switch and the right-hand switch, wait 10 minutes.

Turn the middle one off and run up the stairs.

- If the light bulb is off and cold it is the left-hand switch.
- If the bulb is off and hot it is middle switch.
- If the bulb is on it is the right-hand switch.

EXHIBIT 4
LAMP CHARACTERISTICS

	Standard Incandescent	Tungsten-Halogen	Fluorescent	Compact Fluorescent	Mercury Vapor	Metal Halide	High-Pressure Sodium	Low-Pressure Sodium
Wattage	3-1,500	10-1,500	4-215	4-55	40-1,250	32-2,000	35-1,000	18-180
Average System Efficacy (lm/W)	4-24	8-33	49-89	24-68	19-43	38-86	22-115	50-150
Average Rated Life (hrs)	750-2,000	2,000-4,000	7,500-24,000	7,000-20,000	24,000+	6,000-20,000	16,000-24,000	12,000-18,000
CRI	100	100	49-92	82-86	15-50	65-92	21-85	0
Life Cycle Cost	high	high	low	moderate	moderate	moderate	low	low
Fixture Size	compact	compact	extended	compact	compact	compact	compact	extended
Start to Full Brightness	immediate	immediate	0-5 seconds	0-1 min	3-9 min	3-5 min	3-4 min	7-9 min
Restrike Time	immediate	immediate	immediate	immediate	10-20 min	4-20 min	1 min	immediate
Lumen Maintenance	good/excellent	excellent	fair/excellent	good/excellent	poor/fair	good	good/excellent	excellent

Lighting Fundamentals • Lighting Upgrade Manual • EPA's Green Lights® Program • February 1997

Lighting Quality Measures

- **Visual comfort probability (VCP)** indicates the percent of people who are comfortable with the glare (brightness) from a fixture
- **Spacing criteria (SC)** refers to the maximum recommended distance between fixtures to ensure uniformity
- **Color rendering index (CRI)** indicates the color appearance of an object under a source as compared to a reference source

Compact Fluorescent Example

COMPACT FLUORESCENT LAMPS

For retrofit applications in task lights, wall sconces, downlights, wallwashers, and outdoor fixtures, a wide variety of lamp shapes and types are available. These include globes, capsules, floods, and twin/quad-tube units. The most common retrofit applications are in open fixtures with mounting heights less than 12 feet. In some applications, users may prefer to hardwire the ballast in the fixture to prevent replacement with incandescent lamps. Lamps with excellent color rendering capabilities (80-85 CRI) are recommended for most indoor applications.

Wattages: 5-26W

Replaces: 25-100W incandescents

Energy Savings: 60-75%

Efficacy: 26-58 lm/W

Lamp Cost: $3-6

Ballast Cost: $9-24

Rated Lamp Life: 10,000 hrs

Color Quality: 60-85 CRI

Dimming: Not in retrofit applications

Qualifications: These lamps can have starting limitations in freezing temperatures, and operation in enclosed fixtures may shorten lamp and ballast life and reduce light output. Because compact fluorescents are not point sources, other technologies may be more suitable in applications—such as retail display lighting—where good beam control is required. Some conventional fixture types may not be large enough to accept the larger size of the fluorescent lamp/ballast package. Check manufacturer data to determine impacts of ballast use on power factor and power quality.

Example: Compact Fluorescent Lamps

Old System: Incandescent hallway recessed downlighting in 12' ceiling; 100 fixtures @ 75 watts (@ $3.50); operating hours: 15 hrs/day, 6 days/week (4,680 hrs/yr)

New System: Screw-in fluorescent lamps (82 CRI) with integrated magnetic ballasts; downlighting reflectors; 100 fixtures @ 22 watts (including ballast operation)

Results: 71% energy savings; virtually unchanged light level and appearance; 10 times longer lamp life

Savings: Demand savings: 5.3 kW; energy savings: 24,800 kWh/yr, dollar savings @ $4/kW/mo and $0.08/kWh: $2,238/yr; relamping savings: materials $796/yr; labor $2,106/yr

Net Savings: $5,140/yr

Cost: Material: 100 lamp/ballast capsules @ $18, 100 reflectors @ $4; Labor: 100 installations @ $3

Total Project Cost: $2,500

Payback: $2,500/$5,140/yr = 0.49 yr

Calculation for Compact Fluorescent Example

kW savings
100 fixtures (.075 kW/fixture - .022 kW/fixture) = 5.3 kW

kWh savings
(5.3 kW)(4680 hrs/yr) = 24,804 kWh

Demand $ savings
(5.3 kW)($4/kW-mo)(12 mo/yr) = $254.40/yr

Energy $ savings
(24,804 kWh/yr)($0.08/kWh) = $1,984.32/yr

Total dollar savings
($254.40 + $1,984.32)/yr = $2239/yr

T-8 Example

Example: T-8 Fluorescent System Retrofit

Old System: Office lighting consisting of 360 fluorescent 2'x4' fixtures; operating hours:14 hrs/day, 5 days/week (3640 hrs/yr); each fixture draws 188 watts with 4 standard cool white 40-watt fluorescent lamps (@ $2) and 2 standard magnetic ballasts

New System: Each fixture now draws 112 watts with 4 tri-phosphor F40T8 32-watt fluorescent lamps and 1 electronic T-8 instant-start mode ballast*

Results: 40% energy savings; 2% reduction in light level; improved color rendering; 50% fewer ballasts to replace; 25% less lamp life using instant-start mode ballasts

Savings: Demand savings: 27.4 kW; energy savings: 99,600 kWh/yr; dollar savings @ $4/kW/mo and $0.08/kWh: $9,280/yr; relamping savings: materials <$612/yr>; labor <$437/yr>

Net Savings: $8,231/yr

Cost: Material: 1440 F32T8 fluorescent lamps @ $3.25; 360 T-8 instant-start mode electronic ballasts @ $31; labor: 360 installations @ $20

Total Project Cost: $23,040

Payback: $23,040/$8,231/yr = 2.8 yrs (with 10% a/c factor, payback becomes 2.5 yrs)

*Building codes in some states do not allow all four lamps to be operated by a single ballast. In such cases, two adjacent fixtures can share two ballasts that are wired to leave the two-level switching intact. Assume an additional $15 wiring cost per fixture. The payback period increases to 3.5 years.

Calculation for T-8 Example

Demand savings

(360 fixtures)(.188 - .112) kW/fixture = 27.4kW

Total $ savings

(27.4 kW)[($4/kW-mo)(12 mo/yr) + (3640 hrs/yr x $0.08/kWh)] = $9290/yr

Occupancy Sensor Example

Uncontrolled System: Six conference rooms, each with four 4-lamp fluorescent fixtures (188 watts) operating 10 hrs/day, 5 days/week (2,600 hrs/yr); lamps @ $2

Controlled System: When conference rooms are unoccupied for longer than five minutes, the fixtures are now automatically turned off; they now operate about 7 hrs/day, 5 days/week (1,820 hrs/yr)

Results: 30% energy savings; no change in fixture appearance or light level

Savings: Energy savings: 3,519 kWh/yr; dollar savings @ $0.08/kWh: $282/yr; relamping savings: materials $7/yr; labor $19/yr

Net Savings: $308/yr

Cost: Material: 6 switch-mount occupancy sensors @ $70; labor: 6 installations @ $10

Total Project Cost: $480

Payback: $480/$308/yr = 1.6 yrs (with 10% a/c factor, payback becomes 1.4 yrs)

Energy savings

(24 fixture)(.188 kW/fixture)(2600 hrs/yr)(0.30)($0.08/kWh) = $282/yr

Example Lighting / HVAC Interaction

Location	Cooling Loads	Heating Loads Large Building	Heating Loads Small Building
Tampa, FL	-33%	0%	0%
Phoenix, AZ	-30%	0%	0%
New Orleans, LA	-29%	1%	2%
Los Angeles, CA	-23%	0%	0%
Knoxville, TN	-21%	4%	11%
Philadelphia, PA	-17%	6%	18%
Denver, CO	-16%	7%	22%
San Francisco, CA	-16%	1%	2%
Detroit, MI	-14%	8%	23%
Providence, RI	-13%	7%	22%
Seattle, WA	-7%	4%	13%

Source: Advanced Lighting Guidelines 2003
(based on methodology of Rundquist, et.al. 1993)

Thermal Energy Storage

Session 13.1

Why is There Interest in Thermal Energy Storage?

- Reduced peak demand costs
- Some utilities offer rebates and rate incentives
- Reduced equipment size and cost (new)
- May be improved reliability due to production and storage
- Smaller fans and pumps (colder water with ice storage)

Session 13.2

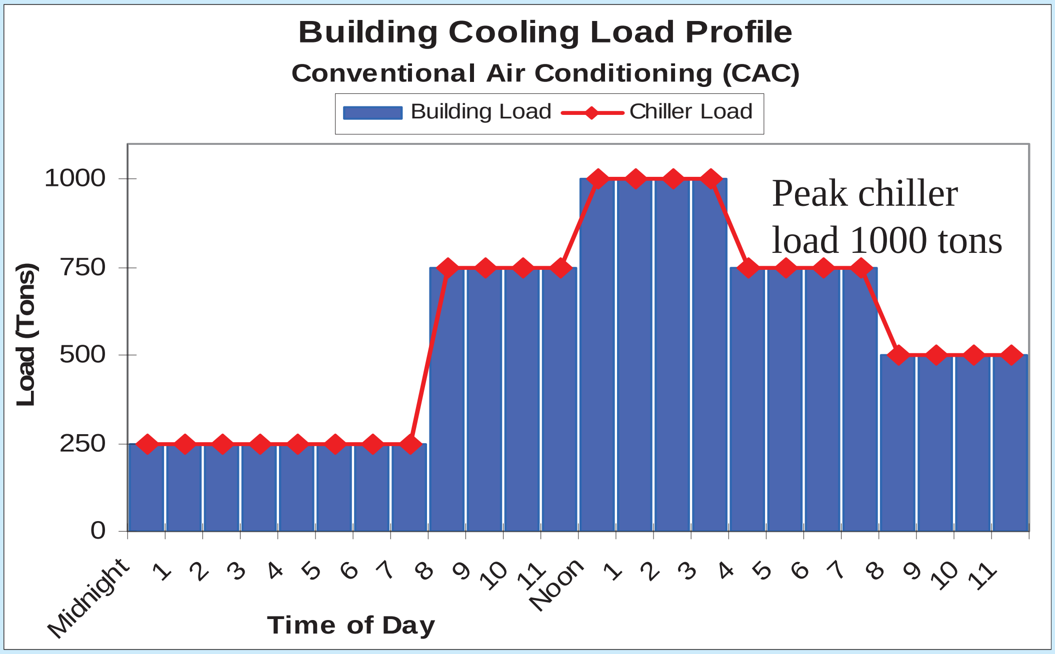
Economic Payback Time

- Typical simple payback of 5 to 7 years (maybe 3 to 5 in some cases) for existing buildings and chillers.
- Recent examples from ASHRAE and others are showing the payback may be immediate to 1 – 2 years for good design in new construction.

Conventional Air Conditioning Operation

- CAC system peaks at peak cooling time
- CAC system is sized to meet peak cooling load
- CAC system may have its lowest efficiency at the time it is needed the most

CAC Operation

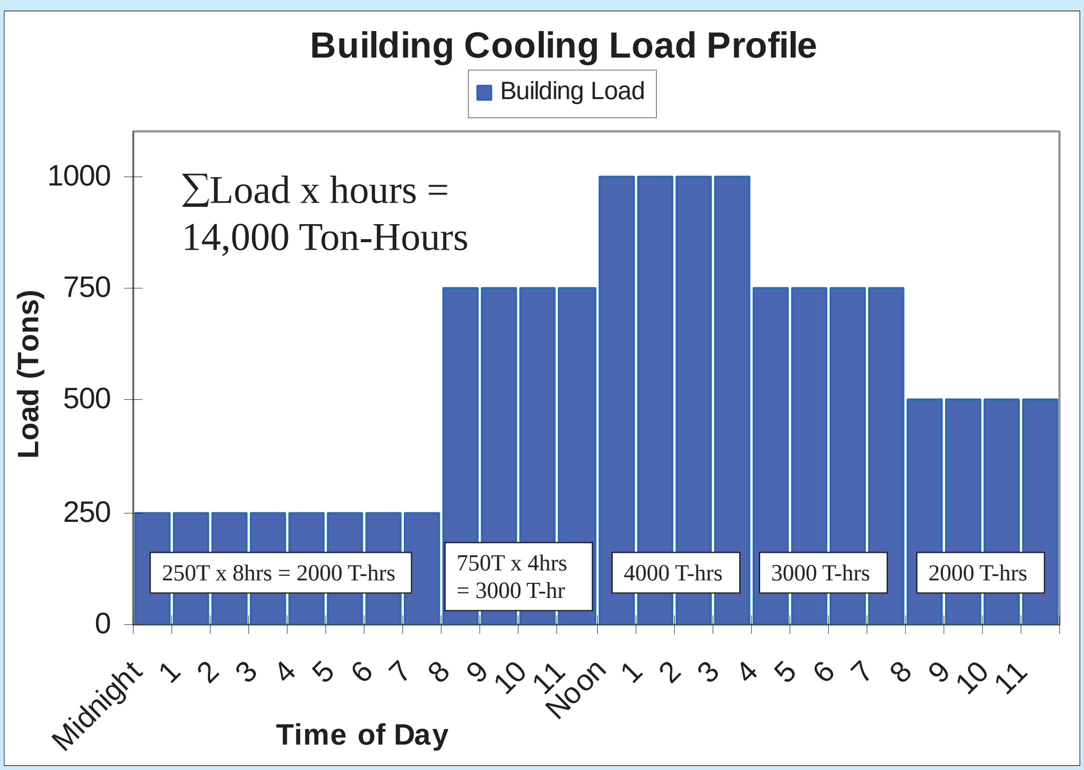


Off-Peak Air Conditioning Operation

- CAC together with storage is used to meet peak cooling loads
- Chilled water or ice is used for storage medium
- Daytime peak load is reduced or eliminated
- OPAC system operates at night when efficiencies are usually higher due to lower outside temperatures

Off-Peak Air Conditioning Operation

- The *Total Daily Cooling Load* (plus system losses) must be met
- The *Instantaneous Cooling Loads* must also be met when they occur, just not directly from the chillers.
- We are simply decoupling the Load (demand) from the Chiller (supply)
- If we take advantage of optimal chiller loading (sweet spot) and cooler condenser temperatures, we may gain significant efficiencies.

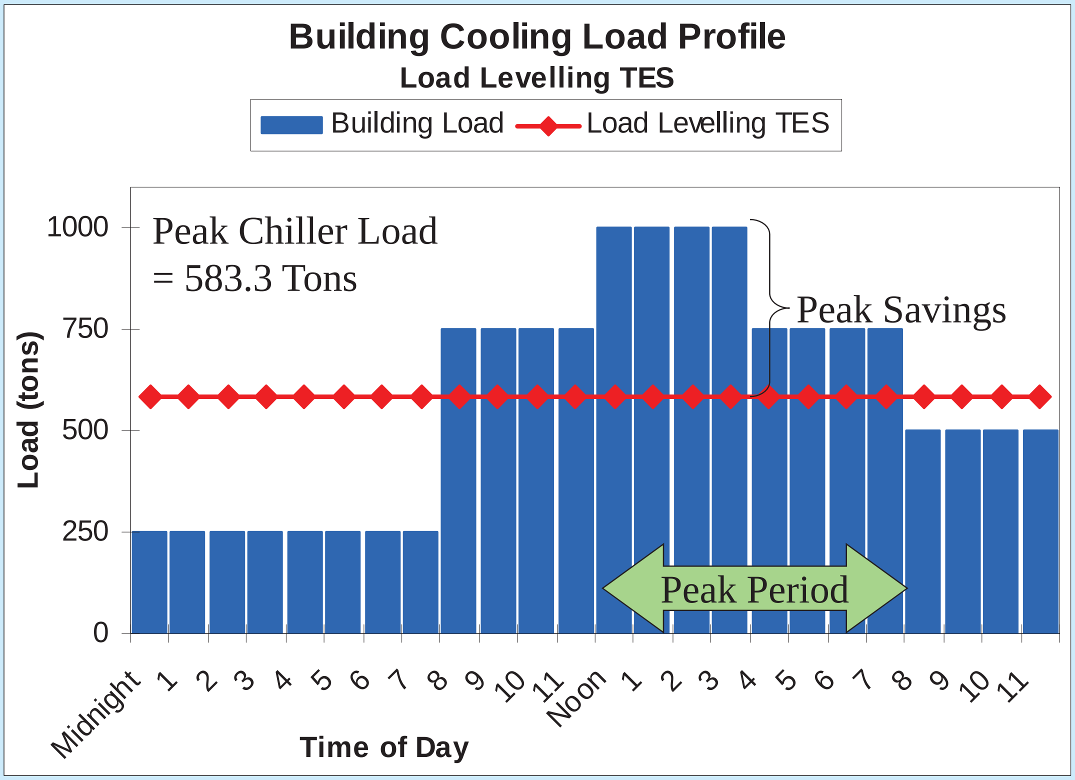


OPAC Operating Strategies

- **Load leveling**
  - Partial shifting of AC load to off-peak hours
  - Chiller runs at constant load or near constant load for 24 hours per day
  - Very cost effective for new construction
  - Less costly to purchase
  - Less space needed
  - But ~ less savings

Load Leveling Chiller Load Calculations

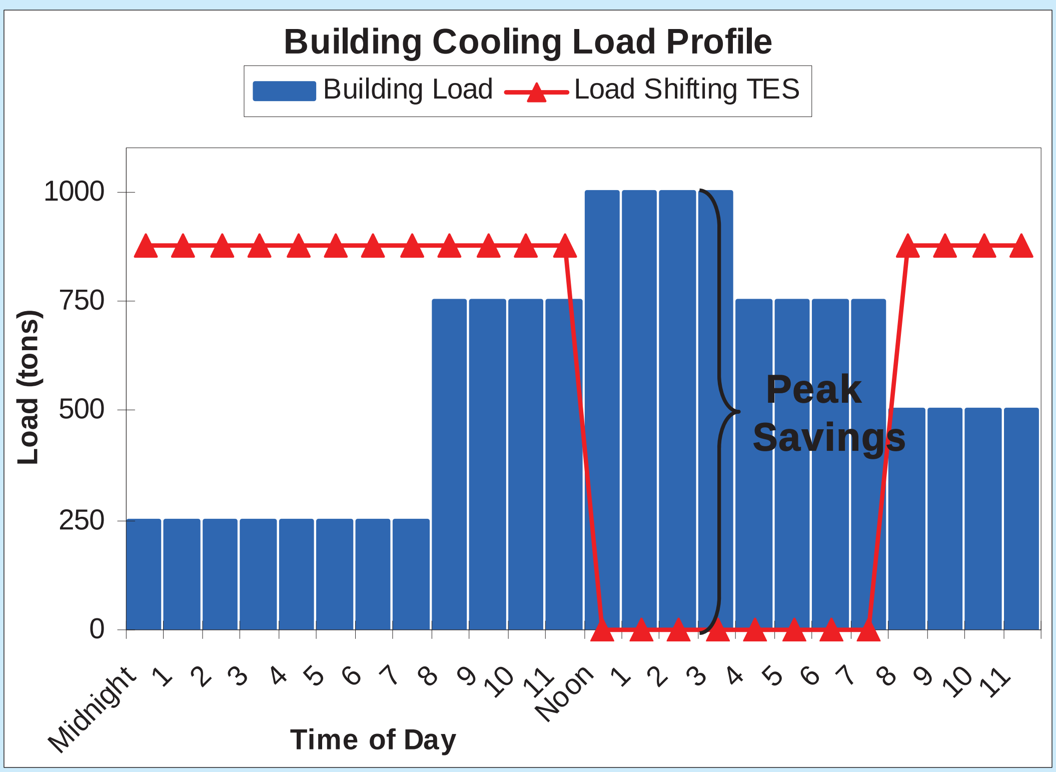
- Where would we need to operate the chiller(s) in order to satisfy the building load? Peak period between 12:00 p.m. to 8 p.m.
- Total Ton Hours / Hours available to operate chillers
- For the Load Leveling Strategy, the chiller will operate 24 hours per day, at a load of:
  - 14,000 Ton-hours / 24 hours = 583.3 Tons



- **Load shifting**
  - Complete shifting of peak hour AC load to off-peak hours
  - OPAC system must be sized to meet peak cooling load in ton-h
  - Usually more cost effective for retrofit situations because of large existing chiller load that can be moved mostly off peak
  - More costly to purchase and install
  - Requires more space for storage tanks
  - But ~ more savings

OPAC Load Calculations

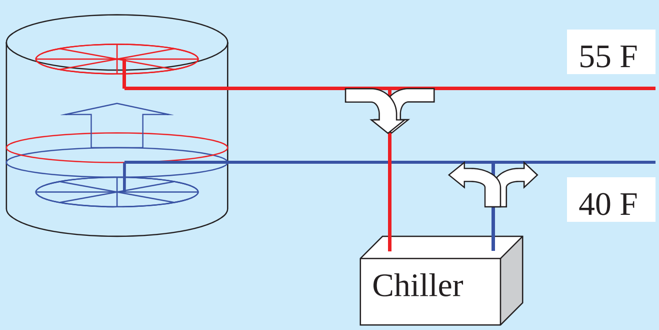
- Total Ton Hours / Hours available to operate chillers
- A peak period from noon to 8 p.m. would only leave 16 hours to generate cooling capacity.
- For the Load Shifting Strategy, the chiller will operate at a load of:
  - 14,000 Ton-hours / 16 hours = 875 Tons



TES Storage Media

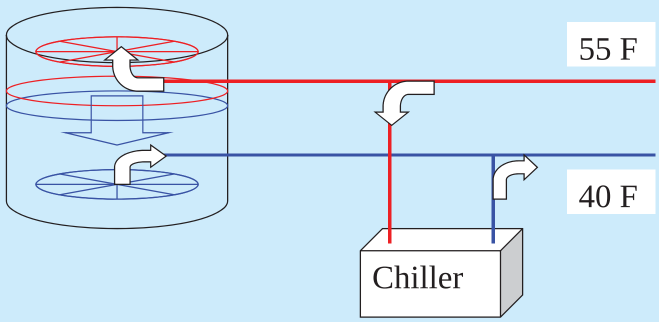
- Chilled water storage
  - Simple ~ but large tanks needed; lots of space. Requires 4 to 5 times the space of ice storage
  - Typical water temperatures of 39 to 40 deg F
  - Practical considerations for water storage tanks
    - Need to minimize mixing of warm return water with the cold water in storage
    - May need two tanks ~ if full capacity of a tank is needed. If temperature stratification of tank is used, the tank may need to be up to 20% bigger

Stratified Water Tank



In Charge mode, the Chiller will generate cooling, and the valve and pump controls will supply building cooling with excess going to the tank.

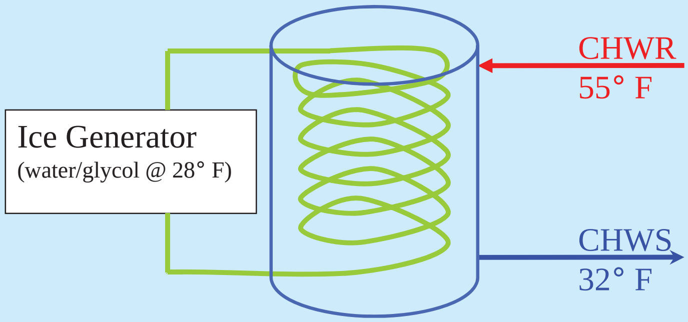
Stratified Water Tank



In Discharge mode, the tank will supplement the chiller ("load leveling" strategy) or Supply all the cooling required by the building as in the "full shift" strategy.

- **Ice Storage**
  - More complex tanks and auxiliary equipment needed; more complex to maintain
  - Ice/water requires around 20 to 30% of the space needed for chilled water tanks
  - Solid ice requires around 10% of the space needed for chilled water tanks
  - Very low temperature water can be used ~ around 34 degrees F
  - Can use ice harvester, ice on coil, or ice/water (slush)

Ice on Coil Tank



In Charge mode, the Ice Generator will circulate 28°F Water/Glycol mixture through Chilled Water Tank, freezing Chilled water on the coils. Warm CHWR melts the ice during Discharge, thus cooling the CHWS.

Properties of Storage Media

- Chilled water systems are typically operated in a manner to use only sensible heat storage and thus stores one Btu per pound of water for each ºF of temperature difference between the stored water and the returned water
- Ice systems are typically operated in a manner to use only latent heat associated with freezing and melting, and one pound of ice at 32ºF absorbs 144 Btu to become 32ºF water

Sizing Chilled Water Storage Tanks

Assume that chilled water is stored at 39ºF and is returned at the standard temperature of 54ºF

- This is a 15ºΔT for the AC system.
- Thus, one pound of water stores 15 Btu.
- One ton-h of AC is 12,000 Btu

So, to store 1 ton-h you need:

(1 lb H20/15 btu)(12,000 btu/ton-h)

800 lbs/ton-h

Sizing Chilled Water Storage Tanks

Assuming there are 8.34 lbs/gal. We have approximately:

(800 lbs H20/ton-hr)(1 gal H20/8.34 lbs)

96 ~ 100 gals/ton hr @ 15 dT

So our full storage system of 7000 ton-hr would be around 700,000 gallons

Or a tank 60' dia, and 30' high.

Conditions That Favor TES

- High peak demand charges
- Low cost of energy used at night
- High on-peak loads
- Low AC loads at night
- Need for increased cooling system capacity

CEM Review Problems

1. TES systems yield large energy savings.
   A) True   B) False

2. Distinguish between full and partial storage systems. Which would likely be better in new system design?

3. Why are utilities encouraging TES?

4. Temperature stratification can occur in
   (A) Chilled water storage
   (B) Hot water storage
   (C) A & B
   (D) None of the above

5. TES for heating uses some of the following storages: 1) building mass; 2) hot water; 3) ground couple; 4) compressed air tanks; 5) rocks; and 6) propane containers. Select the right combination:

   (A) 1,2,3,4 (B) 3,4,5,6
   (C) 1,2,3,5 (D) 2,4,5,6

6. With a load leveling TES strategy, a building manager will
   (A) Not operate the chiller during peak hours
   (B) Essentially base load the chiller (i.e., operate at high load most of the time)
   (C) Operate only during the peak times
   (D) Operate in the “off” season

7. A large commercial building will be retrofitted with a closed loop water to air heat pump system. Individual department meters will meter costs to each department. Demand billing is a small part of the total electrical cost. Would you recommend a TES?
   (A) Yes (B) No

TES Appendix

Another Storage Medium

- There is one more storage medium that is available, but it is almost never used. It is Eutectic Salt.
- Eutectic salt was used some in the 1970s and early 1980s for storage of heat, but its use for air conditioning is not common today. But, it could be used.

- **Eutectic Salt Storage**
  - Expensive, high tech solution
  - Allows use of existing 44 degree F chillers
  - Typical melt range is 41 to 47 degrees F
  - Requires only 30 to 50% of the space needed for chilled water tanks
  - Requires secondary heat exchanger
  - May be considered hazardous
  - The salt has a useful life of about five years, and must then be sent back and replaced

Storage Capability of Eutectic Salts

- Eutectic salts use latent heat associated with freezing and melting, but one pound of solid eutectic salt absorbs only about 50 Btu to become liquid

Summary of Storage Tank Sizing

These are real world, practical numbers – not for use on CEM test

- Chilled water

  15 to 18 cubic feet per ton-hr

- Eutectic salt

  3.5 to 6 cubic feet per ton-h

- Ice

  3 to 3.5 cubic feet per ton-h