Duct Extensions for Improved Terminal Unit Airflow Calibration Accuracy

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Introduction

Have you ever taken a final set of Terminal Unit (TU) airflow readings to confirm the improvement from the K-factor update only to find that the total air flow is less accurate? Have you ever wondered why the calibration of some pressure-independent TUs requires several more iterations than others? The answer is typically right in front of our eyes. If the supply duct static pressure has been proven to be stable, all that we have to do at this point is examine the inlet conditions at the TU duct collar. Ideally, there will be a straight length of hard duct connected to the TU duct collar. This length of duct provides room for the airflow to stabilize prior passing over the airflow pickup for differential pressure measurement and airflow calculation. This creates the optimum conditions for stable airflow readings with minimal fluctuations.

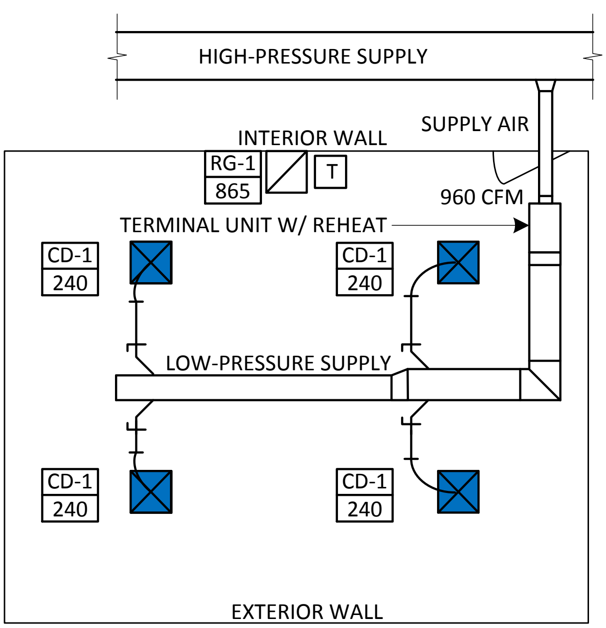


Diagram 1 – Typical Single-Duct TU

TU Airflow Calibration

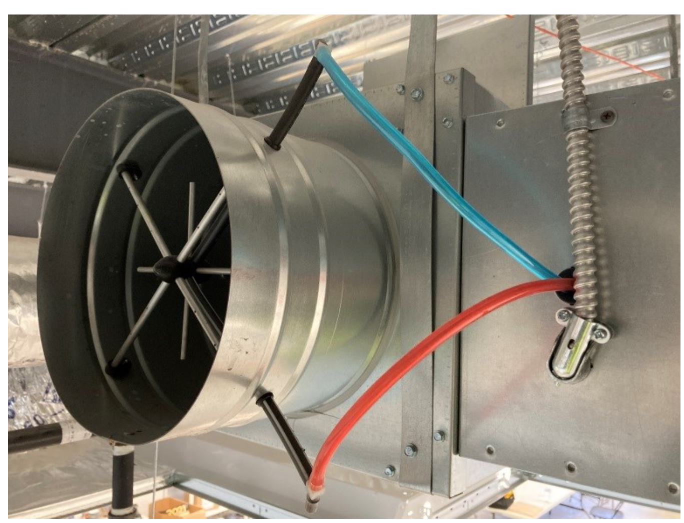
Calibration of pressure-independent TU airflow indications is critically important to controlling space temperature and operating at peak energy efficiency. TU airflow calibration requires a comparison of the actual and indicated (through the BAS) airflow rates while operating at a fixed airflow setpoint (or damper position).

$$Flow = \mathrm{K} * \sqrt{DP} = \mathrm{X}\frac{FT^3}{Minute}$$

Calibration airflow readings are typically taken while operating at the maximum cooling airflow and/or minimum cooling airflow setpoints. The measured airflow and BAS-indicated airflow are used to update the K-factor which determines how the airflow is calculated.

$$Kfactor_{NEW} = Kfactor_{OLD} * \frac{Flow_{Measured}}{Flow_{BAS}}$$

The K-factor may be updated through the space temperature sensor user interface or through the BAS. After the K-factor update, a final set of airflow readings is typically performed to confirm the improvement in the airflow indication. Occasionally, the individual readings as well as the total supply airflow readings get worse – not better. How does this happen? To understand the answer we will review how the typical pressure-independent TU functions.

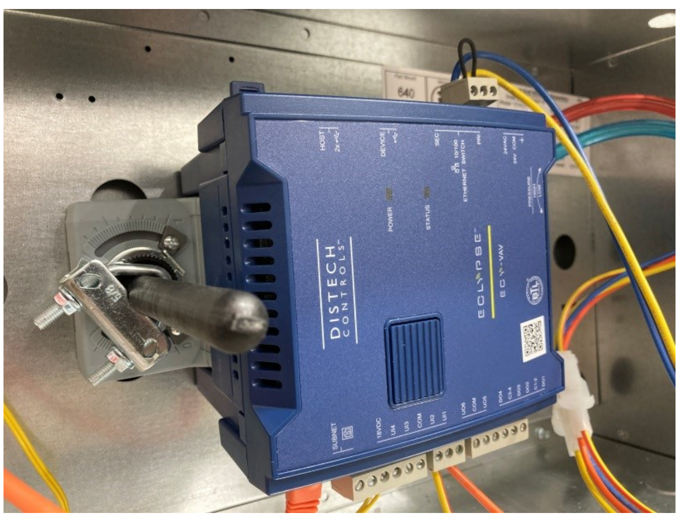


Photograph 1 – TU Airflow Pickup and Inlet Duct Collar

Pressure-Independent Terminal Unit

Pressure-independent Terminal Units (TUs) are an integral part of the variable-air-volume distribution system. They allow the cooling capacity to be controlled by modulating the flow of primary air (also referred to as supply air) delivered to the space(s). A TU controller uses an airflow pickup (Photograph 1), Air Differential Pressure Transmitter (ADPT), and control damper to measure and control the airflow to setpoint.

The control damper is located downstream of the airflow pickup to avoid the turbulence that it generates as it modulates. The TU controller may have an integral or a separate damper actuator that is secured to the control damper shaft (Photograph 2). The control damper is typically a butterfly type that modulates from 0% to 100% open over a 90 degree rotation. Terminal units are typically configured to control the flow of high-pressure supply air to one or more supply air devices which are connected to the low-pressure ductwork (Diagram 1). These devices may be Diffusers, Registers, or Grills (DRGs) or a combination thereof.

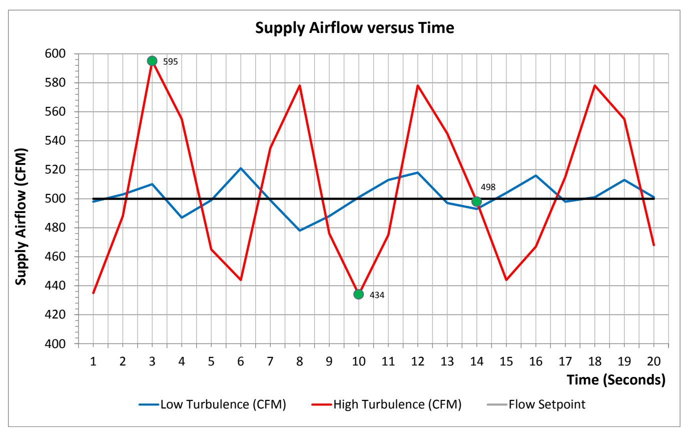


Photograph 2 – Integral Control Damper Actuator

Duct Connections to TUs

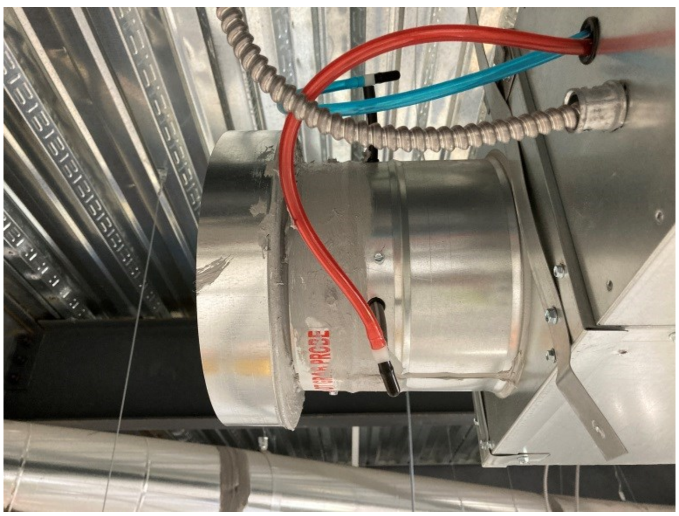
The airflow pickup is typically located in the TU inlet duct collar which is where the adjoining ductwork is connected. Duct connections to pressure-independent TUs are typically made with either hard duct constructed of sheet metal or insulated flexible duct (typically referred to as "flex" duct). Most TUs have a very short inlet duct collar (4-8 inches) as indicated in Photograph 1. Therefore, the airflow indication is highly influenced by the construction of the TU's inlet ductwork. This effect as similar to System Effect which affects the performance of fans. The effect of TU inlet turbulence on the airflow capture hood readings is not as noticeable because the supply air has the opportunity to stabilize as it passes through the heating coil (if equipped), larger low-pressure supply ductwork, and the final DRGs.

To see the effect of turbulence, we need to examine a plot of the differential pressure or airflow readings (Graph 1). The blue curve represents the airflow indication when the inlet duct construction is free of adjacent fittings, transition, and directional changes which generate turbulence. The result is a fairly smooth and consistent airflow profile with minimal airflow fluctuations. The indicated airflow trends closely with the airflow setpoint of 500 CFM. The red curve represents the airflow indications when fittings, transition, and directional changes are in close proximity to the TU inlet duct collar. As you can see, there is a higher degree of airflow fluctuation. The calibration results vary significantly depending on the indicated airflow rate at the instant that the K-factor update was entered into the TU controller. This is why the results of calibration readings can get worse instead of better requiring additional iterations.



Graph 1 – Low versus High Turbulence Airflow Readings

Duct fittings, transitions, and directional changes cause air turbulence which negatively impacts the indicated airflow accuracy and stability. When they are installed too close to the TU duct collar they create turbulence at the airflow pickup. The turbulence creates erratic and pulsating pressure waves which constantly change the differential pressure measured by the ADPT. This in turn affects the airflow indications. With the best TU inlet duct conditions, the differential pressure signal acquired by the ADPT and the resulting airflow indications may fluctuate ±1-10% of design airflow. The TU controllers typically apply some level of signal filtering to reduce the indicated fluctuations, but rest assured that they are happening. When there are less-than-optimum TU inlet duct conditions, the level of stability of the airflow readings can degrade to ±20% of design airflow or more. Photograph 3 shows a step transition installed to account for the difference between the branch duct size and the TU inlet duct collar size. A concentric round duct reducer installed well away from the inlet duct collar to prevent turbulence would have been a better choice for this application.

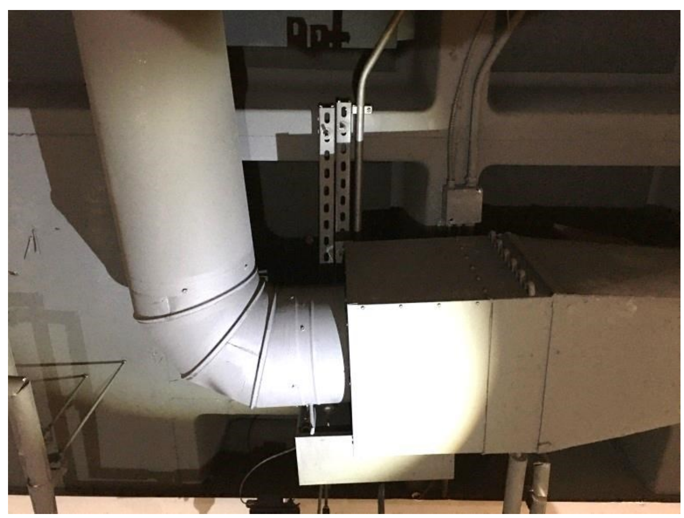


Photograph 3 – Size Transition at TU Inlet

In many installations, the terminal units are connected to the supply ductwork with insulated flexible ducts. (Photograph 4). Flexible ducts permit TU connections when the TU inlet duct collar and the supply duct do not align. Even perfectly straight flexible duct generates significant turbulence because of its rough and irregular internal surface. This is why hard duct extensions are preferred to flexible duct extensions. Hard ductwork provides the optimum internal surface conditions to minimize turbulence. When flexible ducts terminate at the TU inlet duct collar with small angles (<30 degrees), they can impart high levels of turbulence in the supply airstream just as it is measured by the airflow pickup. When the angles of entry are larger than 30 degrees, very high levels of turbulence are produced.

Photograph 4 – Flex Duct at TU Inlet

Turbulence 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 indications (Graph 1). In some situations, airflow control is impossible because turbulence renders the airflow indication useless. The noise generated by the turbulence exceeds the differential pressure signal required to calculate the airflow rate. This, in turn, can cause the damper actuator to constantly adjust which will significantly shorten its life.



Photograph 5 – 90 Degree Elbow at TU Inlet

TU Duct Extension

For optimum accuracy and stability of TU supply airflow readings, a hard duct extension of at least 3-5 duct diameters (minimum 24 inches) constructed of straight sheet metal is recommended. This length of straight duct provides separation from duct features that generate turbulence and provides room for the supply air velocity profile to stabilize before differential pressure measurement.

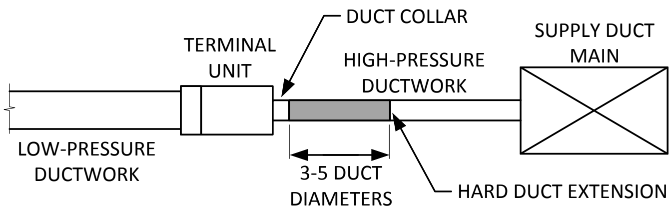


Diagram 2 – Duct Extension at TU Inlet

In addition, the angle of the hard or flexible duct connection to the hard duct extension should not be any larger than 30 degrees from the duct's longitudinal axis. This will result in a more 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 fluctuate erratically. Fewer iterations will be required to calibrate the BAS airflow indications to the reference airflow readings.

Conclusion

The conditions of the TU inlet duct construction are critically important to the accuracy and stability of airflow readings provided by the airflow pickup and ADPT. The hard duct extension allows time for the turbulence in the airstream to dissipate before the differential pressure across the airflow pickup is measured. The airflow entering the terminal unit is anything but smooth and stable. Even in perfectly straight duct with a smooth internal surface, there is always a small amount of turbulence in the airstream. Turbulence generates noise in the voltage signal acquired by the ADPT. Photographs (#3, #4, and #5) were provided of three common examples of TU installations with poor inlet conditions that led to inaccurate, pulsating, and unstable airflow indications.

The hard duct extension ensures a minimum distance from sources of turbulence which decreases the signal noise and increases the stability of the airflow indication which reduces the number of calibrations readings needed to calibrate the airflow readings. Hard duct extensions on existing TUs that have poor inlet conditions and constantly fluctuating airflow indications should be considered as a remedial measure. Design Engineers and Commissioning Agents should strongly consider adding this requirement to the contract documents to ensure that it is provided by the Mechanical Contractor. This is typically done with a TU duct detail similar to Diagram 2. This is the best way to ensure that the Mechanical Contractor and their subcontractors see this requirement. Hard duct extensions improve the performance of the pressure-independent TUs and reduce the man-hours required to calibrate the pressure-independent TU airflows. We need to work to ensure that hard duct extensions become common industry knowledge and standard TU installation practice.

Photograph 6 – Hard Duct Extension at TU Inlet