VAV AIRFLOW CONTROL

Reliable Without Limitations?

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21st National Conference on Building Commissioning

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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Presentation Description

1. VAV Airflow Station…
2. …testing at Factory Facilities
3. …testing on projects
4. …inaccuracy AFTER calibration
5. Medical Research facility example
6. Energy usage implications
7. Suggestions

Learning Objectives

At the end of this session, participants will be able to:

1. Apply practical methods for evaluating VAV systems for proper operation and possible excessive energy use at minimum airflow.

2. Communicate with HVAC professionals about VAV terminal units regarding performance and minimum airflow verification methodology.

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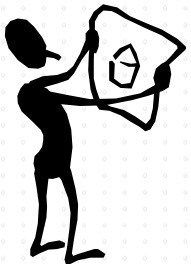
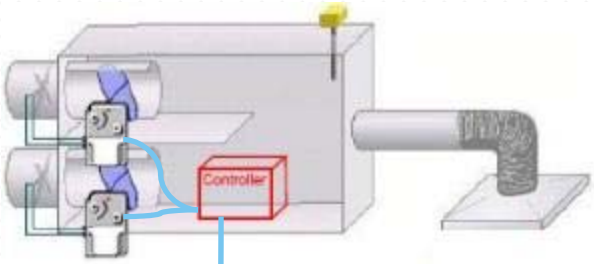
VAVs…What's the big deal anyway?

…review project documents…





Building **A**utomation **S**ystem (BAS) guys…

…enter the VAV data into BAS application…

…upload BAS to each VAV controller

T

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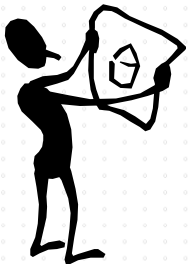
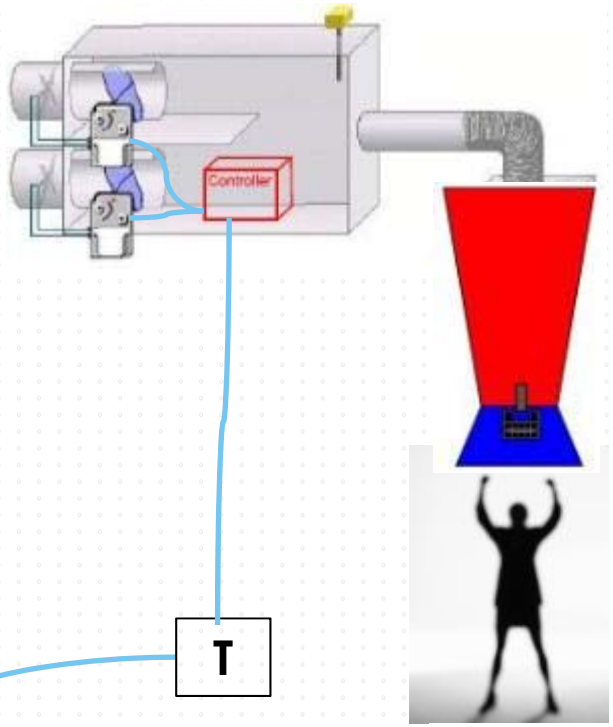
Testing **A**djusting **B**alance (TAB) guys…

…review project information…



…connect to the VAV…



…proportionately balance the outlets…

…calibrate the airflow station…

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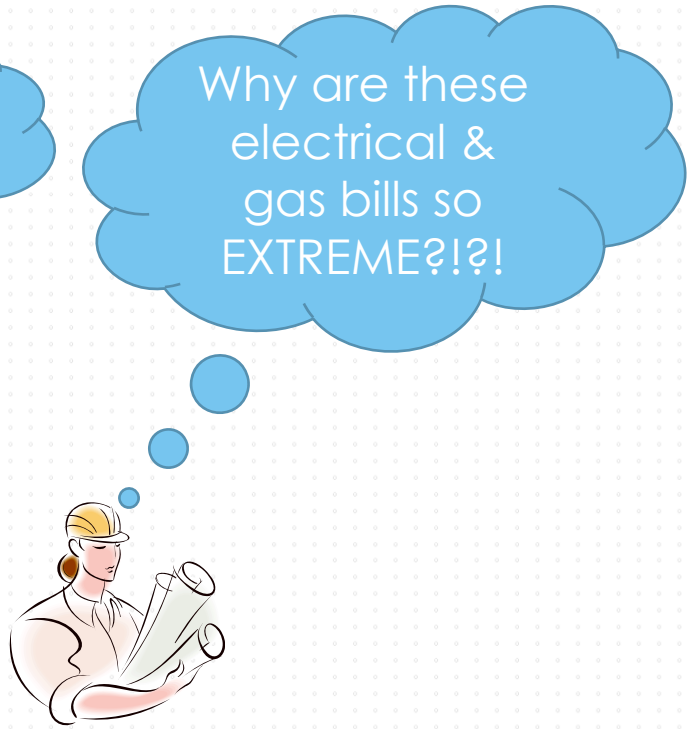
…the VAV operates happily ever after…THE END…

…umm…isn't that true???



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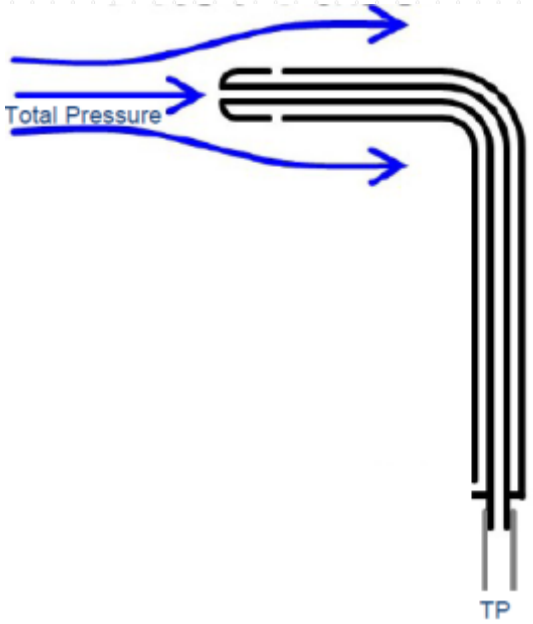
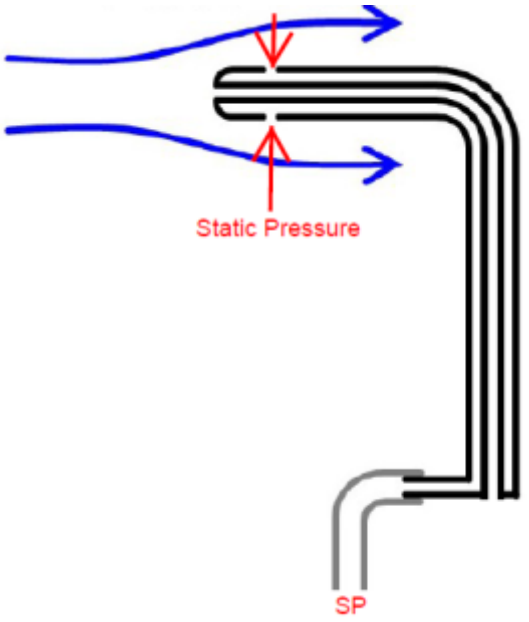
Pitot Tube Airflow Measurements

TOTAL PRESSURE



STATIC PRESSURE



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Pitot Tube Airflow Measurements

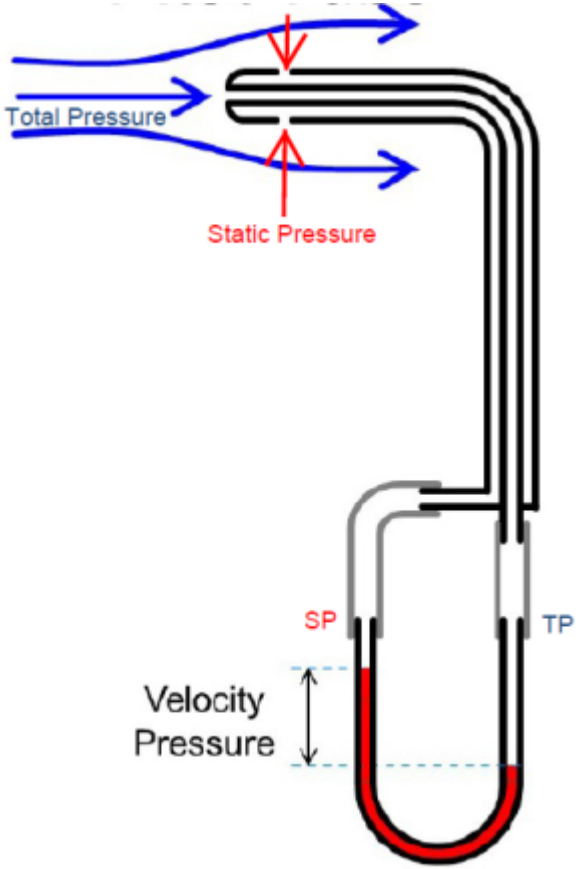
TOTAL PRESSURE

-

STATIC PRESSURE

=

VELOCITY PRESSURE (VP)



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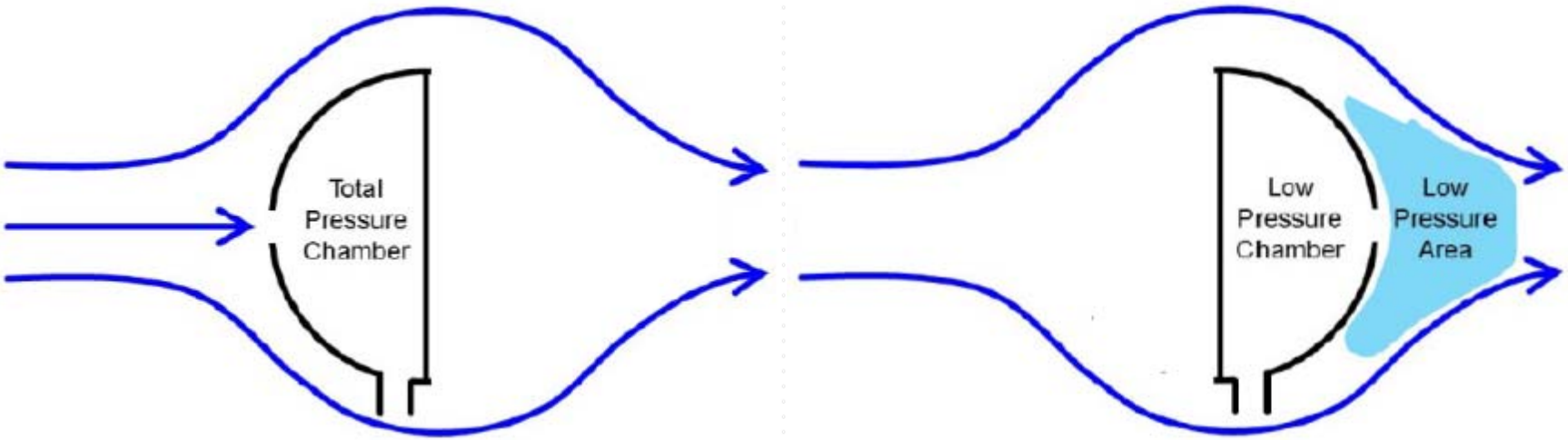
VAV Airflow Measurement…similar but different…

TOTAL PRESSURE

LOW PRESSURE



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VAV Airflow Sensor Measurements

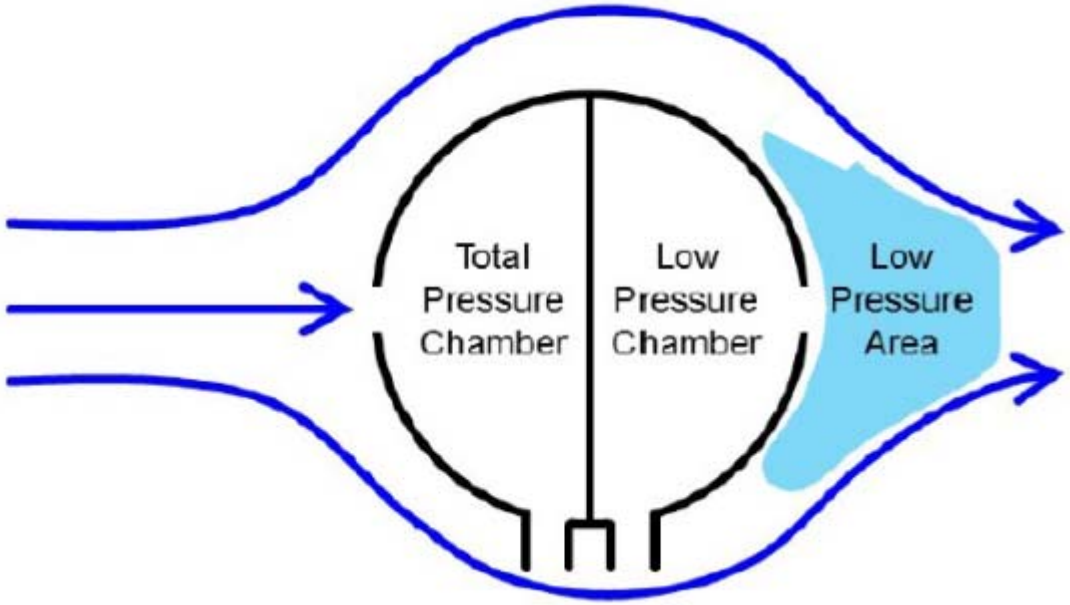
TOTAL PRESSURE

-

LOW PRESSURE

=

DIFFERENTIAL PRESSURE (ΔP)



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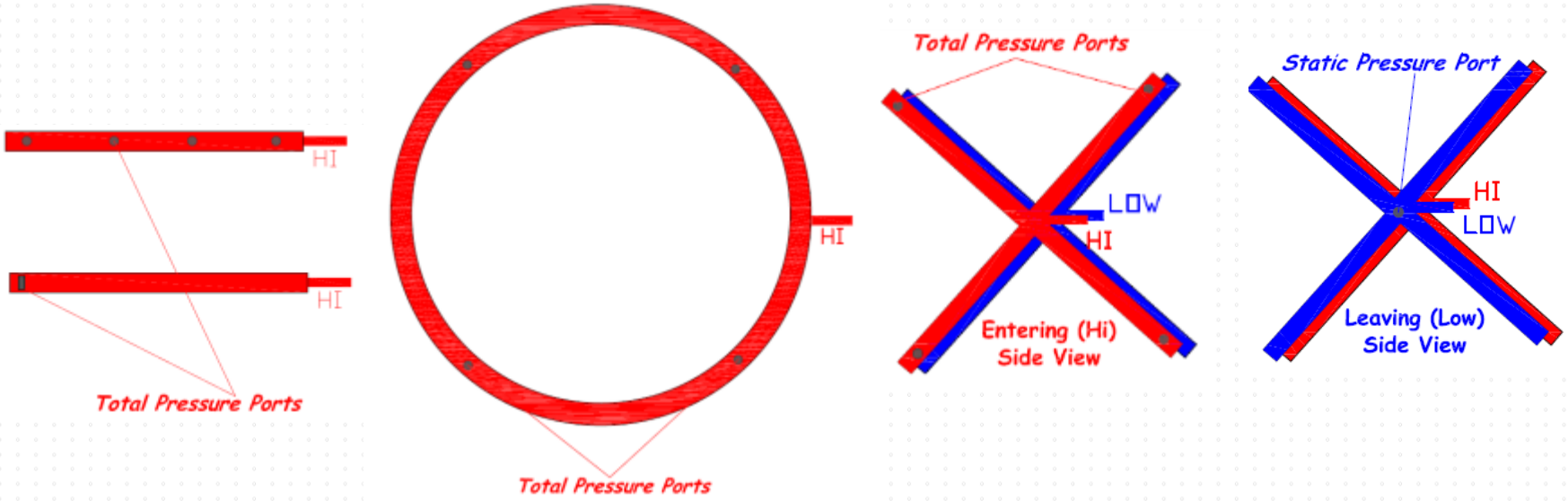
Examples of VAV Airflow Sensor Types

Examples of VAV airflow velocity sensors…



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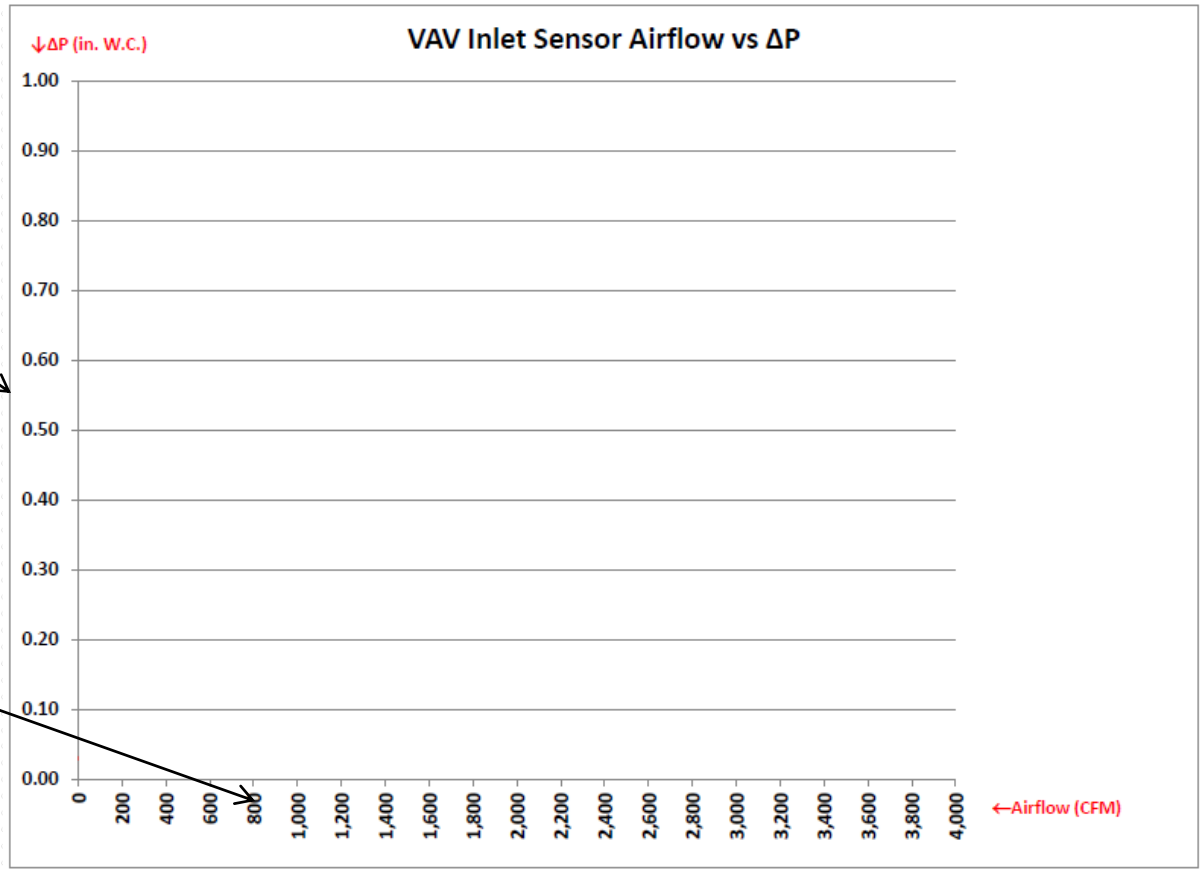
VAV Airflow Sensor Chart

ΔP Measured at sensor…

Sensor Airflow (CFM)…



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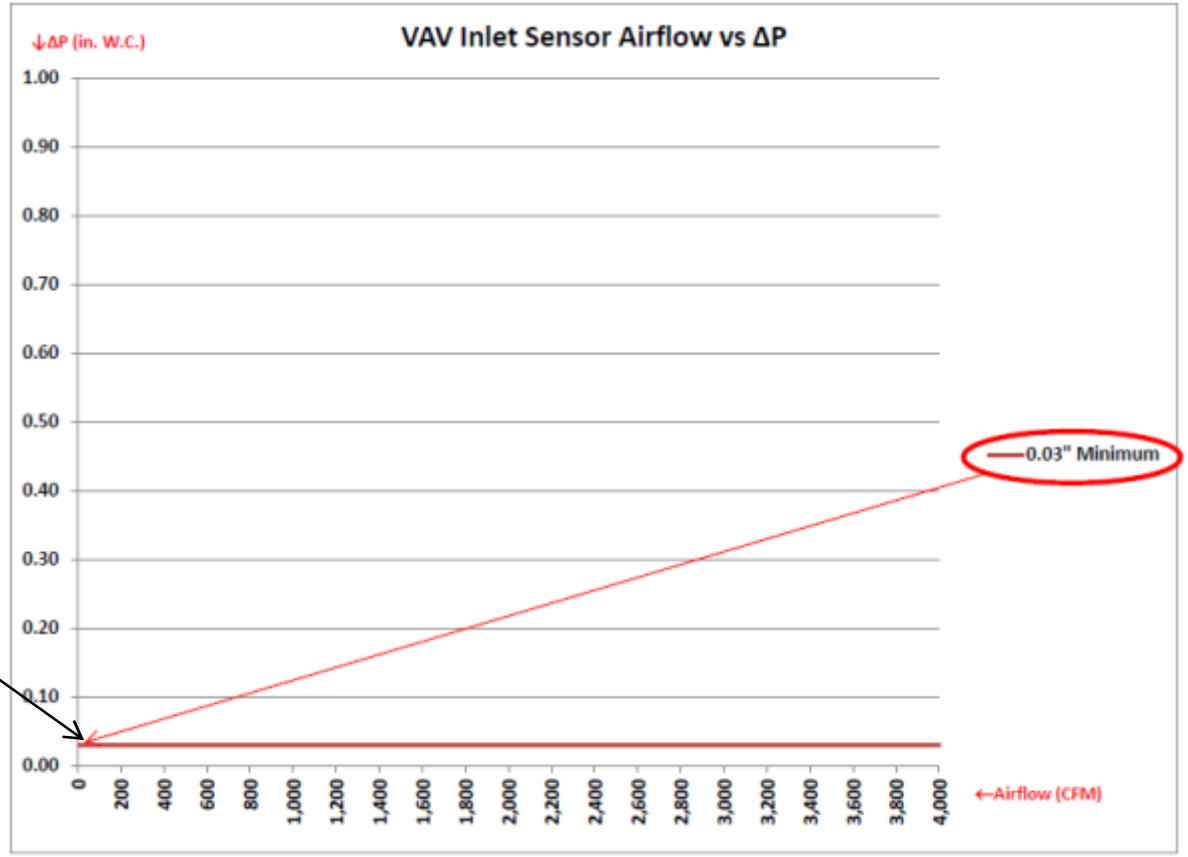
VAV Airflow Sensor Chart

Minimum measureable (Controllable) ΔP.



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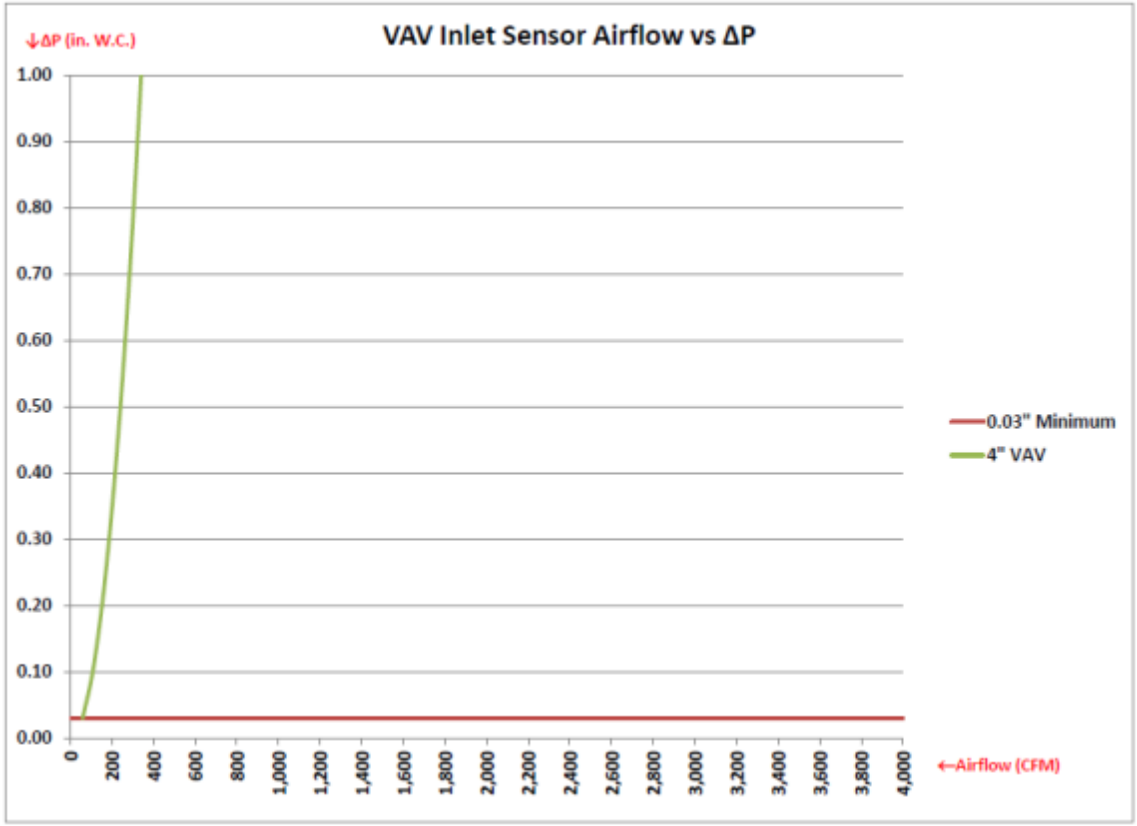
VAV Airflow Sensor Chart

ΔP / CFM relationship…

…4-inch VAV Inlet size…



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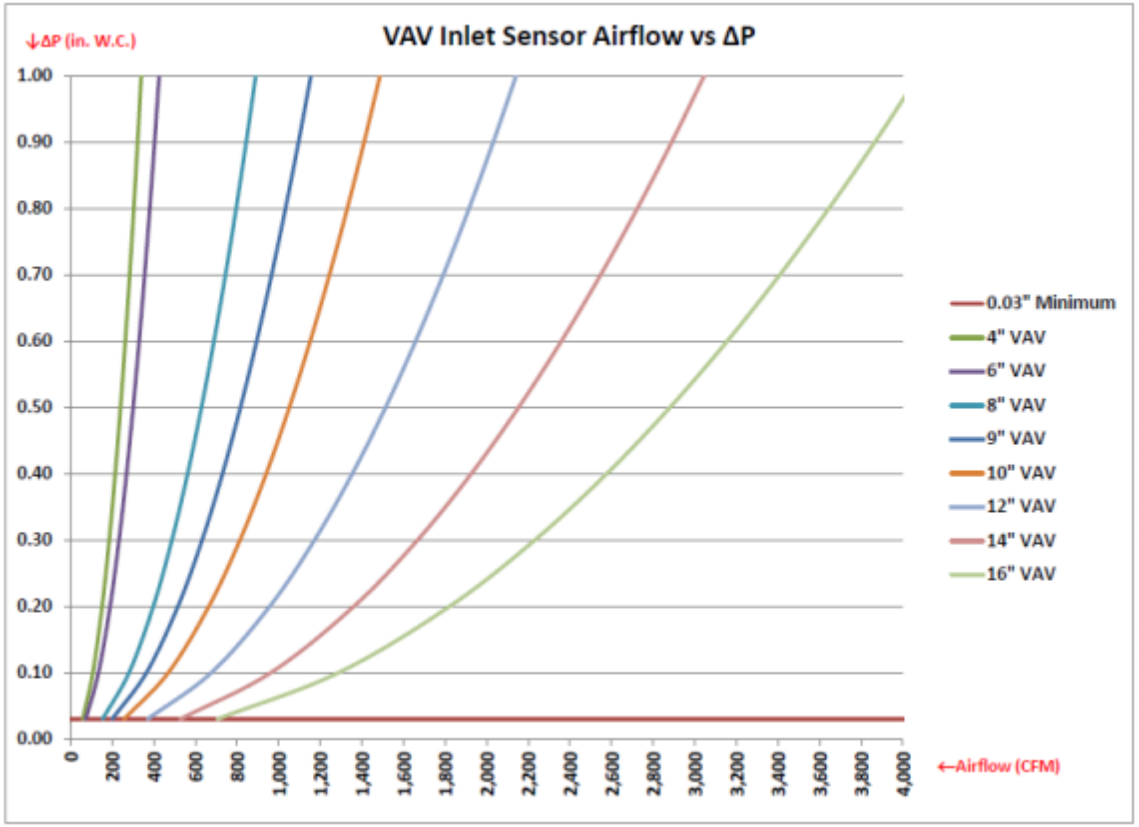
VAV Airflow Sensor Chart

…through 16-inch VAV Inlet size…



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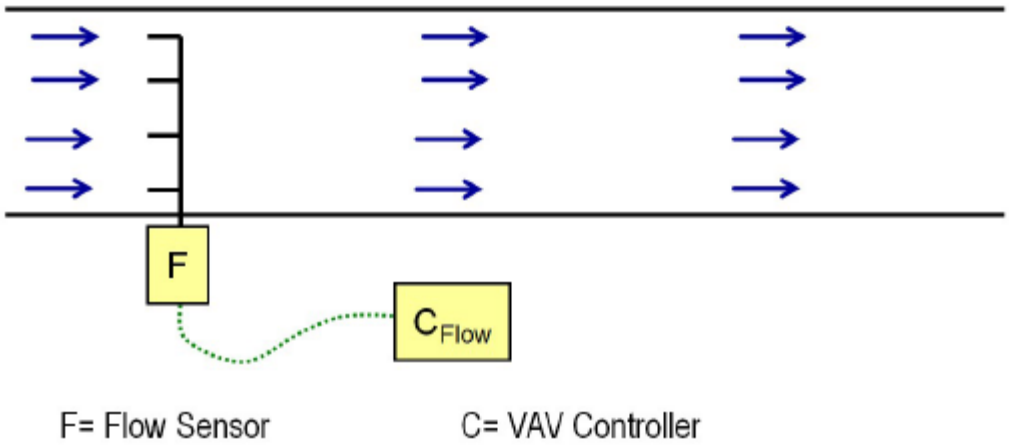
1. No VAV Damper
2. Airflow modulated by a fan with a VFD
3. Airflow measured at calibrated AFS.
4. Airflow pattern across sensor very laminar & consistent

VAV Configuration deriving the Airflow Sensor Chart



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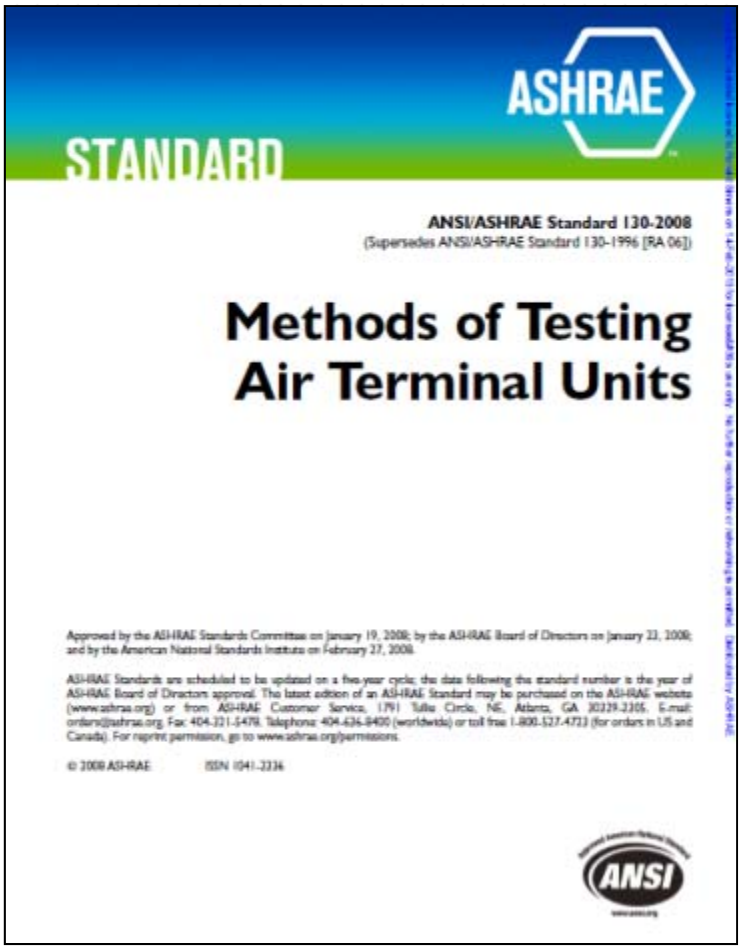
VAV Manufacturers refer
to ASHRAE 130-2008 for VAV testing
Procedures…

Standard for Testing VAV Terminal Units



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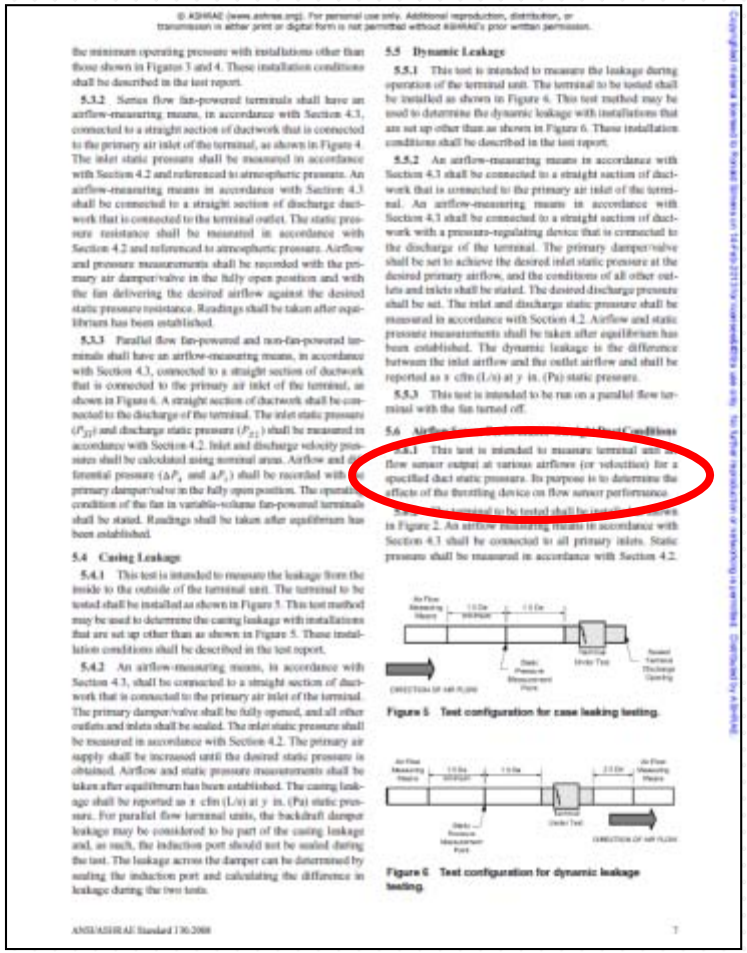
Paragraph (5.6.1): "This test is intended to measure terminal unit air flow sensor output at various airflows (or velocities) for a specified duct static pressure. Its purpose is to determine the effects of the throttling device on flow sensor performance."

Standard for Testing VAV Terminal Units (Section 5.6)



the minimum operating pressure with installations other than those shown in Figures 3 and 4. These installation conditions shall be described in the test report.

5.3.2 Series flow fan-powered terminals shall have an airflow-measuring means, in accordance with Section 4.3, connected to a straight section of ductwork that is connected to the primary air inlet of the terminal, as shown in Figure 4. The inlet static pressure shall be measured in accordance with Section 4.2 and referenced to atmospheric pressure. An airflow-measuring means in accordance with Section 4.3 shall be connected to a straight section of discharge ductwork that is connected to the terminal outlet. The static pressure resistance shall be measured in accordance with Section 4.2 and referenced to atmospheric pressure. Airflow and pressure measurements shall be recorded with the primary air damper/valve in the fully open position and with the fan delivering the desired airflow against the desired static pressure resistance. Readings shall be taken after equilibrium has been established.

5.3.3 Parallel flow fan-powered and non-fan-powered terminals shall have an airflow-measuring means, in accordance with Section 4.3, connected to a straight section of ductwork that is connected to the primary air inlet of the terminal, as shown in Figure 6. A straight section of ductwork shall be connected to the discharge of the terminal. The inlet static pressure (P_{T1}) and discharge static pressure (P_{T2}) shall be measured in accordance with Section 4.2. Inlet and discharge velocity pressures shall be calculated using nominal areas. Airflow and differential pressure (ΔP_1 and ΔP_2) shall be recorded with the primary damper/valve in the fully open position. The operating condition of the fan in variable-volume fan-powered terminals shall be stated. Readings shall be taken after equilibrium has been established.

5.4 Casing Leakage

5.4.1 This test is intended to measure the leakage from the inside to the outside of the terminal unit. The terminal to be tested shall be installed as shown in Figure 5. This test method may be used to determine the casing leakage with installations that are set up other than as shown in Figure 5. These installation conditions shall be described in the test report.

5.4.2 An airflow-measuring means, in accordance with Section 4.3, shall be connected to a straight section of ductwork that is connected to the primary air inlet of the terminal. The primary damper/valve shall be fully opened, and all other outlets and inlets shall be sealed. The inlet static pressure shall be measured in accordance with Section 4.2. The primary air supply shall be increased until the desired static pressure is obtained. Airflow and static pressure measurements shall be taken after equilibrium has been established. The casing leakage shall be reported as x cfm (L/s) at y in. (Pa) static pressure. For parallel flow terminal units, the backdraft damper leakage may be considered to be part of the casing leakage and, as such, the induction port should not be sealed during the test. The leakage across the damper can be determined by sealing the induction port and calculating the difference in leakage during the two tests.

5.5 Dynamic Leakage

5.5.1 This test is intended to measure the leakage during operation of the terminal unit. The terminal to be tested shall be installed as shown in Figure 6. This test method may be used to determine the dynamic leakage with installations that are set up other than as shown in Figure 6. These installation conditions shall be described in the test report.

5.5.2 An airflow-measuring means in accordance with Section 4.3 shall be connected to a straight section of ductwork that is connected to the primary air inlet of the terminal. An airflow-measuring means in accordance with Section 4.3 shall be connected to a straight section of ductwork with a pressure-regulating device that is connected to the discharge of the terminal. The primary damper/valve shall be set to achieve the desired inlet static pressure at the desired primary airflow, and the conditions of all other outlets and inlets shall be stated. The desired discharge pressure shall be set. The inlet and discharge static pressure shall be measured in accordance with Section 4.2. Airflow and static pressure measurements shall be taken after equilibrium has been established. The dynamic leakage is the difference between the inlet airflow and the outlet airflow and shall be reported as x cfm (L/s) at y in. (Pa) static pressure.

5.5.3 This test is intended to be run on a parallel flow terminal with the fan turned off.

5.6 Airflow [illegible] Conditions

5.6.1 This test is intended to measure terminal unit flow sensor output at various airflows (or velocities) for a specified duct static pressure. Its purpose is to determine the effects of the throttling device on flow sensor performance.

[illegible] is in Figure 2. An airflow measuring means in accordance with Section 4.3 shall be connected to all primary inlets. Static pressure shall be measured in accordance with Section 4.2.

Figure 5 Test configuration for case leaking testing.

Figure 6 Test configuration for dynamic leakage testing.

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Standard for Testing VAV Terminal Units (Section 5.6)

Question 1: Is there a completely open VAV damper in test unit while creating the published airflow sensor chart?

In correspondence I have been told "…no damper…" is present.

Question 2: No VAV damper means ASHRAE 130-2008, 5.6.1 testing is not performed?

No answer yet, still corresponding…

Question 3: Where is ASHRAE 130-2008, 5.6.1 testing data published?

No answer yet, still corresponding…

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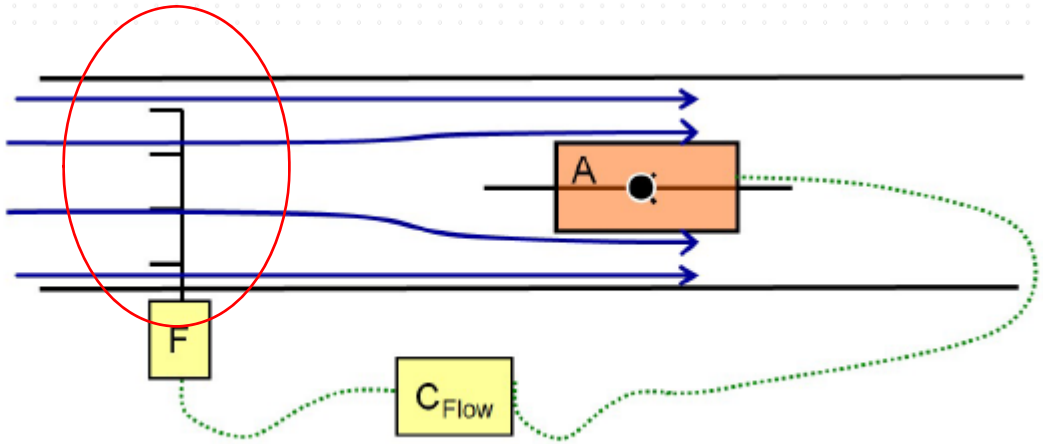
VAV Field Conditions

Airflow pattern across airflow sensor of field installed VAV fairly laminar…



…Unfortunately…

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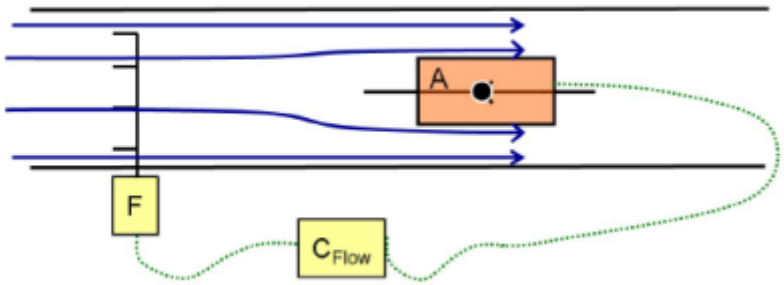
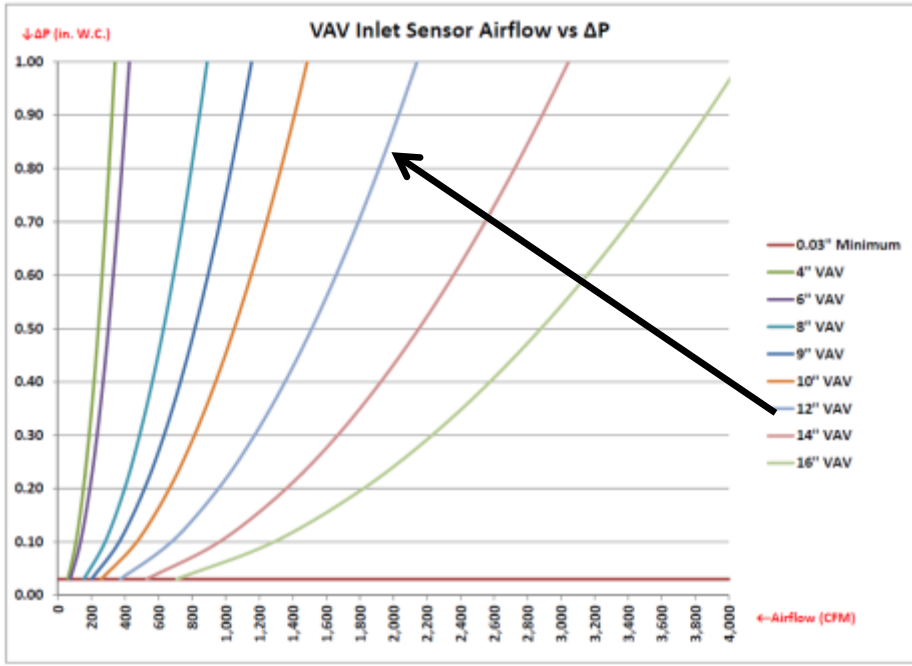
VAV Field Testing: Chart comparisons with Measured CFM

Field tests are perplexing…

Maximum CFM



12" VAV…



VAV AIRFLOW CONTROL

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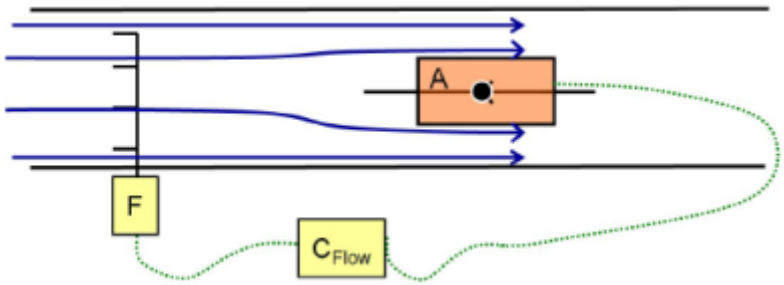
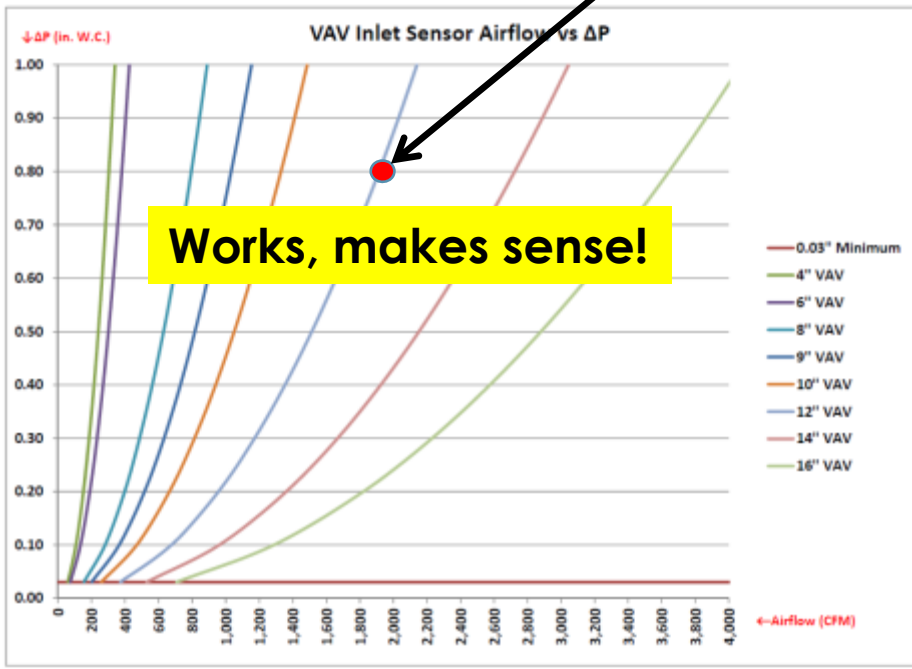
VAV Field Testing: Chart comparisons with Measured CFM

Field tests are perplexing…

Maximum CFM



12" VAV, 1800 CFM @ 0.80 in. W.G.



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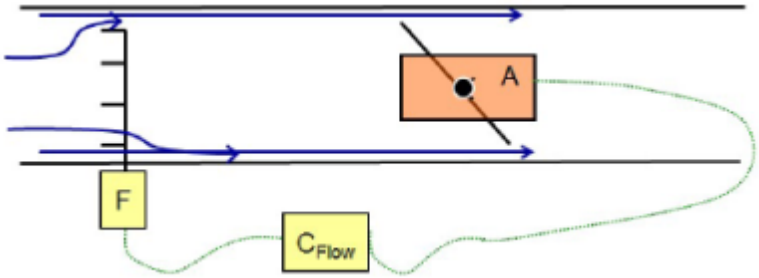
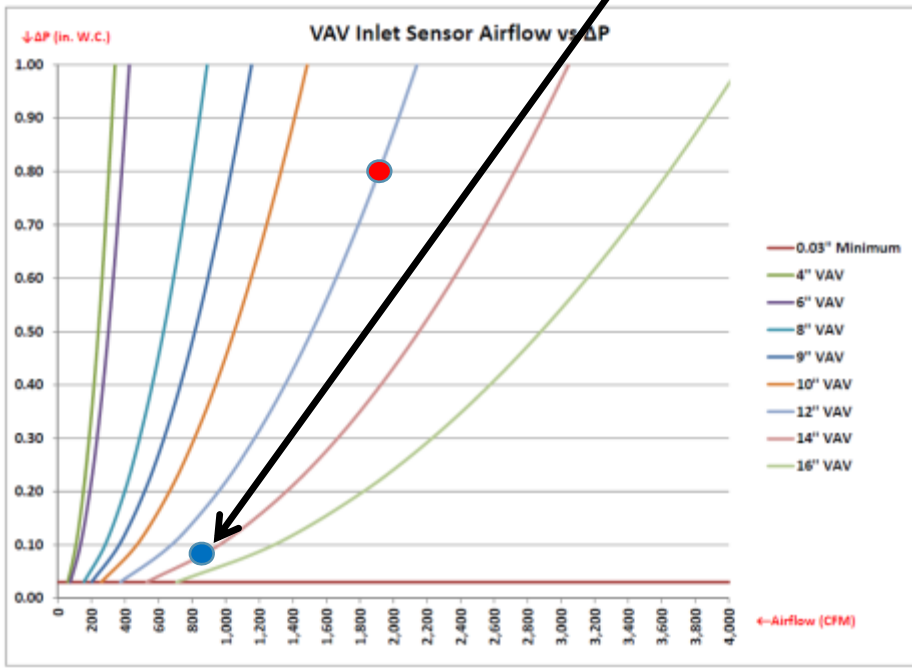
VAV Field Testing: Chart comparisons with Measured CFM

Minimum CFM



12" VAV, 800 CFM @ 0.08 in. W.G.



Why does the Minimum CFM plot on the 14" VAV curve?

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VAV Field Testing: Chart comparisons with Measured CFM

Attempted CFM / ΔP comparisons many times…
LIMITED success…

…very LIMITED success…

CAUTION for the faint of heart…

"Traumatic" project experience follows…

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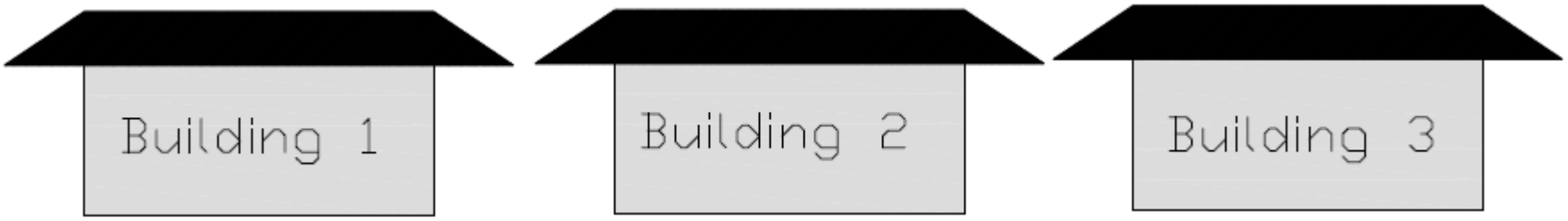
VAV Field Testing:

Accelerated Project Schedule

3 buildings…



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VAV Field Testing:
(Continued)

…each building had 5 floors…

… dedicated AHU on each floor…

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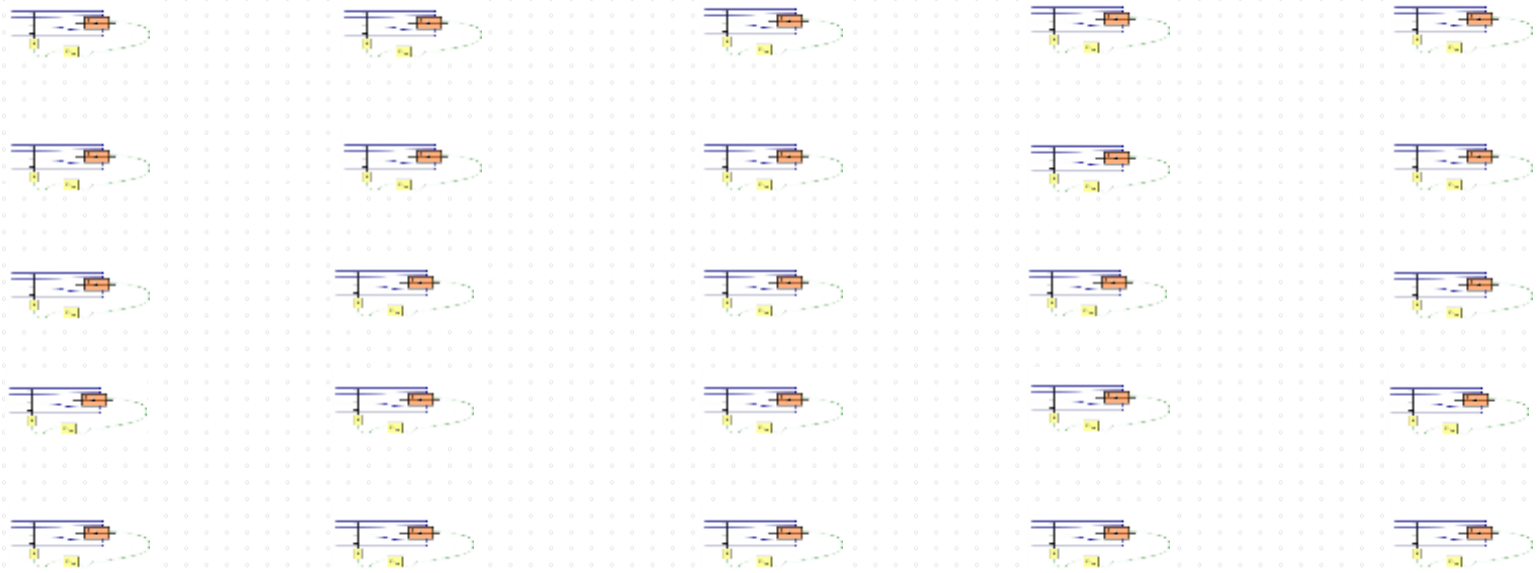
VAV Field Testing:

Large DDC VAV Project with an Accelerated Project Schedule

…each AHU served 20-30 VAVs…



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VAV Field Testing:

"Unusual" Problem…

No Down-Duct Static control …

…BUT…

…TAB needed to start to meet project schedule commitments!

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VAV Field Testing:

How TAB proceeded…

Closed 50% of VAVs on the floor we were working on…

…building down-duct static for other floor VAV calibration…

…calibrated & proportionately balanced VAVs…

…set completed VAV to control temperature (72°) moved to next VAV…

…until entire floor was completed.

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VAV Field Testing:

Why this would work

VAV's are "Pressure Independent".

Set final AHU down-duct static @ Operator Work Station (OWS)

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VAV Field Testing:

Great Opportunity!

Kill two birds with one stone at OWS:

Identify hydraulically hardest to satisfy VAV(s) on each AHU...

Adjust AHU Down-Duct-Static setpoint to satisfy this VAV(s)

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VAV Field Testing:

What we failed to take into account…

VAV dampers @ Minimum CFM were 5-15% open…

…VAV dampers @ Maximum CFM were 20-30% open…

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VAV Field Testing:

…Later in our story @ OWS…

After 2 days at OWS…

…VAVs controlled Maximum Airflow with dampers 70-90% Open.

Concluded that it was time to:

Set AHU Minimum Outside Air…

Measure & document final AHU operational data…

…mere hours from project completion!

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VAV Field Testing:

…Spot check VAV airflow…

Zone airflow verification revealed…

Most VAV actual CFM was 20-30%…

HIGHER or LOWER than Design & BAS CFM!

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VAV Field Testing:

HUGE PROBLEM

WHAT HAPPENED?!?!

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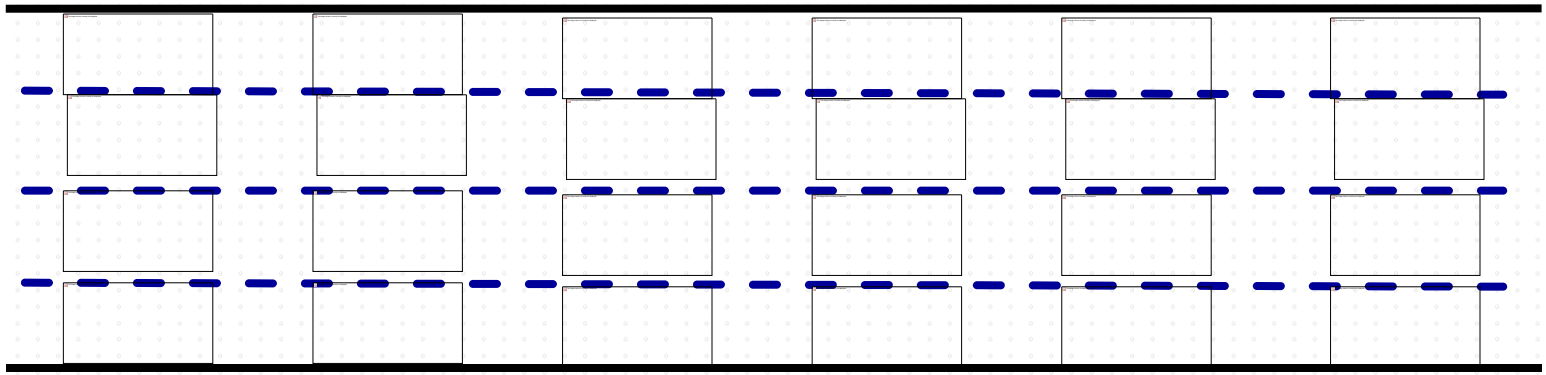
Airflow in a duct is a lot like cars on a freeway…



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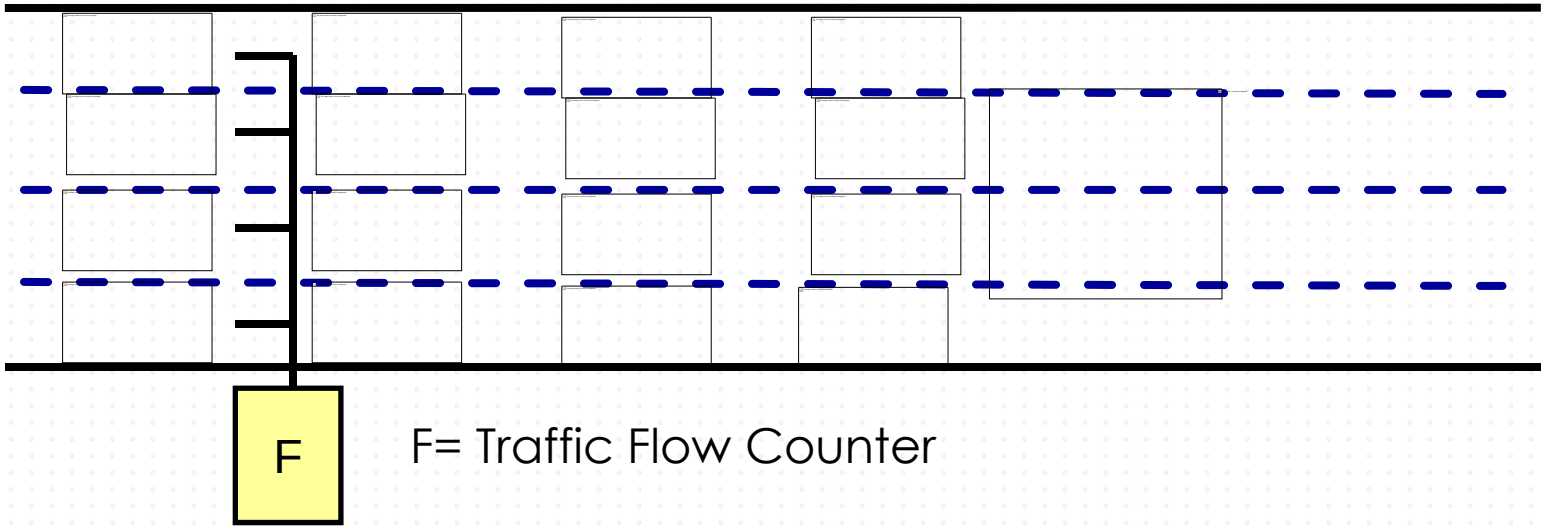
…add a traffic counting device…



…traffic moves at a measurable rate…

…but what happens when…

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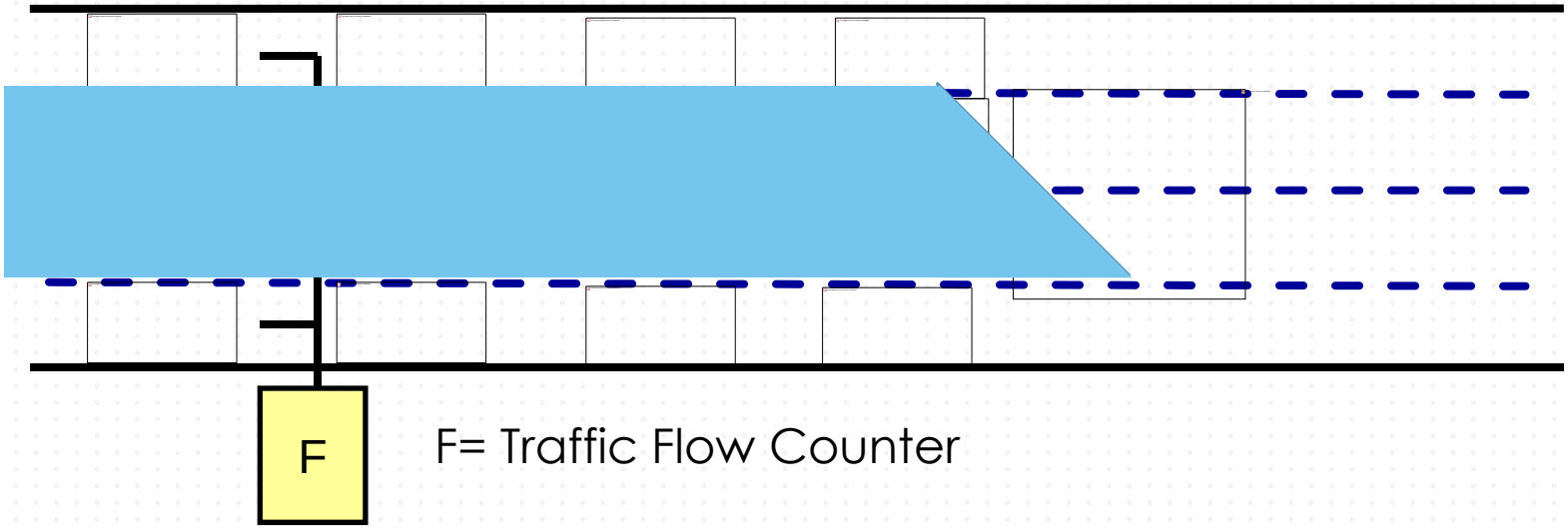
…big rig spin-out = traffic backup…



…creating a freeway "Dead-Zone"

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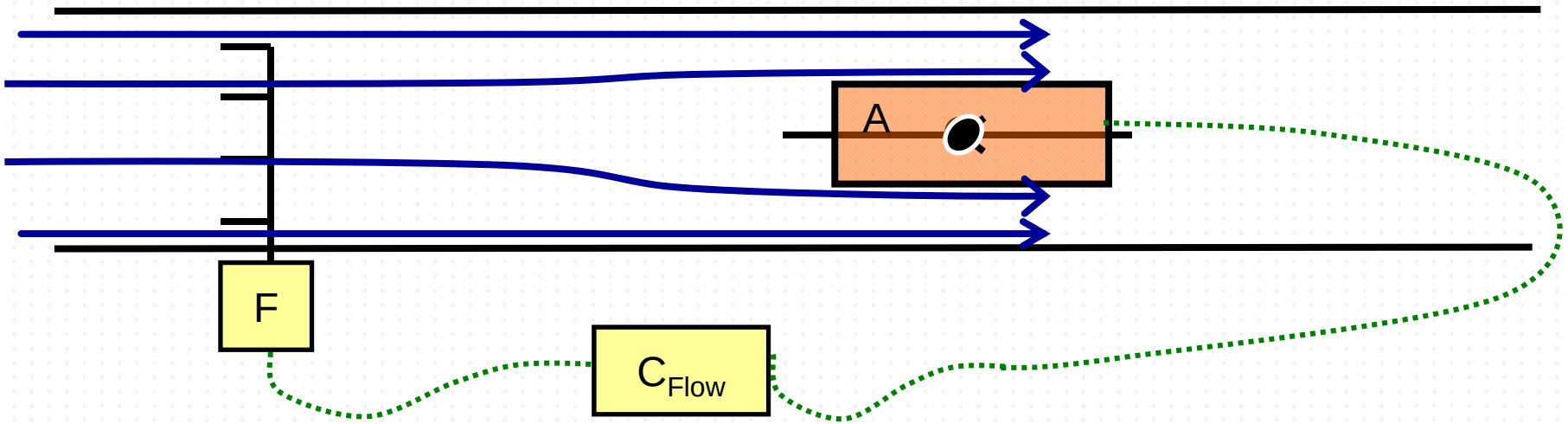
Airflow through airflow sensor with open VAV damper…no problem



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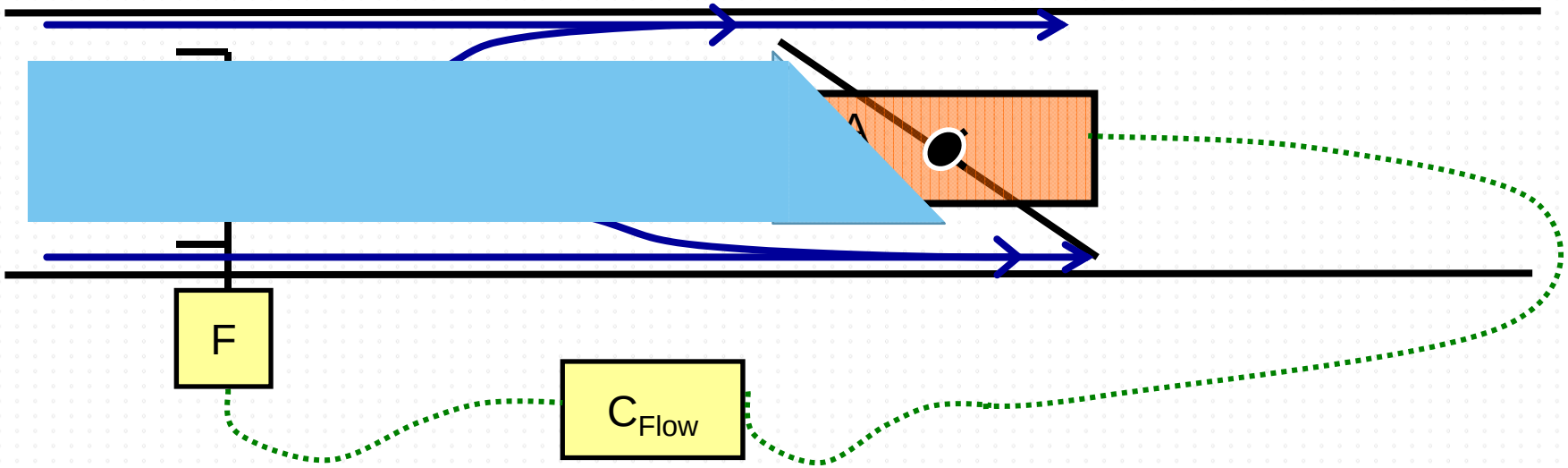
VAV damper closing is similar to the big rig spin-out…



…how far the "Dead-Zone" extends depends on the "traffic" or duct pressure behind the damper.

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Is this really THAT big of a deal?

How do you diagnose this issue?

EXAMPLE:

- **397,000 Square Foot Medical Research facility**
- **We'll look at 1 AHU (of many) supplying 100% OA through…**
- **Hot Deck (Steam Coil) and Cold Deck (CHW) at AHU down to…**
- **62 Dual Duct VAVs, constant outlet airflow serving…**
- **Laboratories & Lab Support Administration areas**

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Our initial approach…

- Using the BAS, we began to evaluate zone performance.
- Rebalance had occurred 6-months earlier so…
- …TAB report was in our hands.
- Began to look for "Targets of Opportunity" to allow us to…
- …move to zone level with our instruments to verify system operation.

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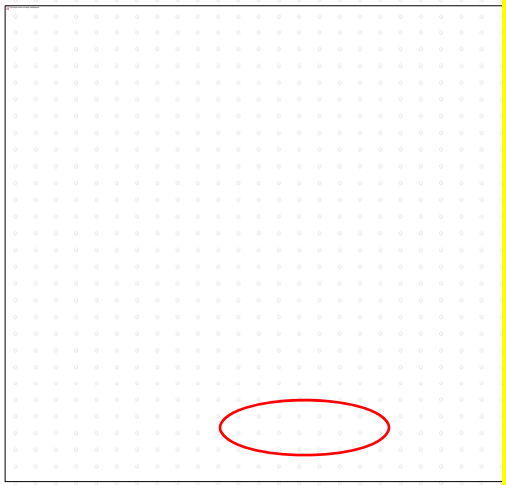
Typical VAV:



Design Flow Total = 3,015 CFM

NOBODY KNEW ANYTHING…

TAB calibrated Hot & Cold VAV controllers at 2,380 Max CFM but…

…did not document Minimum airflow calibration in the TAB Report…

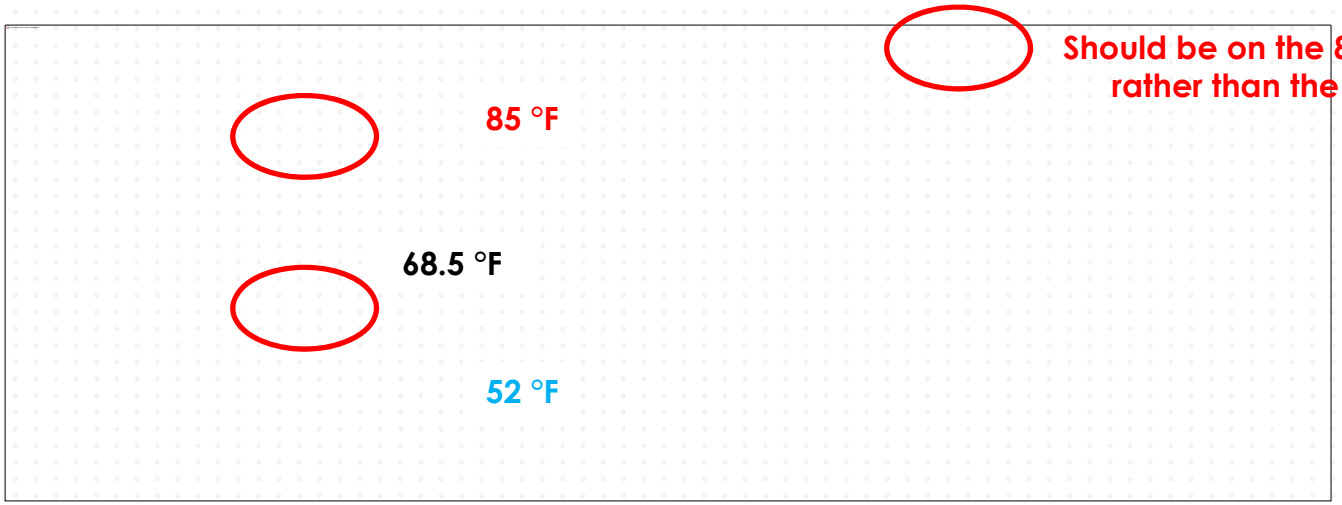
…Max CFM discrepancy and lack of Min CFM documentation…

…in other words…

VAV AIRFLOW CONTROL

Reliable Without Limitations?

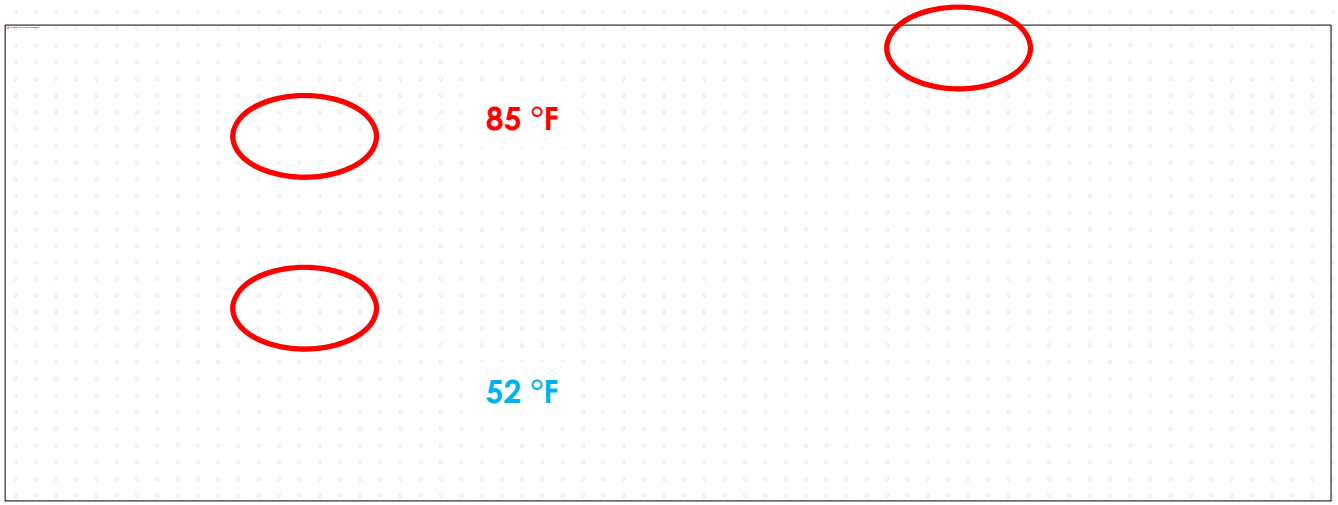
Discharge Air Temperature…



VAV AIRFLOW CONTROL

Reliable Without Limitations?

Discharge Air Temperature…



DAT = [(1,087 CFM / 1808 CFM) * 85° F] + [(721 CFM / 1808 CFM) * 52° F] 71.8° F

VAV AIRFLOW CONTROL

Reliable Without Limitations?

MOVING FORWARD…

AT BAS:

- **Repeated DAT calculation (Spreadsheet) for each VAV…**
- **…found many VAVs with identical issue.**

In Field @ three random VAVs:

- **Verified DAT sensor location; GREAT location!**
- **BAS Temperature indication within ½° calibrated instrument**

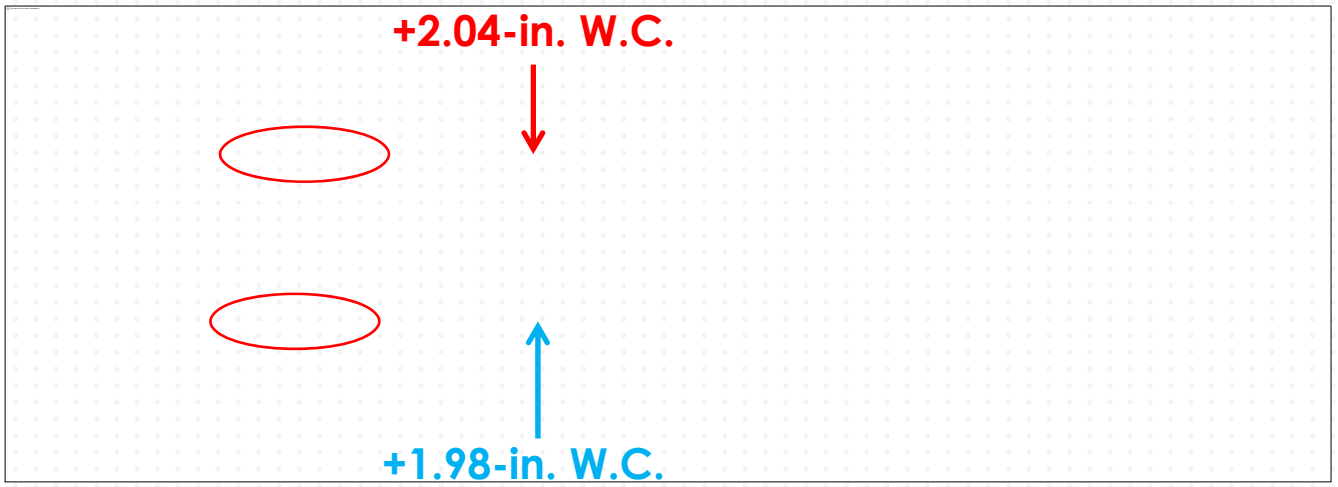
VAV AIRFLOW CONTROL

Reliable Without Limitations?

FIELD VERIFICATION…

Actual VAV damper position vs. BAS indication…

…matched…



Measured Hot and Cold Duct inlet pressure…

…pretty high for VAVs without coils…

VAV AIRFLOW CONTROL

Reliable Without Limitations?

Tested Airflow at VAV inlets…

Hot Duct Traverse Results @ As-Found Maximum CFM Setpoint:

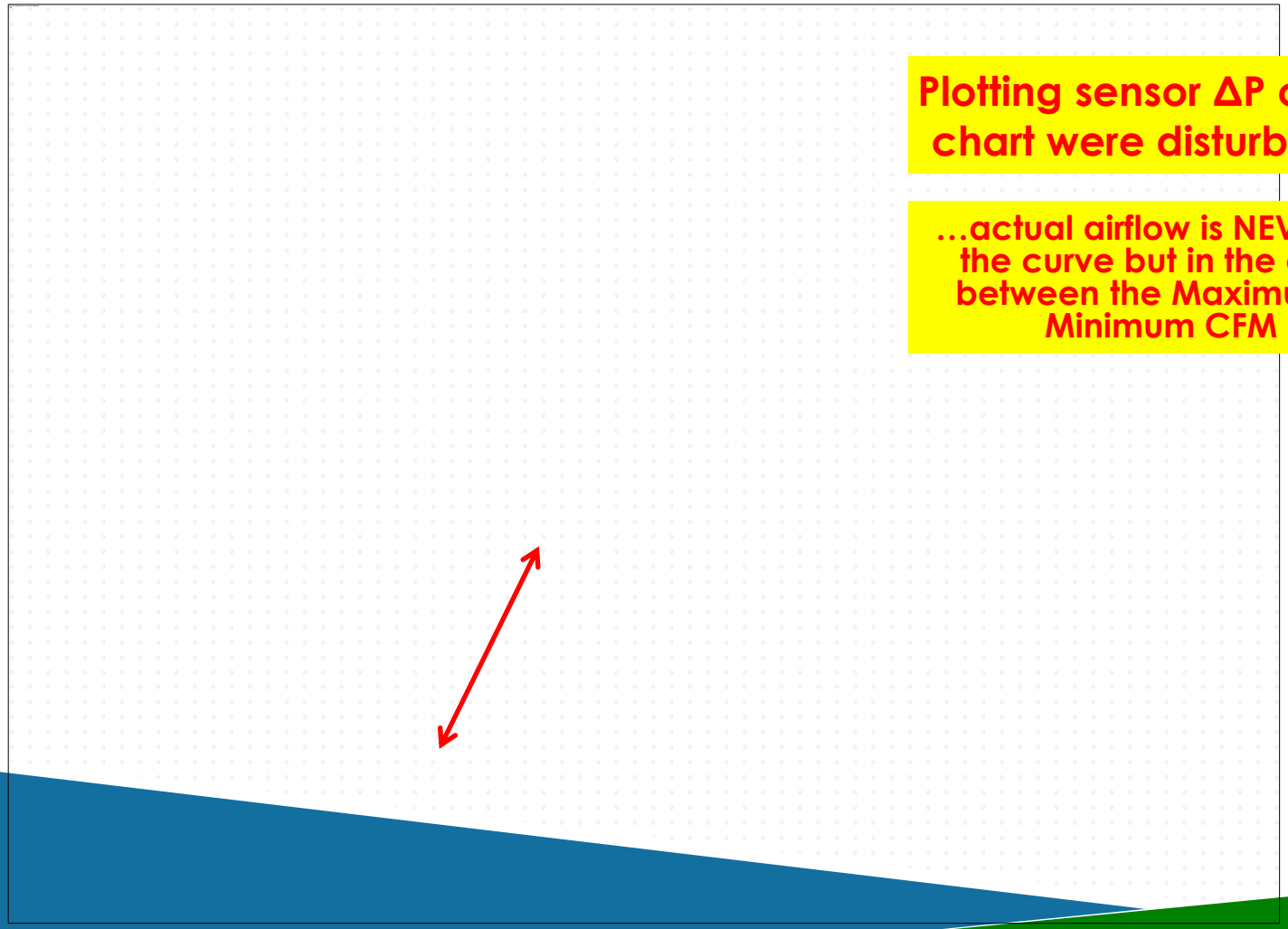
BAS: 1,835 CFM	**Traversed: 1,962 CFM**	**Actual 107% BAS**
BAS: 963 CFM	**Traversed: 1,125 CFM**	**Actual 117% BAS**

Hot Duct Traverse Results @ Design Minimum CFM Setpoint:

VAV AIRFLOW CONTROL

Reliable Without Limitations?

Comparison of data plot on airflow chart (Typical of 3)…



Plotting sensor ΔP on this chart were disturbing…

…actual airflow is NEVER on the curve but in the area between the Maximum & Minimum CFM

VAV AIRFLOW CONTROL

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Thoughts…Next Steps…

Just how big was this issue?

Verify airflow for entire AHU…

VAV AIRFLOW CONTROL

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AT AHU…

- **Measure Fan Operational Data (RPM, Volts, Amps, TSP), plot on fan curve and fan tables…**
- **Traverse Hot & Cold Deck Coils…**
  - **Shortridge VelGrid at discharge with 6-inch stand-offs**
  - **Unit free area @ traverse point calculate airflow**
- **Traverse all Supply Air ducts (4 Hot ducts & 4 Cold ducts)…**

VAV AIRFLOW CONTROL

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AHU CFM vs. BAS CFM

- **AHU airflow comparisons…**
  - **All three sets of airflow data ±2% of one another which is…**
  - **…WELL within acceptable instrument error…**
- **BAS Hot & Cold VAV CFM summary vs. measured CFM:**
  - **Actual Hot Deck airflow 122% of BAS indication**
  - **Actual Cold Deck airflow 118% of BAS indication**

VAV AIRFLOW CONTROL

Reliable Without Limitations?

Points of Energy Saving

- **Fan Energy:**

- **Down-Duct Static AND CFM reduction (VFD or Sheave Change) = SIGNIFICANT kW/hour reduction**
- **Heating Coil Steam load…**
  - **100% Outside Air, winter would require significant steam…**
- **Chilled Water production and distribution costs:**
  - **100% OA Sensible & Latent cooling**

VAV AIRFLOW CONTROL

Reliable Without Limitations?

…significant energy expenses due to inaccurately calibrated, Pressure Independent VAV Terminal Units.

VAV AIRFLOW CONTROL

Reliable Without Limitations?

WHAT TO DO?

- **Educate MEP, TAB & Cx Personnel**

1. **Project schedule/completion dates drive project activities instead of logic…**
   - **Sometimes this works…**
   - **Other times, it can be catastrophic**

VAV AIRFLOW CONTROL

Reliable Without Limitations?

WHAT TO DO?

- **Educate MEP, TAB & Cx Personnel (contined)**

2. **TAB with incomplete AHU control system cannot be overlooked without consequences.**

   - **Educated & diligent TAB personnel can overcome this…**
   - **…and make it right at the end of the project but…**
   - **…this is a LOT of extra work requiring compensation.**

VAV AIRFLOW CONTROL

Reliable Without Limitations?

WHAT TO DO?

- **Educate MEP, TAB & Cx Personnel (contined)**

2. **NEBB, AABC & TABB Procedural Standards require fully operational control systems to commence TAB activities.**

Proceeding with system TAB without completed BAS control compromises the NEBB, AABC & TABB process…

…will compromise the guarantee of accuracy by these bodies which is often paid for by the owners.

VAV AIRFLOW CONTROL

Reliable Without Limitations?

WHAT TO DO?

- **Educate MEP, TAB & Cx Personnel (contined)**

3. **Calibrate VAV near operational static pressure.**

4. **ALWAYS be aware of hydraulically hardest to satisfy VAV.**

VAV AIRFLOW CONTROL

Reliable Without Limitations?

WHAT TO DO?

- **Educate MEP, TAB & Cx Personnel (contined)**

5. **Cx personnel need to support TAB personnel…**

6. **Cx personnel must educate clients, introduce intelligence into the process, ENERGY LATER vs. Project Schedule gain now.**

VAV AIRFLOW CONTROL

Reliable Without Limitations?

WHAT TO DO?

BAS Applications for DDC VAVs Need Additional Calibration Capability

7. **Most DDC VAV programs reconcile inlet duct airflow sensor ΔP with actual airflow using a form of the algorithm below…**

$$\text{Current CFM} = (\sqrt{\Delta P \text{ Current}}/\Delta P \text{ at Calibration}) * \text{CFM at Calibration} * \text{Correction Factor}$$

8. **Add additional calibration points into the VAV application**

VAV AIRFLOW CONTROL

Reliable Without Limitations?

WHAT TO DO?

Request Publiction of ASHRAE 130-2008, Section 5.6 Test Data

Something is going on, let's hear from the experts!

VAV AIRFLOW CONTROL

Reliable Without Limitations?

CONCLUSION

NOT a "Silver Bullet" for energy reduction in every building with pressure independent VAV systems.

DOES represent potential energy waste.

SHOULD be investigated and understood.

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THANK YOU

Commissioning-Controls-Remedial Engineering