Variable air volume (VAV) Air Handling System
What Makes VAV Box Performance Better

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Variable air volume (VAV) Air Handling System

VAV systems are very popular in many modern buildings

- VAV systems contain many zones with diverse airflow needs
- VAV systems have “bad” zones
- VAV systems are dynamic
- VAV systems have minimum airflow zones
Consider the relationship between damper position and airflow

- System is sensitive as damper starts to open, so large proportional band is needed
- When damper is almost open, system is not very sensitive, so a small proportional band is needed

Consider the “optimal” proportional band for a mixed air control loop

- It will vary by a factor of ten between summer and winter
- Good commissioning is critical

Conventional PI control resulted in

- Systems tuned for “worst case” (typically low load) conditions and unresponsive at other times
- Comfort problems
- High energy (fan consumption) cost
Variable air volume (VAV) Terminal Unit

1. Velocity Sensor
   - Measures air flow

2. Flow Damper
   - Controls air flow

3. Mixing Box
   - Reduces noise

4. VAV Brain
   - Calculates & controls air flow

5. Reheat Option

Diagram:
- 1. Velocity Sensor
- 2. Flow Damper
- 3. Mixing Box
- 4. VAV Brain
- 5. Reheat Option
What makes VAV box performance better

1. Air flow measuring – Velocity sensor
   - more accurate to measure the air flow = better control (less hunting) = less temperature variation = less energy consumption
   - not easy to maintain accuracy when flow rate is lower

2. Air flow controlling – Flow damper
   - Pressure drop across the VAV box
     - Less the pressure drop = less fan energy consumption

3. Noise level – Mixing box
   - Lower dB rating = quieter the box = more comfortable

4. Controller
Air Flow Measuring – Velocity sensor

Flow measurement is the key factor in VAV controls

1. Based on ASHRAE 2001 Fundamentals, Chapter 14.15 Measurement and Instruments (table 4)
   - Pitot tube is a Standard instrument for measuring duct velocities
   - It can measure air velocity in the duct from 0.9 to 50 m/s with micro manometer
   - The accuracy is 1-5% and falls off at low end of range

2. Large turn down ratio (Vmax/Vmin) can save energy but how to measure low velocity accurately when Vmin is very small.
   - Using expansive measuring instrument, such as ultrasonic sensor
   - Using amplify velocity pressure signal to increase accuracy
     - Check Patented FlowStar™ airflow sensor (Patent #5,481,925)
Air Flow Measuring – Velocity sensor

**ASHRAE 2001 Fundamentals**

Chapter 14.17 - Measuring Flow in Ducts

- Velocity in a duct is seldom uniform, a traverse is usually made to determine average velocity.
- Point velocities are determined by the log-Tchebycheff rule (ISO Standard 3966) or, if care is taken, by the equal area method.
- Figure 6 shows suggested sensor locations for traversing round and rectangular ducts.
- For a rectangular duct traverse, a minimum of 25 points should be measured.

<table>
<thead>
<tr>
<th>No. of Points for Traverse Lines</th>
<th>Position Relative to Inner Wall</th>
<th>No. of Measuring Points per Diameter</th>
<th>Position Relative to Inner Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.074, 0.288, 0.500, 0.712, 0.926</td>
<td>6</td>
<td>0.032, 0.135, 0.321, 0.679, 0.865, 0.968</td>
</tr>
<tr>
<td>6</td>
<td>0.061, 0.235, 0.437, 0.563, 0.765, 0.939</td>
<td>8</td>
<td>0.021, 0.117, 0.184, 0.345, 0.655, 0.816, 0.883, 0.981</td>
</tr>
<tr>
<td>7</td>
<td>0.053, 0.203, 0.366, 0.500, 0.634,0.797, 0.947</td>
<td>10</td>
<td>0.019, 0.077, 0.153, 0.217, 0.361, 0.639, 0.783, 0.847, 0.925, 0.981</td>
</tr>
</tbody>
</table>
Air Flow Measuring – Velocity sensor

Example VAV box

2 sensing points

16 sensing points

ASHREA Standard vs. Non-ASHREA Standard
Air Flow Measuring – Velocity sensor

Example VAV box

**Non-Averaging Method**

- Reading will skewed by Stratification of the velocity profile

**Averaging Method**

- Accurate reading, even there is a higher velocity on one side of the sensor
## Example of VAV Box selection

- Maximum inlet velocity less than 8 m/s

<table>
<thead>
<tr>
<th></th>
<th>PRIMARY AIRFLOW</th>
<th>NOM</th>
<th>VAV Inlet Velocity /Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MAX [l/s]</td>
<td>Turn Down</td>
<td>MIN [l/s]</td>
</tr>
<tr>
<td>Example 1</td>
<td>395</td>
<td>30%</td>
<td>119</td>
</tr>
<tr>
<td>Example 2</td>
<td>395</td>
<td>50%</td>
<td>198</td>
</tr>
<tr>
<td>Example 1</td>
<td>420</td>
<td>30%</td>
<td>126</td>
</tr>
<tr>
<td>Example 2</td>
<td>420</td>
<td>60%</td>
<td>252</td>
</tr>
</tbody>
</table>

- The turn down ratio (minimum air flow) has to be increased to compensate stable control at low flow rate
Air Flow Measuring – Velocity sensor

**Amplified Velocity Pressure**

- Compensate for VAV Controller Limitations
- Prevent need to undersize VAV unit
- Minimum suggested Velocity is 3.56m/s
- Improved Temperature Control
- Meet IAQ Airflow Requirements
- Use Properly Sized Terminals
Air Flow Measuring – Velocity sensor

Amplified Velocity Pressure

Line AB using pitot tube
- A: 12.2 m/s, 89 pa
- B: 2.4 m/s, 3.7 pa

Line XY using FlowStarTM
- X: 12.2 m/s, 246 pa
- Y: 2.4 m/s, 10 pa

Flowstar pressure gain
- Increase from 89 to 246 pa
- Increase from 3.7 to 10 pa

Increase Control Range
- Increase from 3.7 to 10 pa

Decrease minimum controllable setpoint
- Increase from 89 to 246 pa
## Amplified Velocity Pressure

### Increased Range of Control
- **Pitot Tube:** 3.7 to 90 Pa
- **FlowStar:** 10 to 246 Pa

### Decreased Minimum Controllable Setpoint
- **Example. Size 8:**
  - **Pitot Tube:** 44 l/s @ 3.7 Pa
  - **FlowStar:** 29 l/s @ 3.7 Pa

<table>
<thead>
<tr>
<th>Size 8 example</th>
<th>Velocity</th>
<th>Velocity Pressure</th>
<th>Yield increase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pitot/Pv</td>
<td>FlowStar/dP</td>
</tr>
<tr>
<td></td>
<td>m/s</td>
<td>Pa</td>
<td>Pa</td>
</tr>
<tr>
<td><strong>Vmax</strong></td>
<td>15.3</td>
<td>139.5</td>
<td>373.6</td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td>12.2</td>
<td>89.7</td>
<td>246.6</td>
</tr>
<tr>
<td><strong>Vmin</strong></td>
<td>2.44</td>
<td>3.7</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Yields 230 to 290% amplification

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**Amplified Velocity Pressure**

<table>
<thead>
<tr>
<th>Velocity</th>
<th>Pitot Tube (Pv)</th>
<th>FlowStar (dP)</th>
<th>Amplification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vmax</td>
<td>15.3 m/s</td>
<td>139.5 Pa</td>
<td>373.6 Pa</td>
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<tr>
<td>Design</td>
<td>12.2 m/s</td>
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<tr>
<td>Vmin</td>
<td>2.44 m/s</td>
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</tr>
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</table>

**Example:**

- **Size 8:**
  - **Pitot Tube:** 44 l/s @ 3.7 Pa
  - **FlowStar:** 29 l/s @ 3.7 Pa

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**Air Flow Measuring – Velocity sensor**
Air Flow Controlling – Flow damper

1. **ASHRAE 2001 Fundamentals, Chapter 15.7 Fundamentals of Control Damper**

   - Automatic dampers are used in air-conditioning and ventilation to control airflow
     - A. Multi-blade dampers are used to control flow through large openings typical of those in air handlers
     - B. Single-blade dampers are typically used for flow control at the zone

2. Multi-blade damper requires smaller actuator (torque) than single-blade damper to control/modulate airflow

3. Control accuracy
   - No difference in control accuracy between multi-blade or single blade damper
   - 5% accuracy from minimum flow rate to maximum flow rate as standard requirement
4. Energy consumption

- Damper leakage, particularly where tight shutoff is necessary to reduce significantly
- Less pressure drop, less fan energy consumption
- Example of VAV Boxes comparison
1. Noise will occur when damper is throttling/controlling air flow
   - Discharge sound power is more significant to the noise level in the room

2. Mixing box is critical to reduce noise level
   - Poor quality designed mixing box will require an extra acoustic barrier in downstream of VAV box to reduce noise level

<table>
<thead>
<tr>
<th>Size</th>
<th>Air Flow</th>
<th>Flow Valve</th>
<th>Single-Blade</th>
<th>Multi-Blade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L/S</td>
<td>125 250 500 1K 2K 4K Ave</td>
<td>125 250 500 1K 2K 4K Ave</td>
<td>125 250 500 1K 2K 4K Ave</td>
</tr>
<tr>
<td>8</td>
<td>350</td>
<td>53 54 51 50 53 50 99% 57 55 52 48 43 40 94% 62 59 56 54 54 53 107%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>500</td>
<td>55 55 53 52 54 52 99% 57 55 52 49 43 40 91% 63 62 61 58 57 57 110%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>700</td>
<td>57 57 55 53 56 54 101% 56 55 54 49 45 42 91% 65 61 61 58 57 56 109%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>1,000</td>
<td>59 60 57 56 58 57 101% 58 56 55 50 46 42 89% 70 64 62 63 61 60 110%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>1,250</td>
<td>60 61 59 57 59 59 101% 60 55 54 49 46 42 88% 74 66 65 63 61 59 111%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Discharge Sound power**

**Radiated Sound power**
1. Flow control algorithm provides fast, accurate control and extends actuator life
   - Integral actuator is ninety times more precise than a traditional actuator
   - (US Patents 5768121 and 5875109)

2. Precision damper actuator provides accurate control
   - (US Patent 6198243)

3. Finite State Machine eliminate simultaneous heating and cooling to reduce energy
   - (US Patents 6006142 and 6219590)
   - Finite State Machine now incorporated into ASHRAE Fundamentals Handbook

97% reduction in actuator wear & tear
Pattern Recognition Adaptive Control eliminates tuning and speeds commissioning (US Patents 5355305, 5506768 and 5568377)

1. Continuously monitors and adjusts tuning parameters based on present and past conditions
2. Handles unmeasured load or process disturbances
3. Automatically adjusts to seasonal and setpoint changes
4. Places a Variable Dead-band around the setpoint based on noise level sampled
5. Reduces actuator hunting

Energy savings
Better quality control
Extended actuator life
Control stability during setpoint change
Eliminates tuning
Speeds commissioning

PRAC
going in

PRAC turned on

Process Output

Static Pressure (Pa)

0 2 4 6 8 10 12

Time (minutes)
Heating Water Coil Controlling – PICV

Pressure Independent Control Valve

- adjusts the flow rate in case of partial load
- the differential pressure regulator corrects any differential pressure variation
- allows precise modulating control.
- guarantees a suitable flow rate and avoiding too high energy consumption.

*a considerable reduction in temperature variations and adjustment movements and to the extension of the life of the moving devices*
Conclusion

- The sensing point of velocity sensor is critical to measure air flow accurately.
- Amplified Velocity Pressure is the solution to measure low air flow rate when high turn-down ratio required.
- Single-blade has advantage of lower pressure drop and lower noise level.
- Fast_Accurate_Stable air flow controller can deliver both comfortable and energy efficient VAV system.
- PICV for hot water coil is another solution to deliver both comfortable and energy efficient VAV system.

- Factory calibrated VAV box with Generic Bacnet MS/TP controller for any BMS system.
- Control system can deliver both comfortable and energy efficient solution ONLY when the mechanical equipment allows to...