2014 NEBB Annual Conference

Delivering Building Performance and Energy Efficiency

Fort Lauderdale, FL
April 3-5, 2014 – Hyatt Regency Pier 66

NEBB
VAV Laboratory Airflow Control Solutions Venturi Valve vs. Single Blade Damper
Agenda

• Introduction
• Control Valve Fundamentals
• Control Valve Design Criteria
• Summary
Standards & Guidelines

Primary Standards
- ANSI Z9.5 – 2012
- ASHRAE 110 – 1995
- NEBB Fume Hood Testing – 2009

Related Standards
- ASHRAE 90.1 – 2010
- NFPA 45
Laboratory Valves
Control Valve Fundamentals

Airflow Control Valves

Blade Damper Control Valve

• Direct airflow measurement using in-stream flow sensors

• Typical 6:1 turndown ratios

• Typically require three duct diameters of straight duct leading into and out of the valve
Control Valve Fundamentals

Airflow Control Valves

Venturi Valves
- Electronic flow feedback
- Mechanical pressure independent control valves
- Typical 16:1 turndown ratio
- No straight inlet/outlet duct run requirements
Control Valve Fundamentals
Mechanical Operation

**Venturi Valve**
- Actuator Shaft
- Actuator
- Lever Arm
- Cone Shaft
- Cone
- Venturi Body
- Airflow Area
- Airflow

**Single Blade Damper**
- Damper Shaft Crank Arm
- Multipoint Sensor
- Duct Housing
- Airflow
Control Valve Fundamentals
Pressure Dependent Positioning

Airflow remains constant – Damper position not constant
Control Valve Fundamentals
Mechanical Pressure Independence

Airflow remains constant – Damper position constant
Control Valve Fundamentals

Mechanical Pressure Independence

Valve Calibration
Closed Loop Control – Blade Damper Control Valve

- A **closed loop** or **feedback** control measures actual changes in the controlled variable and actuates the controlled device to bring about a change. *

*2005 ASHRAE Handbook – Fundamentals of Control, Chapter 15*
Control Valve Fundamentals
Airflow Control Concepts

Flow Characteristics of the Blade Damper Control Valve

- In a closed loop flow control application, accuracy depends mainly on the airflow transducer but the resolution of the blade damper will greatly impact the flow measurement accuracy at low flows.
Control Valve Fundamentals

Airflow Control Concepts

Open Loop Control – Venturi Valve Control

- An **open-loop** control does not have a direct link between the value of the controlled variable and the controller. An open-loop control anticipates the effect of an external variable on the system and adjusts the set point to avoid excessive offset.

*2005 ASHRAE Handbook – Fundamentals of Control, Chapter 15*
Flow Characteristics of the Venturi Valve

- In an open loop application, flow control depends entirely on the flow versus position relationship of the valve but control resolution is improved at low flows.
Control Valve Fundamentals

Airflow Control Accuracy

Air Flow Transducers
- Advantages
  - Common in HVAC industry
  - Relatively inexpensive
- Disadvantages
  - Accuracy typically percent of full scale

<table>
<thead>
<tr>
<th>CFM</th>
<th>Actual VP*</th>
<th>Transducer Error</th>
<th>Measured VP</th>
<th>Measured CFM</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>0.4522</td>
<td>0.01</td>
<td>0.4622</td>
<td>1011</td>
<td>1.1%</td>
</tr>
<tr>
<td>500</td>
<td>0.1131</td>
<td>0.01</td>
<td>0.1231</td>
<td>521</td>
<td>4.2%</td>
</tr>
<tr>
<td>200</td>
<td>0.0181</td>
<td>0.01</td>
<td>0.0281</td>
<td>249</td>
<td>24.5%</td>
</tr>
<tr>
<td>100</td>
<td>0.0045</td>
<td>0.01</td>
<td>0.0145</td>
<td>179</td>
<td>79.0%</td>
</tr>
</tbody>
</table>

*Size 10 blade damper control valve; K-Factor = 1487
Factory Valve Calibration

- 48 point characterization
- N.I.S.T.* traceable equipment
- +/- 5% accuracy

### Calibrated Flow Range

<table>
<thead>
<tr>
<th>Calibrated Flow Range</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 scfm to &lt; 100 scfm</td>
<td>4.0%</td>
</tr>
<tr>
<td>101 scfm to &lt; 250 scfm</td>
<td>2.5%</td>
</tr>
<tr>
<td>251 scfm to &lt; 5000 scfm</td>
<td>1.4%</td>
</tr>
</tbody>
</table>

*National Institute of Standards and Technology*
## Control Valve Fundamentals
### Airflow Sound

<table>
<thead>
<tr>
<th>Valve Size</th>
<th>Flow (CFM)**</th>
<th>Terminal Discharge NC Value*</th>
<th>Terminal Radiated NC Value *</th>
<th>Venturi Discharge NC Value*</th>
<th>Venturi Radiated NC Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size 8</td>
<td>400</td>
<td>21</td>
<td>21</td>
<td>31</td>
<td>23</td>
</tr>
<tr>
<td>Size 10</td>
<td>750</td>
<td>25</td>
<td>21</td>
<td>37</td>
<td>29</td>
</tr>
<tr>
<td>Size 12</td>
<td>900</td>
<td>27</td>
<td>21</td>
<td>32</td>
<td>24</td>
</tr>
<tr>
<td>Size 14</td>
<td>1500</td>
<td>26</td>
<td>26</td>
<td>41</td>
<td>44</td>
</tr>
</tbody>
</table>

*Test data obtained in accordance with AHRI Standard 880-2011 and ASHRAE Standard 130-2008

*NC values are calculated based on typical attenuation values outlined in Appendix E, AHRI Standard 885-2008

** Flow measurements taken at 1.5 in.W.C.
Control Valve Design Criteria
Control Valve Design Criteria

System Objectives

Safety
- Speed of Response

Reduce Operating Costs
- Airflow Capacity
- Minimum Operation Pressure
Control Valve Design Criteria

Speed of Response

ANSI Z9.5 – 2012 Section 6.5.3.2

VAV Response shall be sufficient to increase or decrease flow within 90% of the target flow or face velocity in a manner that does not increase potential for escape.

A response time of < 3 sec. after completion of the sash movement is considered acceptable for most operations. Faster response times may improve hood containment following the sash movement.
Control Valve Design Criteria

Speed of Response

ANSI Z9.5 – 2012 Section 6.5.3.2

VAV Response shall be sufficient to increase or decrease flow within 90% of the target flow or face velocity in a manner that does not increase potential for escape.

A response tie of <3 sec. after completion of the sash movement is considered acceptable for most operations. Faster response times may improve hood containment following the sash movement.
Control Valve Design Criteria

Speed of Response

ASHRAE 110-1995 - Section 6.4
The sash shall be fully opened in a smooth motion at a velocity between 1.0 ft/s and 1.5 ft/s.

The time it takes from the start of the sash movement until the sash reaches the top and the time it takes from the start if the sash movement until the face velocity reaches and maintains, within 10%, the design face velocity shall be recorded.
Control Valve Design Criteria

Speed of Response

ASHRAE 110-1995 - Section 6.4
The sash shall be fully opened in a smooth motion at a velocity between 1.0 ft/s and 1.5 ft/s.

The time it takes from the start of the sash movement until the sash reaches the top and the time it takes from the start if the sash movement until the face velocity reaches and maintains, within 10%, the design face velocity shall be recorded.
Control Valve Design Criteria

Speed of Response

NEBB Fume Hood Performance Testing - Section 9.3
VAV hoods are also to be tested to determine response time to return to a near steady state condition after a change in sash position.

The response time test involves 3 cycles of opening and closing the sash position from full closed to the operating sash position. When changing the sash position, use a smooth continuous motion and move the sash at a rate of approximately 1.5 ft/s.

Measure, record and report the VAV Speed of Response Time to first obtain a velocity equal to 90% of the baseline for each iteration.
Control Valve Design Criteria

Speed of Response

NEBB Fume Hood Performance Testing - Section 9.3
VAV hoods are also to be tested to determine response time to return to a near steady state condition after a change in sash position.

The response time test involves 3 cycles of opening and closing the sash position from full closed to the operating sash position. When changing the sash position, use a smooth continuous motion and move the sash at a rate of approximately 1.5 ft/s.

Measure, record and report the VAV Speed of Response Time to first obtain a velocity equal to 90% of the baseline for each iteration.
Control Valve Design Criteria

Speed of Response

Venturi Valve – Time from completion of sash movement

*Results from testing completed at Engineered Air Balance Laboratory, Houston - 2014
Control Valve Design Criteria

Speed of Response

Venturi Valve – Time from start of sash movement

*Results from testing completed at Engineered Air Balance Laboratory, Houston - 2014
Control Valve Design Criteria

Speed of Response

Blade Damper Control Valve—Time from completion of sash movement

*Results from testing completed at Price Research Center North, Winnipeg - 2014
Control Valve Design Criteria

Speed of Response

Blade Damper Control Valve – Time from completion of sash movement

*Results from testing completed at Price Research Center North, Winnipeg - 2014
Control Valve Design Criteria

Airflow Capacity

Laboratory spaces are subject to high makeup airflow rates, especially if the room has multiple fume hoods.

Designing diversity into laboratories can allow for the ability to downsize equipment and reduce operating costs.

\[ \text{Diversity} = \frac{\text{Actual Volume Flowrate}}{\text{Total Installed Exhaust Capacity}} \]
Control Valve Design Criteria

Airflow Capacity

The biggest driver of lab energy is make up air delivered to the space

What are the drivers of outside air in labs?
  • Fume Hood airflow requirements
  • Thermal loads
  • Ventilation rates

For many VAV labs the minimum hood exhaust rate is a bigger factor in reducing energy usage than face velocity
Control Valve Design Criteria

Airflow Capacity

Lab valve/boxes need proper sizing
- Hood valve sized to cover min to max flow
- Supply range based on lab design
- General exhaust sized for cooling & efficiency
Control Valve Design Criteria

Airflow Capacity

The mechanism that controls the exhaust fan speed or damper position to regulate the hood exhaust volume shall be designed to ensure a minimum exhaust volume in constant volume systems equal to the larger of 50 cfm/ft of hood width, or 25 cfm/ft² of hood work surface area, except where a written hazard characterization indicates otherwise, or if the hood is not in use.

ANSI Z9.5 - 2003

Where attempting to save energy in typically higher hood density installations, minimum fume hood flow rates in the range of 150 to 375 hood air changes per hour (ACH) have been used to control vapor concentrations inside hood interiors. (1–7)

ANSI Z9.5 - 2012
Control Valve Design Criteria

Airflow Capacity

The mechanism that controls the exhaust fan speed or damper position to regulate the hood exhaust volume shall be designed to ensure a minimum exhaust volume in constant volume systems equal to the larger of 50 cfm/ft of hood width, or 25 cfm/ft² of hood work surface area, except where a written hazard characterization indicates otherwise, or if the hood is not in use.

Approx. 10 cfm/ft²

Where attempting to save energy in typically higher hood density installations, minimum fume hood flow rates in the range of 150 to 375 hood air changes per hour (ACH) have been used to control vapor concentrations inside hood interiors.(1–7)
Example:

A typical bench type fume hood has a working depth of approximately 2 feet.

Airflow necessary to maintain 25 cfm per square foot of internal work surface for each linear foot of width becomes:

\[ 2 \text{ ft (Depth)} \times 1 \text{ ft (Width)} \times 25 \text{ cfm/ft}^2 = 50 \text{ cfm} \]
Control Valve Design Criteria

Fume Hood Minimum Exhaust Airflow

Example:

A typical bench type fume hood has a working depth of approximately 2 feet.

Airflow necessary to maintain 25 cfm per square foot of internal work surface for each linear foot of width becomes:

\[ 2 \text{ ft (Depth)} \times 1 \text{ ft (Width)} \times 25 \text{ cfm/ft}^2 = 50 \text{ cfm} \]

Airflow necessary to maintain 10 cfm per square foot of internal work surface for each linear foot of width becomes:

\[ 2 \text{ ft (Depth)} \times 1 \text{ ft (Width)} \times 10 \text{ cfm/ft}^2 = 20 \text{ cfm} \]
Control Valve Design Criteria

Fume Hood Minimum Exhaust Airflow

Example:

Constant volume at 300 CFM

- A 6 foot hood would give a min flow of 300 CFM
- Affects flow rates at minimum or closed sash positions
Control Valve Design Criteria

Fume Hood Minimum Exhaust Airflow

Example:

Constant volume at 120 CFM

- A 6 foot hood would give a min flow of 120 CFM
- Affects flow rates at minimum or closed sash positions
Control Valve Design Criteria

Fume Hood Minimum Exhaust Airflow

Example:

Constant volume at 120 CFM

- A 6 foot hood would give a minimum flow of 120 CFM
- Affects flow rates at minimum or closed sash positions
- Does not affect face velocity
Control Valve Design Criteria

Fume Hood Maximum Exhaust Airflow

Example:

ANSI Z9.5 recommends an average face velocity of 80-120 fpm

Exhaust airflow needed to maintain an average face velocity of 100 fpm for each foot of sash width is:

\[ 1.5 \text{ ft (Height)} \times 1 \text{ ft (Width)} \times 100 \text{ ft/min} = 150 \text{ cfm} \]

Fume hood with a fully open vertical sash will have a maximum exhaust airflow of approximately 150 cfm for every foot of sash width.
Example:

ANSI Z9.5 recommends an average face velocity of 80-120 fpm

Exhaust airflow needed to maintain an average face velocity of 100 fpm for each foot of sash width is:

\[ 1.5 \text{ ft (Height)} \times 1 \text{ ft (Width)} \times 100 \text{ ft/min} = 150 \text{ cfm} \]

Fume hood with a fully open vertical sash will have a maximum exhaust airflow of approximately 250 cfm for every foot of sash width.

A 6 foot hood would give a max flow requirement of 900 CFM.
Control Valve Design Criteria

Airflow Capacity

- The fundamental selection criteria for a flow control device is the range of flow rates

<table>
<thead>
<tr>
<th>Sizing Parameter</th>
<th>Blade Damper Control Valve</th>
<th>Venturi Valve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Criteria</td>
<td>Typical Valve</td>
</tr>
<tr>
<td>Maximum Airflow</td>
<td>System may be considered too loud or have too a high pressure drop</td>
<td>1,000 - 3,000 fpm.</td>
</tr>
<tr>
<td>Minimum Airflow</td>
<td>The flow sensor may be inaccurate due to low velocity pressures</td>
<td>0 - 500 fpm.</td>
</tr>
</tbody>
</table>
Control Valve Design Criteria

Airflow Turndown

- Airflow turndown is commonly used to express the airflow control range without the need to have specific max and min flow rates.

- A valve with a turndown of 16:1 does not equate to double the airflow of a valve with an 8:1 turndown.

![Graph showing airflow turndown comparison between 16:1 and 8:1 turndowns.](image)
Control Valve Design Criteria

Airflow Capacity

- A blade damper control valves typically have a larger airflow capacity than a venturi air valve of the same diameter but the turndown ratio is reduced due to the increase in minimum airflow.

<table>
<thead>
<tr>
<th>Valve Size</th>
<th>Terminal Unit</th>
<th>Terminal Turndown</th>
<th>Low Pressure Valve</th>
<th>Low Pressure Turndown</th>
<th>Medium Pressure Valve</th>
<th>Medium Pressure Turndown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size 8</td>
<td>130-800</td>
<td>6:1</td>
<td>35 – 500</td>
<td>14:1</td>
<td>35 – 700</td>
<td>20:1</td>
</tr>
<tr>
<td>Size 10</td>
<td>220-1350</td>
<td>6:1</td>
<td>50 – 550</td>
<td>11:1</td>
<td>50 – 1000</td>
<td>20:1</td>
</tr>
<tr>
<td>Size 12</td>
<td>300-2100</td>
<td>7:1</td>
<td>90 – 1200</td>
<td>13:1</td>
<td>90 – 1500</td>
<td>16.5:1</td>
</tr>
<tr>
<td>Size 14</td>
<td>440-3000</td>
<td>7:1</td>
<td>200 – 1400</td>
<td>7:1</td>
<td>200 – 2500</td>
<td>12.5:1</td>
</tr>
</tbody>
</table>
Control Valve Design Criteria

Fume Hood Valve Selection

Example:

Old Criteria – ANSI Z9.5 – 2003

Using the 6 foot hood example, a turn down of 3:1 is required to achieve the full range of 300 – 900 CFM for the hood.

Valve Selection:

Size 12 Venturi Valve – Low Pressure
90 -1200 CFM

or

Size 10 Blade Damper Control Valve
220-1350 CFM

Both valves can achieve the required minimum turndown and maximum flow for the fume hood
Control Valve Design Criteria

Fume Hood Valve Selection

Example:

New Criteria – ANSI Z9.5 – 2012

Using the 6 foot hood example, a turn down of 7.5:1 is required to achieve the full range of 120 – 900 CFM for the hood.

Valve Selection:

- Size 12 Venturi Valve – Low Pressure
  90 -1200 CFM

or

- Size 10 Blade Damper Control Valve
  220-1350 CFM

At $7.5/CFM/yr*, selection of the venturi valve will give a savings of ~$500/yr if sash is closed 70% of the time

*http://fumehoodcalculator.lbl.gov/
Minimum pressure drop is an important parameter of an airflow control device. It is the pressure drop across a fully open device at a given airflow rate.
## Control Valve Design Criteria
### Operating Pressure

The minimum pressure drop depends on the size of the airflow area.

<table>
<thead>
<tr>
<th>Sizing Parameter</th>
<th>Blade Damper Control Valve</th>
<th>Venturi Valve</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum Pressure Drop</strong></td>
<td>Above this pressure, control may become difficult.</td>
<td>Dampers have been applied successfully at 6 in. WC of drop.</td>
</tr>
<tr>
<td><strong>Minimum Pressure Drop</strong></td>
<td>Pressure measured across the fully open damper at a rated flow.</td>
<td>Usually less than 0.1 in. WC.</td>
</tr>
</tbody>
</table>
Control Valve Design Criteria

Operating Pressure
Control Valve Design Criteria

Pressure Drop

Cost of Static Pressure Loss

- The fan power is directly proportional to the pressure loss; twice as much pressure consumes twice as much power.

\[ \text{Fan Power} = \frac{\text{Airflow} \times \text{Fan Pressure}}{\text{Fan Efficiency}} \]

<table>
<thead>
<tr>
<th>Valve Type</th>
<th>Operation Pressure (in. WC)</th>
<th>Fan Power (kW) *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blade Damper Control Valve</td>
<td>0.1</td>
<td>0.017</td>
</tr>
<tr>
<td>Low Pressure Venturi Valve</td>
<td>0.3</td>
<td>0.052</td>
</tr>
<tr>
<td>Medium Pressure Venturi Valve</td>
<td>0.6</td>
<td>0.1</td>
</tr>
</tbody>
</table>

*Per 1000 cfm assuming 70 % fan efficiency
Control Valve Design Criteria

Pressure Drop

Example

Assume a laboratory has 20 fume hoods on a 18,000 CFM system.

Using the same fan efficiency of 70%, the difference in kW between a blade damper control valve and venturi valve would be as follows:

\[
\text{Fan Power} = \frac{\text{Airflow} \times \text{Fan Pressure}}{\text{Fan Efficiency}}
\]

- Blade Damper Control Valve = 0.306 kW
- Low Pressure Venturi Valve = 0.936 kW

Savings by selecting the blade damper control valve would be at most $550/year*

*Assuming 10 cents/kWh and a total annual usage of 8760 hours
Control Valve Design Criteria

Pressure Drop

Example

Using the same example of a laboratory has 20 fume hoods on a 18,000 CFM system that are sized the same as the previous Air Capacity example.

20 Fume Hoods x $500 Savings/hood = $10,000

This shows that reducing the airflow provides a significantly higher impact to the potential savings from reducing the system static pressure.
Summary

• Required speed of response for fume hood control can be achieved using both blade damper and venturi control valves depending on what test standard is to be applied.

• Cutting flow is the most effective way to reduce energy consumption in a laboratory and with changes to minimum hood flow rates in ANSI Z9.5, venturi valves can provide additional savings over terminal units.

• Delivering air more efficiently by minimizing system static pressure comes second to reducing airflow rates to lower energy costs.
Summary

Questions & Discussion