Using System Curves to Avoid Problems in VAV Systems

Ronald Wroblewski
Owner, Productive Energy Solutions, LLC,
Madison, Wisconsin, USA
Ron@ProductiveEnergy.com

Air System Engineering & Technology (ASET) Conference–Europe
Lyon, France • L’Espace Tête d’Or • 20 February 2018
Copyright Materials

This educational activity is protected by U.S. and International copyright laws. Reproduction, distribution, display, and use of the educational activity without written permission of the presenter is prohibited.

© AMCA International
Learning Objectives

1. Review VAV concept and purpose
2. Review basic system curve construction
3. Construct a more detailed system curve model for VAV air conditioning system
4. Review basic fan curve with surge region
5. Overlay the system curve and fan curve to determine the effect on the fan
Why Variable Air Volume (VAV)?

Main purpose of VAV is to avoid reheat associated with constant volume (CV) systems.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Peak Flow</th>
<th>Summer morning</th>
<th>Spring morning</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>1</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>East</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>South</td>
<td>1.5</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>West</td>
<td>1.5</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Interior</td>
<td>3</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>8.5</td>
<td>4.3</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Typical air conditioning zoning
Mainly to Save Energy – But what energy?

• Energy saved at the chiller
• Energy saved by shutting off the re-heat
• Energy saved at the fan

Typical Constant Volume HVAC system energy

- Chiller: 0.17 – 0.28 kW_e/kW_t, 0.6 to 1.0 kW/ton
- Reheat boiler: 0.2 kW_e/kW_t, 0.7 kW/ton plus standby losses
- Pumps: 0.03 kW_e/kW_t, 0.1 kW/ton
- Fans: 0.03 kW_e/kW_t, 0.1 kW/ton
- Cooling tower: 0.01 kW_e/kW_t, 0.04 kW/ton
Variable Air Volume (VAV) Systems

1. Central Air Handling Unit
   a) Heating Coil
   b) Cooling Coil
   c) Filters
   d) Fan
2. Ducting
3. Flow Variators (VAV box)
4. Supply Air Terminal
5. Room Thermostat
6. Pressure Transducer

Courtesy Bill Cory
“Common” System Curve

The system curve is a graphical representation of the pressure required to drive a given amount of flow through the system.

- “Common” assumptions
  - “Constant Orifice” system
  - Passes through the origin (0,0)
  - Parabolic in shape
    \[ Y = a \times X^2 \]
  - When the flow is cut in half, the pressure loss drops to one-fourth
System Curve Elements

- System effect loss
  Exponent of 2 or 1.9
- Loss through ductwork
  Exponent of 2 or 1.9
- Loss through cooling coils
  Exponent of 1.6
- Loss through filters
  Exponent of 1 (linear)
- Fixed pressure set point
  Adds constant offset

\[ Y = aX^2 + bX^{1.6} + cX + d \]
## Cooling Coil Pressure Loss

### Coil Selection criteria
- Wet Coil
- 5 rows
- 470 fins/meter

*Courtesy McQuay*

In examining the catalog data for cooling coil we see that the exponent 1.6 closely matches actual catalog information.

<table>
<thead>
<tr>
<th>Face velocity (m/s)</th>
<th>Pressure loss</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Catalog Pa</td>
<td>Exponent of 1.6 Pa</td>
</tr>
<tr>
<td>1.0</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>192</td>
<td>196</td>
</tr>
<tr>
<td>2.5</td>
<td>269</td>
<td>280</td>
</tr>
<tr>
<td>3.0</td>
<td>369</td>
<td>375</td>
</tr>
</tbody>
</table>
Filter Pressure Loss

Initial Resistance vs. Filter Face Velocity

Losses very close to linear

Courtesy American Air Filter
VAV System Typical Characteristic Curve

System curve for a VAV system
System curve for a constant orifice system
This pressure is maintained constant by the pressure transducer

AHU Coils, Filters, System Effect
Ductwork Mains
Transducer maintained pressure

Courtesy Bill Cory
Calculated VAV System Characteristic Curve

Total including Ductwork Mains and System Effect

Control pressure plus AHU Loss (Coils, Filters)

Transducer maintained control pressure
VAV vs. Constant Orifice System Curve

At lower flow rates, the disparity is more pronounced.
Characteristics Curve and Fan Stall Regions for Backward Bladed Fans

- As speed decreases, operating point:
  - Gets closer to stall zone
  - Moves away from best efficiency point
- Minimum speed is limited to approximately 45 or 50% by pressure requirements and stall considerations

Courtesy Bill Cory
# Actual Fan Selections

<table>
<thead>
<tr>
<th>Model Name</th>
<th>Relative Cost</th>
<th>Operating Cost / Yr (USD)</th>
<th>Outlet Velocity (m/sec)</th>
<th>Fan Class</th>
<th>Fan Speed (RPM)</th>
<th>Max Fan Speed (RPM)</th>
<th>Min Speed (RPM)</th>
<th>Drive Loss (%)</th>
<th>Operating Power (kW)</th>
<th>Motor Size NEMA (hp)</th>
<th>SE (%)</th>
<th>Pts within Peak TE (%)</th>
<th>FEG</th>
<th>Wheel Diameter (mm)</th>
<th>Inlet dBA (dB)</th>
<th>Best Lead Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFDW-18</td>
<td>1.39</td>
<td>7,374</td>
<td>26.520</td>
<td>III</td>
<td>3598</td>
<td>3865</td>
<td>651</td>
<td>4.6</td>
<td>27.8</td>
<td>40</td>
<td>43</td>
<td>18</td>
<td>80</td>
<td>464</td>
<td>97</td>
<td>Standard</td>
</tr>
<tr>
<td>AFDW-20</td>
<td>1.33</td>
<td>5,621</td>
<td>22.100</td>
<td>III</td>
<td>2864</td>
<td>3526</td>
<td>536</td>
<td>4.7</td>
<td>21.95</td>
<td>30</td>
<td>55</td>
<td>6</td>
<td>80</td>
<td>508</td>
<td>94</td>
<td>Standard</td>
</tr>
<tr>
<td>AFDW-22</td>
<td>1.00</td>
<td>5,098</td>
<td>17.870</td>
<td>II</td>
<td>2271</td>
<td>2575</td>
<td>434</td>
<td>4.7</td>
<td>19.22</td>
<td>30</td>
<td>62</td>
<td>1</td>
<td>75</td>
<td>565</td>
<td>90</td>
<td>10 Day</td>
</tr>
<tr>
<td>AFDW-24</td>
<td>1.00</td>
<td>4,540</td>
<td>14.733</td>
<td>II</td>
<td>1832</td>
<td>2192</td>
<td>397</td>
<td>4.8</td>
<td>17.03</td>
<td>25</td>
<td>70</td>
<td>0</td>
<td>80</td>
<td>622</td>
<td>86</td>
<td>10 Day</td>
</tr>
<tr>
<td>AFDW-30</td>
<td>1.14</td>
<td>4,305</td>
<td>9.827</td>
<td>I</td>
<td>1316</td>
<td>1348</td>
<td>355</td>
<td>4.8</td>
<td>16.14</td>
<td>25</td>
<td>74</td>
<td>3</td>
<td>85</td>
<td>762</td>
<td>83</td>
<td>10 Day</td>
</tr>
<tr>
<td>BIDW-18</td>
<td>1.55</td>
<td>8,007</td>
<td>26.520</td>
<td>III</td>
<td>3285</td>
<td>3530</td>
<td>594</td>
<td>4.6</td>
<td>30.31</td>
<td>50</td>
<td>39</td>
<td>22</td>
<td>80</td>
<td>464</td>
<td>99</td>
<td>Standard</td>
</tr>
<tr>
<td>BIDW-20</td>
<td>1.30</td>
<td>6,629</td>
<td>22.100</td>
<td>III</td>
<td>2643</td>
<td>3219</td>
<td>496</td>
<td>4.6</td>
<td>24.99</td>
<td>40</td>
<td>48</td>
<td>15</td>
<td>80</td>
<td>508</td>
<td>95</td>
<td>Standard</td>
</tr>
<tr>
<td>BIDW-22</td>
<td>1.02</td>
<td>5,539</td>
<td>17.870</td>
<td>II</td>
<td>2091</td>
<td>2294</td>
<td>424</td>
<td>4.7</td>
<td>20.88</td>
<td>30</td>
<td>57</td>
<td>8</td>
<td>80</td>
<td>565</td>
<td>91</td>
<td>10 Day</td>
</tr>
<tr>
<td>BIDW-24</td>
<td>1.04</td>
<td>4,818</td>
<td>14.733</td>
<td>II</td>
<td>1717</td>
<td>2045</td>
<td>387</td>
<td>4.8</td>
<td>18.07</td>
<td>25</td>
<td>66</td>
<td>1</td>
<td>75</td>
<td>622</td>
<td>87</td>
<td>10 Day</td>
</tr>
<tr>
<td>BIDW-27</td>
<td>1.12</td>
<td>4,634</td>
<td>12.134</td>
<td>II</td>
<td>1458</td>
<td>1855</td>
<td>344</td>
<td>4.8</td>
<td>17.38</td>
<td>25</td>
<td>69</td>
<td>0</td>
<td>75</td>
<td>686</td>
<td>84</td>
<td>10 Day</td>
</tr>
<tr>
<td>BIDW-30</td>
<td>1.12</td>
<td>4,800</td>
<td>9.827</td>
<td>I</td>
<td>1258</td>
<td>1279</td>
<td>333</td>
<td>4.8</td>
<td>18</td>
<td>25</td>
<td>67</td>
<td>3</td>
<td>75</td>
<td>762</td>
<td>83</td>
<td>10 Day</td>
</tr>
</tbody>
</table>

8.5 m³/s, 1345 Pa, Sea Level, Density 1.2 kg/m³

Fan selection data and fan curves courtesy Greenheck
Characteristic Curve and Fan Stall Regions for 686 mm fan

Minimum speed is limited to 60%!
Characteristic Curve and Stall Regions for 762 mm Fan

Minimum speed is limited to 80%!
Comparison of Fan Curves

A. AFDW 22  (565 mm)
B. AFDW 24  (622 mm)
C. AFDW 27  (686 mm)
D. AFDW 30  (762 mm)
E. BIDW 18  (464 mm)
Take-Aways - Fans in VAV systems

• Larger fans typically have lower energy usage
• Beware of fan selections with their operating point to the left of Best Efficiency Point
• Ensure a sufficient residual pressure capacity of 15% or more between selection point and peak fan pressure
• Limit minimum fan speed to 50%
• Be particularly cautious if you are oversizing the AHU to minimize face velocity
Wrap-up: VAV System Typical Assumptions

Some of the typical assumptions designers make when analyzing VAV systems may be more myth than reality:

<table>
<thead>
<tr>
<th>Myth</th>
<th>Reality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency of fan = constant</td>
<td>Fan efficiency decreases as fan speed is reduced</td>
</tr>
<tr>
<td>System curve parabolic and passes through the origin (0,0) point</td>
<td>System curve is shifted upward and flattened</td>
</tr>
<tr>
<td>Pressure loss decreases as square of flow reduction</td>
<td>Pressure loss in cooling coils and filters do not follow the square law</td>
</tr>
<tr>
<td>Minimum fan speed can be as low as 25%</td>
<td>Minimum fan speed limited by static pressure set point and stall considerations</td>
</tr>
</tbody>
</table>
Questions?

Ronald Wroblewski
Owner
Productive Energy Solutions, LLC
www.productiveenergy.com
ron@productiveenergy.com
### Cooling Coil Pressure Loss (Imperial)

**Coil Selection criteria**
- Wet Coil
- 5 rows
- 12 fins/inch

*Courtesy McQuay*

<table>
<thead>
<tr>
<th>Face velocity (Feet per minute)</th>
<th>Catalog (Inches w.g.)</th>
<th>Calculated w exponent 1.6 (Inches w.g.)</th>
<th>Calculated w exponent 2 (Inches w.g.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>0.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>0.77</td>
<td>0.79</td>
<td>1.04</td>
</tr>
<tr>
<td>500</td>
<td>1.08</td>
<td>1.13</td>
<td>1.63</td>
</tr>
<tr>
<td>600</td>
<td>1.48</td>
<td>1.51</td>
<td>2.34</td>
</tr>
</tbody>
</table>

*In examining the catalog data for cooling coil we see that the exponent 1.6 closely matches actual catalog information.*
## Actual Fan Selections

<table>
<thead>
<tr>
<th>Model Name</th>
<th>Relative Cost</th>
<th>Operating Cost / Yr (USD)</th>
<th>Outlet Velocity (m/sec)</th>
<th>Fan Class</th>
<th>Fan Speed (RPM)</th>
<th>Max Fan Speed (RPM)</th>
<th>Min Speed (RPM)</th>
<th>Drive Loss (%)</th>
<th>Operating Power (kW)</th>
<th>Motor Size NEMA (hp)</th>
<th>SE (%)</th>
<th>Pt % within Peak TE (%)</th>
<th>FEG</th>
<th>Wheel Diameter (mm)</th>
<th>Inlet dBA (dB)</th>
<th>Best Lead Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFDW-18</td>
<td>1.39</td>
<td>7,374</td>
<td>26.520</td>
<td>III</td>
<td>3598</td>
<td>3865</td>
<td>651</td>
<td>4.6</td>
<td>27.3</td>
<td>40</td>
<td>43</td>
<td>18</td>
<td>80</td>
<td>464</td>
<td>97</td>
<td>Standard</td>
</tr>
<tr>
<td>AFDW-20</td>
<td>1.33</td>
<td>5,821</td>
<td>22.100</td>
<td>III</td>
<td>2864</td>
<td>3526</td>
<td>536</td>
<td>4.7</td>
<td>21.55</td>
<td>30</td>
<td>55</td>
<td>6</td>
<td>80</td>
<td>508</td>
<td>94</td>
<td>Standard</td>
</tr>
<tr>
<td>AFDW-22</td>
<td>1.00</td>
<td>5,098</td>
<td>17.870</td>
<td>II</td>
<td>2271</td>
<td>2575</td>
<td>434</td>
<td>4.7</td>
<td>19.12</td>
<td>30</td>
<td>62</td>
<td>1</td>
<td>75</td>
<td>565</td>
<td>90</td>
<td>10 Day</td>
</tr>
<tr>
<td>AFDW-24</td>
<td>1.00</td>
<td>5,540</td>
<td>14.733</td>
<td>II</td>
<td>1832</td>
<td>2192</td>
<td>397</td>
<td>4.8</td>
<td>17.03</td>
<td>25</td>
<td>70</td>
<td>0</td>
<td>80</td>
<td>622</td>
<td>86</td>
<td>10 Day</td>
</tr>
<tr>
<td>AFDW-30</td>
<td>1.14</td>
<td>4,305</td>
<td>9.827</td>
<td>I</td>
<td>1316</td>
<td>1348</td>
<td>355</td>
<td>4.8</td>
<td>16.14</td>
<td>25</td>
<td>74</td>
<td>3</td>
<td>85</td>
<td>762</td>
<td>83</td>
<td>10 Day</td>
</tr>
<tr>
<td>BIDW-18</td>
<td>1.55</td>
<td>8,007</td>
<td>26.520</td>
<td>III</td>
<td>3285</td>
<td>3530</td>
<td>594</td>
<td>4.6</td>
<td>30.31</td>
<td>50</td>
<td>39</td>
<td>22</td>
<td>80</td>
<td>464</td>
<td>99</td>
<td>Standard</td>
</tr>
<tr>
<td>BIDW-20</td>
<td>1.30</td>
<td>6,629</td>
<td>22.100</td>
<td>III</td>
<td>2643</td>
<td>3219</td>
<td>496</td>
<td>4.6</td>
<td>24.99</td>
<td>40</td>
<td>48</td>
<td>15</td>
<td>80</td>
<td>508</td>
<td>95</td>
<td>Standard</td>
</tr>
<tr>
<td>BIDW-22</td>
<td>1.02</td>
<td>5,539</td>
<td>17.870</td>
<td>II</td>
<td>2091</td>
<td>2294</td>
<td>424</td>
<td>4.7</td>
<td>20.88</td>
<td>30</td>
<td>57</td>
<td>8</td>
<td>80</td>
<td>565</td>
<td>91</td>
<td>10 Day</td>
</tr>
<tr>
<td>BIDW-24</td>
<td>1.04</td>
<td>4,818</td>
<td>14.733</td>
<td>II</td>
<td>1717</td>
<td>2045</td>
<td>387</td>
<td>4.8</td>
<td>18.67</td>
<td>25</td>
<td>66</td>
<td>1</td>
<td>75</td>
<td>622</td>
<td>87</td>
<td>10 Day</td>
</tr>
<tr>
<td>BIDW-27</td>
<td>1.12</td>
<td>4,634</td>
<td>12.134</td>
<td>II</td>
<td>1458</td>
<td>1855</td>
<td>344</td>
<td>4.8</td>
<td>17.38</td>
<td>25</td>
<td>69</td>
<td>0</td>
<td>75</td>
<td>686</td>
<td>84</td>
<td>10 Day</td>
</tr>
<tr>
<td>BIDW-30</td>
<td>1.12</td>
<td>4,800</td>
<td>9.827</td>
<td>I</td>
<td>1258</td>
<td>1279</td>
<td>333</td>
<td>4.8</td>
<td>18</td>
<td>25</td>
<td>67</td>
<td>3</td>
<td>75</td>
<td>762</td>
<td>83</td>
<td>10 Day</td>
</tr>
</tbody>
</table>

8.5 m³/s, 1345 Pa, Sea Level, Density 1.2 kg/m³

Fan selection data and fan curves courtesy Greenheck