AMCA International

# Using System Curves to Avoid Problems in VAV Systems


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PRODUCTIVE ENERGY SOLUTIONS LLC

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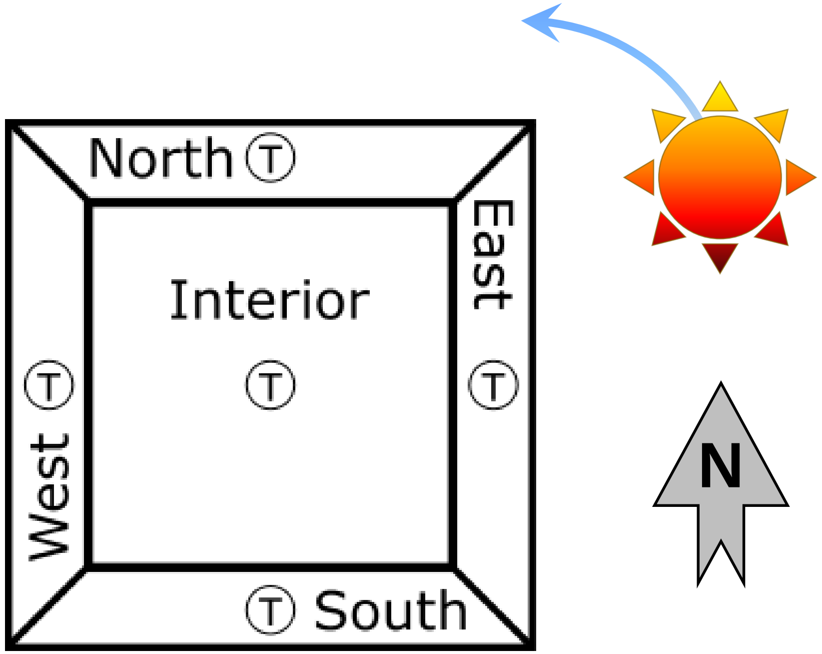
# Copyright Materials

# 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)?




Typical air conditioning zoning

| 6C cooling airflow required (hypothetical) $m^3/s$ | | | |
|---|---|---|---|
| Zone | Peak Flow | Summer morning | Spring morning |
| North | 1 | 0.3 | 0.2 |
| East | 1.5 | 1.5 | 1.5 |
| South | 1.5 | 0.5 | 0.3 |
| West | 1.5 | 0.5 | 0.3 |
| Interior | 3 | 1.5 | 1 |
| | 8.5 | 4.3 | 3.3 |

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

# Why VAV? (continued)

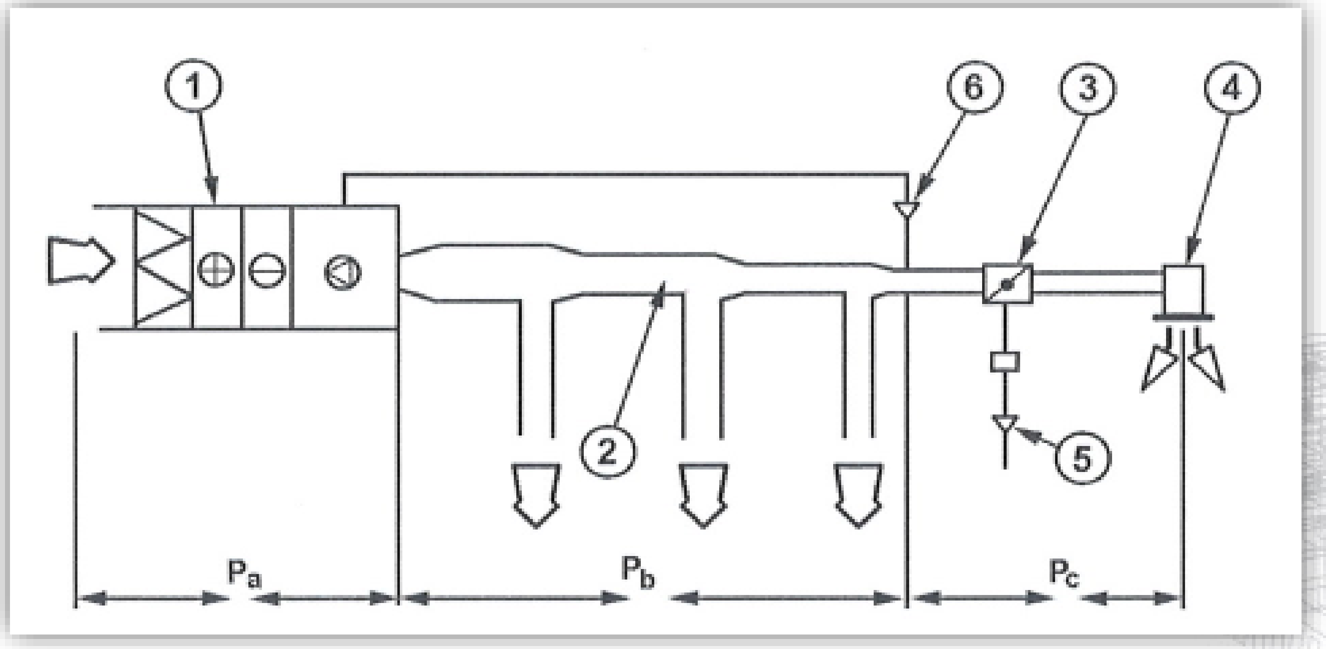
## Mainly to Save Energy – But what energy?

- 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




Courtesy Bill Cory

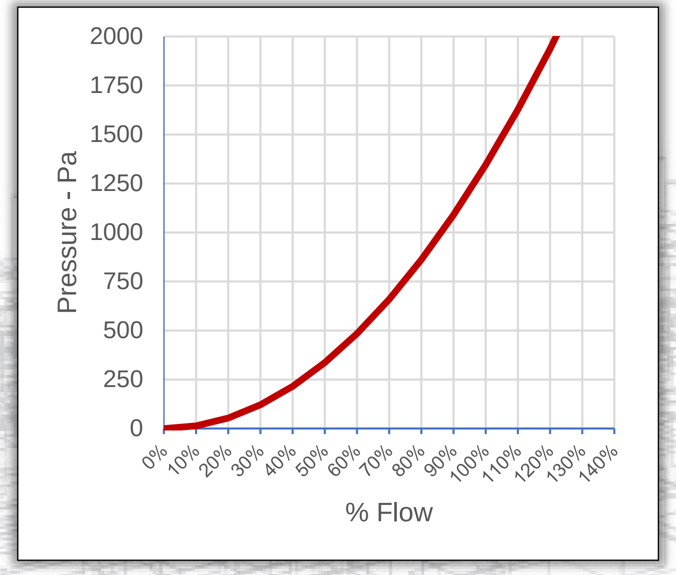
1. Central Air Handling Unit
   a) Heating Coil
   b) Cooling Coil
   c) Filters
   d) Fan
2. Ducting
3. Flow Variators (VAV box)
4. Supply Air Terminal
5. Room Thermostat
6. Pressure Transducer

# “Common” System Curve

The system curve is 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

| Face velocity m/s | Pressure loss | | |
|---|---|---|---|
| | Catalog Pa | Exponent of 1.6 Pa | Exponent of 2 Pa |
| 1.0 | 65 | | |
| 2.0 | 192 | 196 | 259 |
| 2.5 | 269 | 280 | 405 |
| 3.0 | 369 | 375 | 583 |

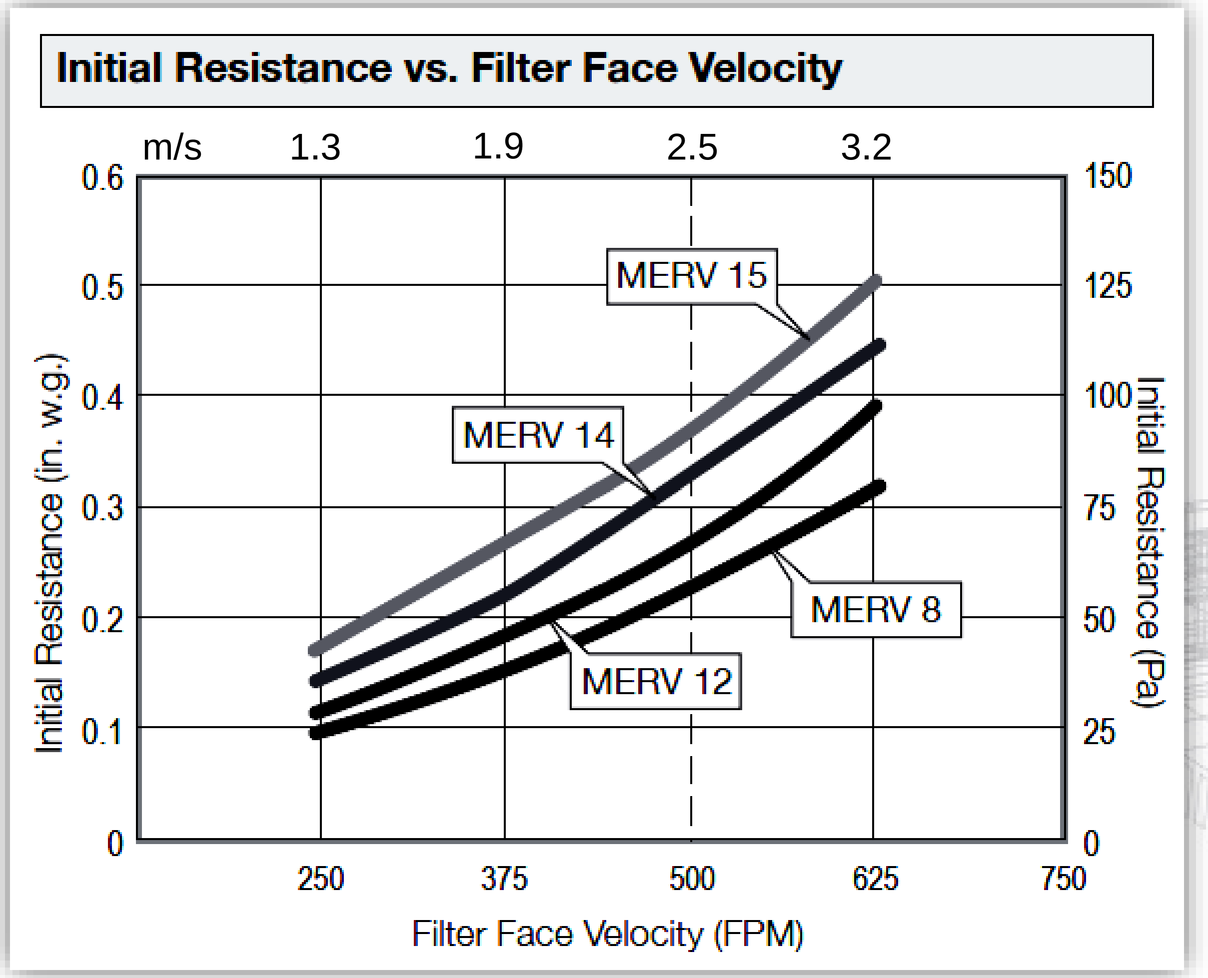
## Coil Selection criteria

- 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.*

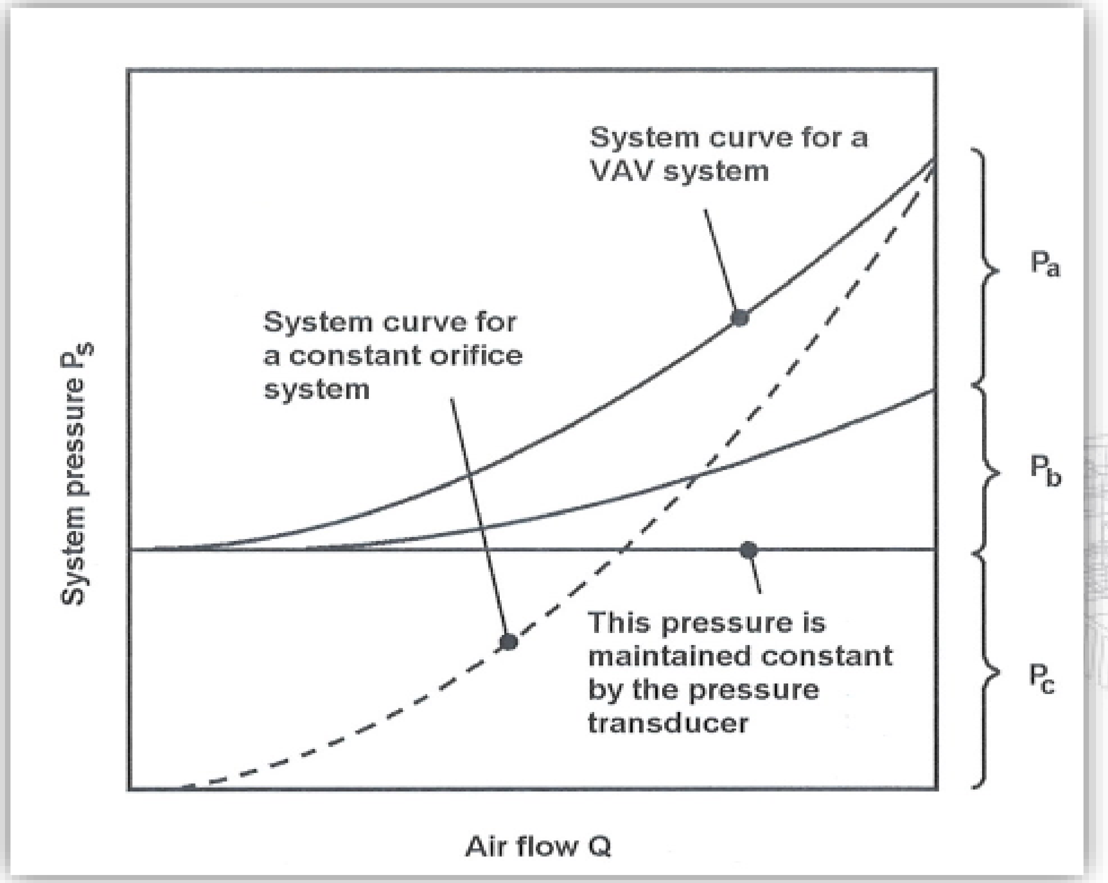
# Filter Pressure Loss




## Losses very close to linear

Courtesy American Air Filter

# VAV System Typical Characteristic Curve



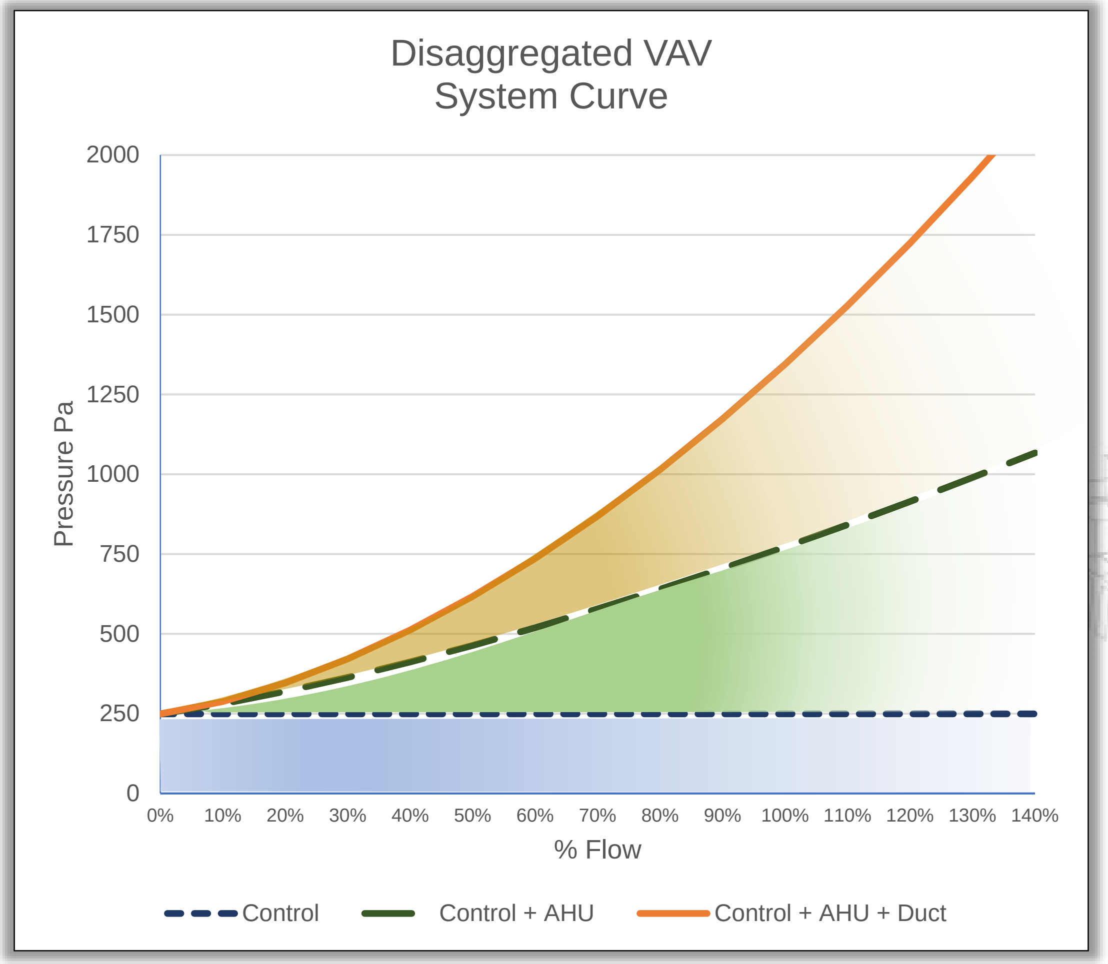

Courtesy Bill Cory

AHU Coils, Filters, System Effect

Ductwork Mains

Transducer maintained pressure

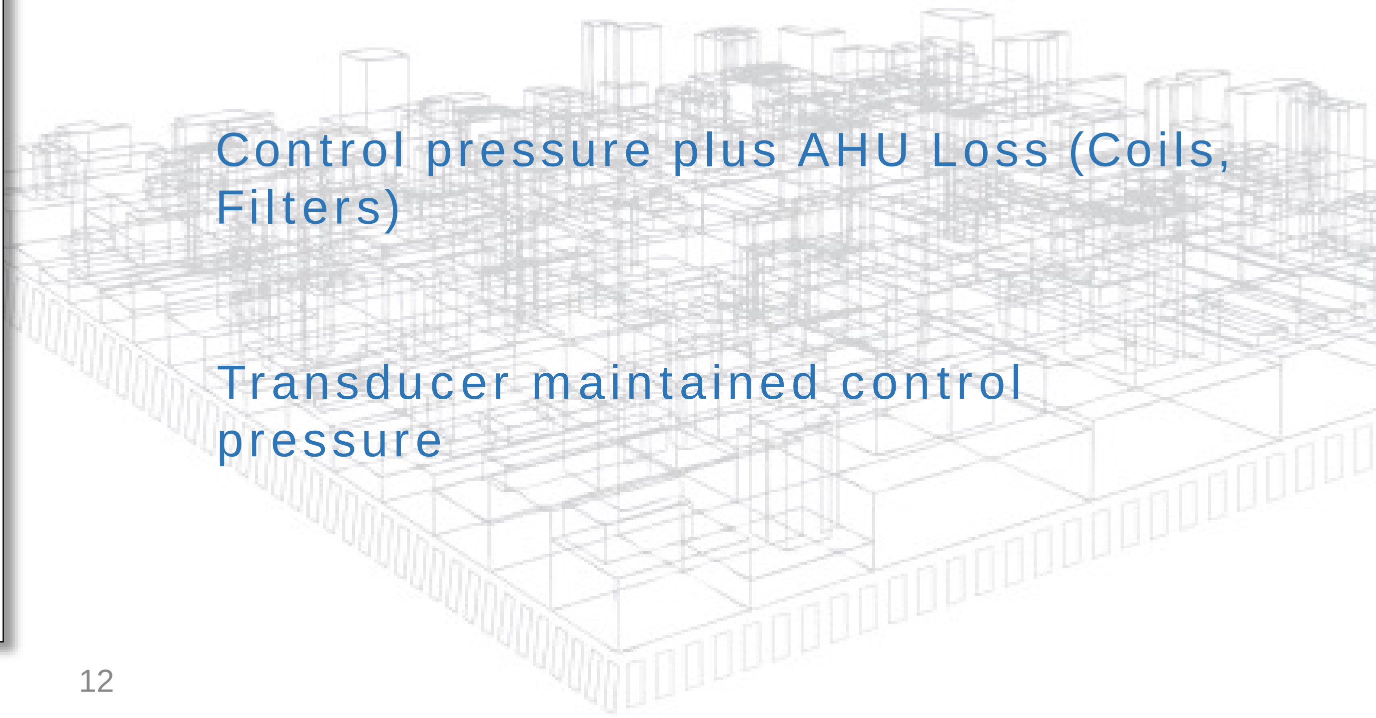
# Calculated VAV System Characteristic Curve



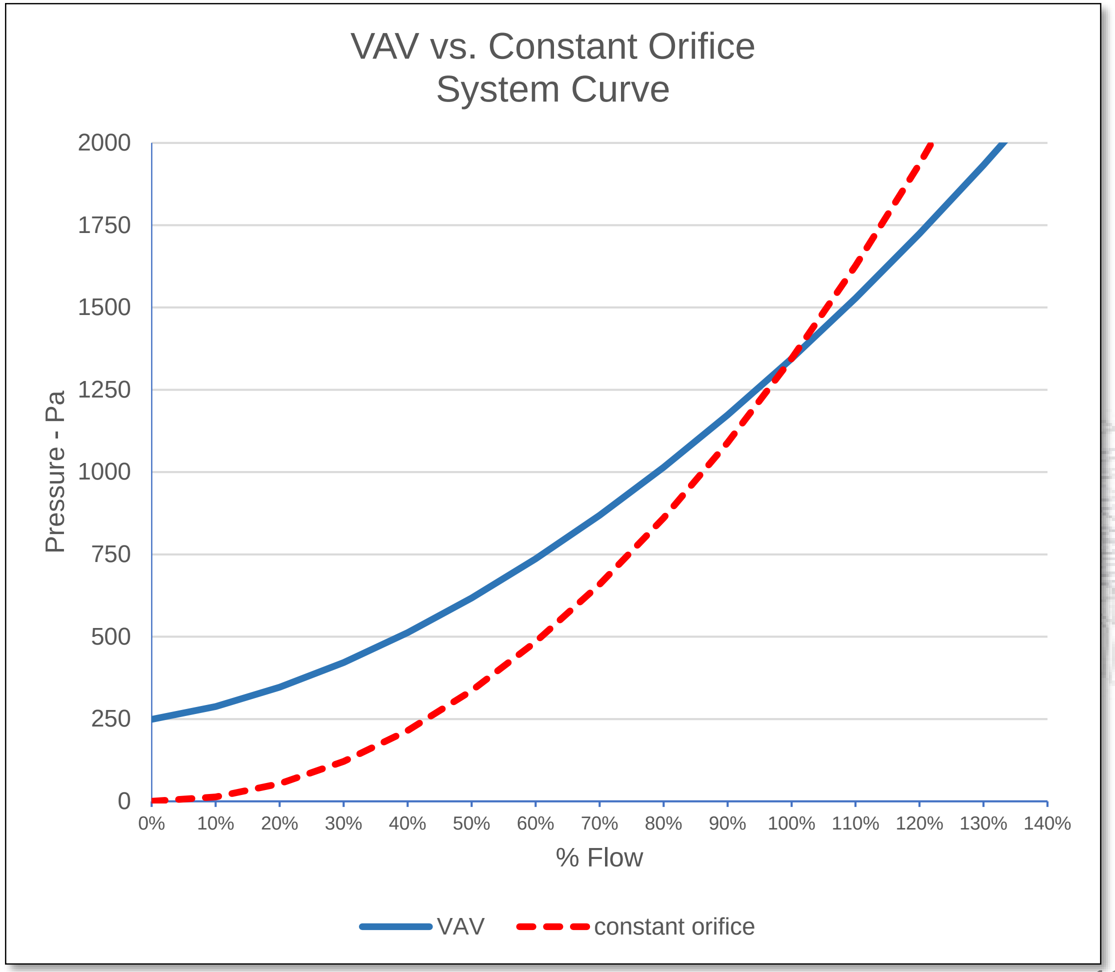

Total including Ductwork Mains and System Effect

Control pressure plus AHU Loss (Coils, Filters)

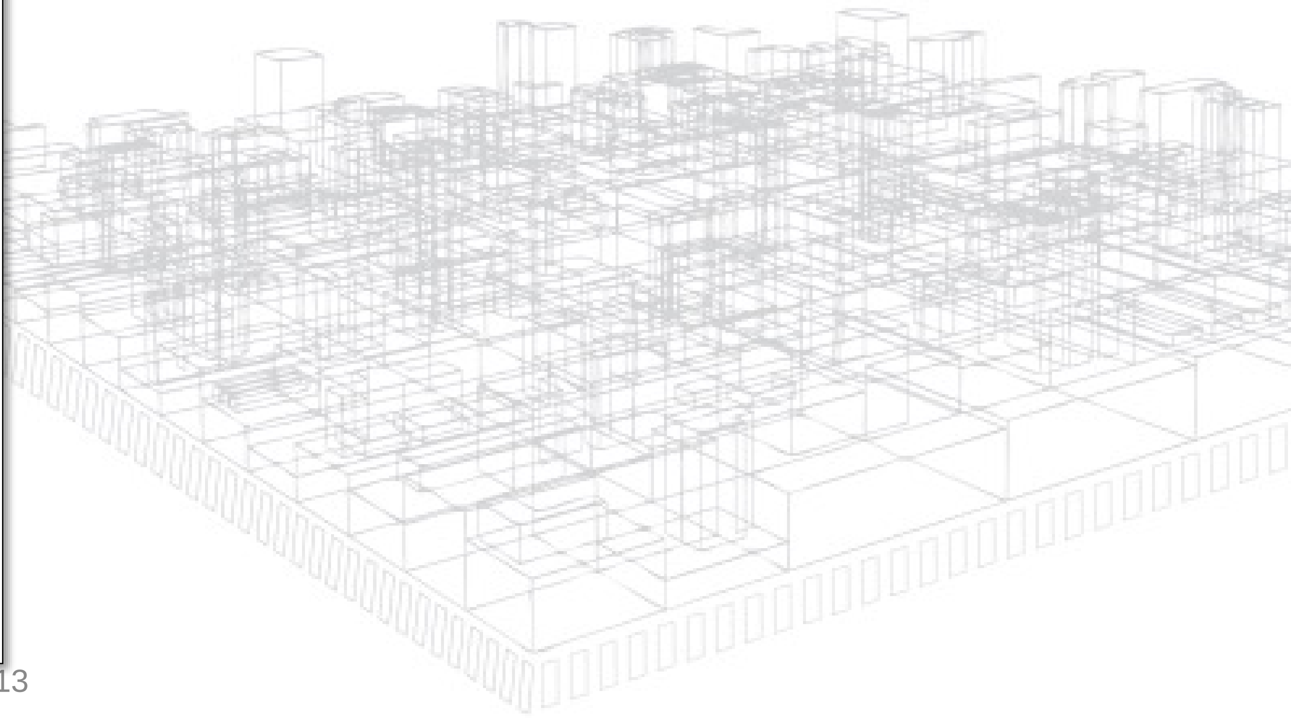
Transducer maintained control pressure



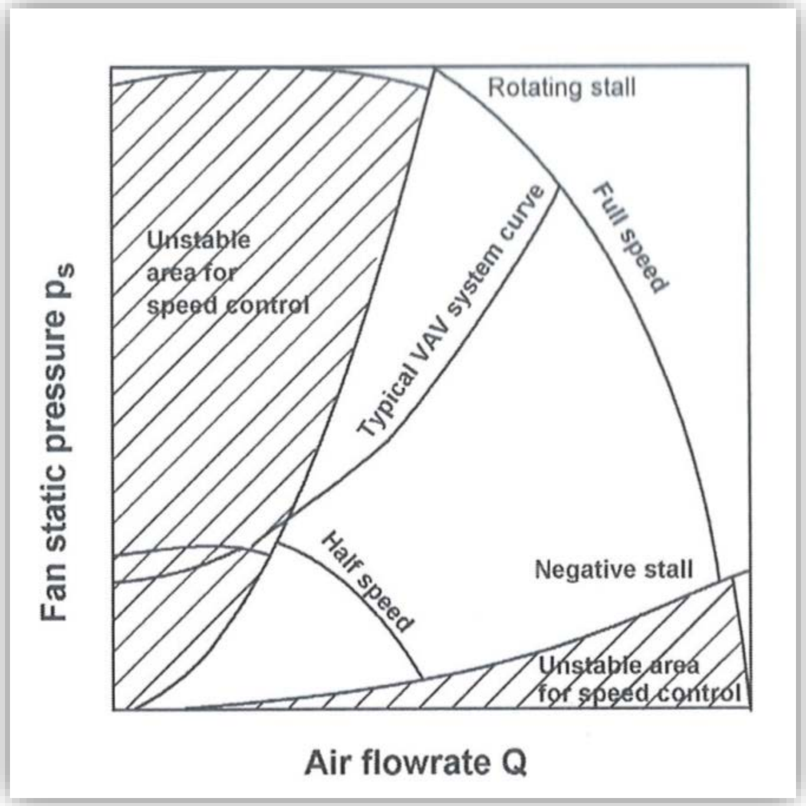
# VAV vs. Constant Orifice System Curve




At lower flow rates, the disparity is more pronounced.



# Characteristic Curve and Fan Stall Regions for Backward Bladed Fans




Courtesy Bill Cory

- 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

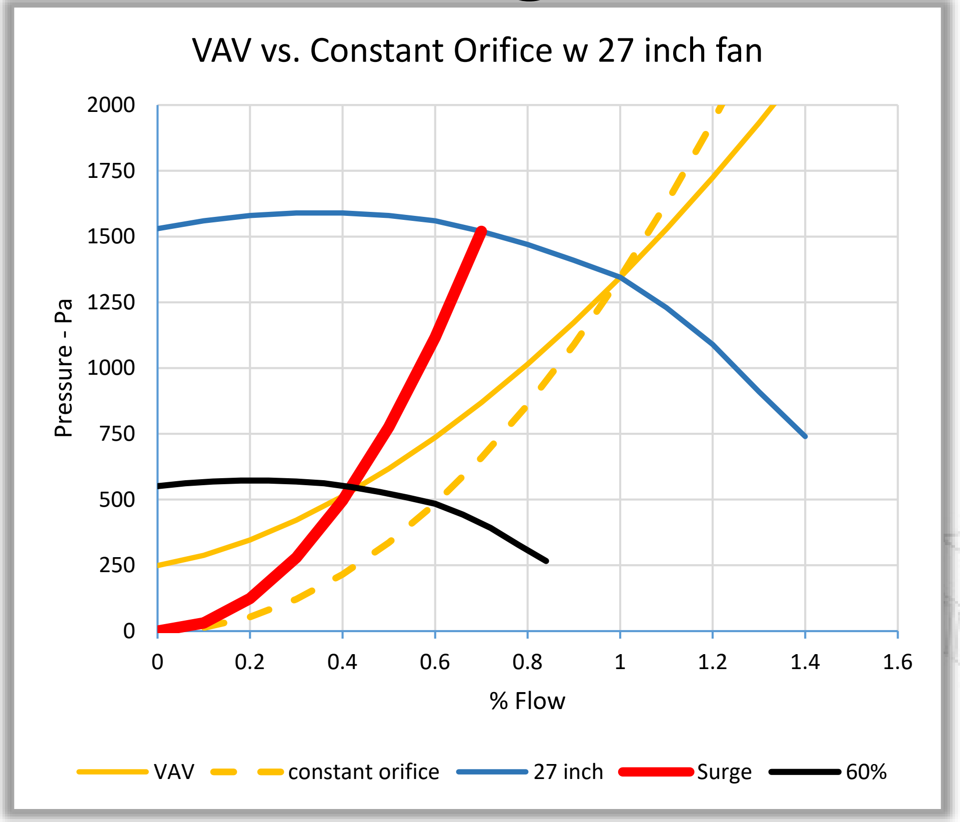
# Actual Fan Selections

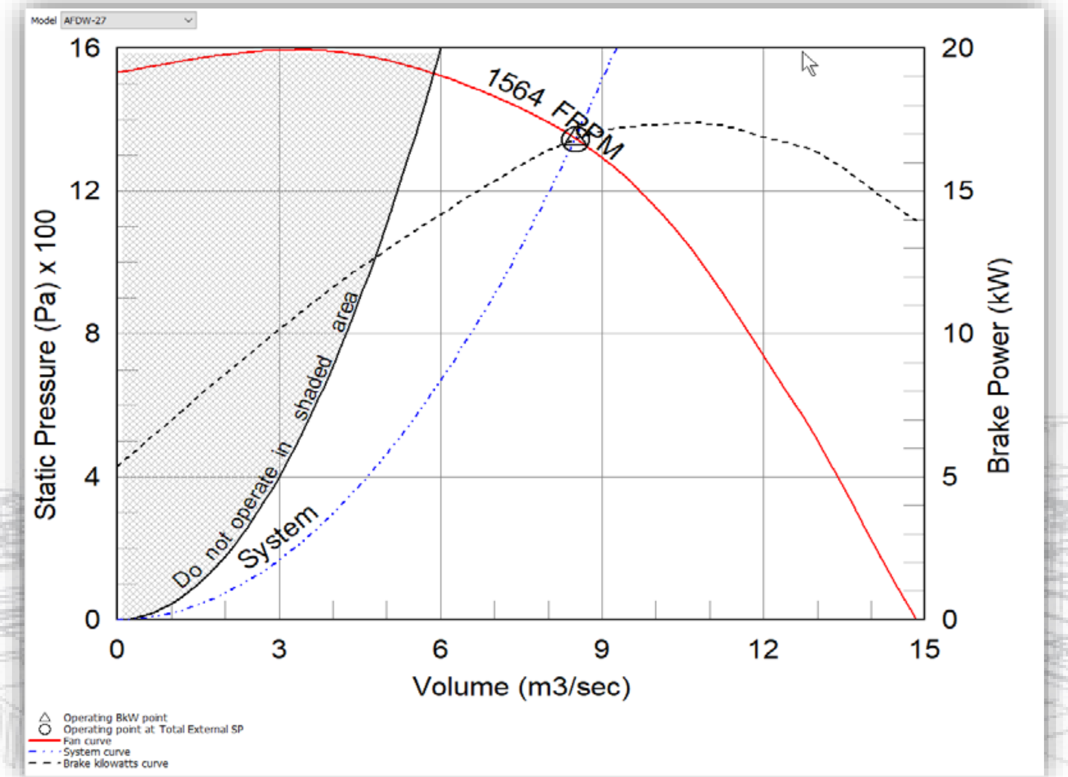
| Model Name | Relative Cost | Operating Cost / Yr (USD) | Outlet Velocity (m/sec) | Fan Class | Fan Speed (RPM) | Max Fan Speed (RPM) | Min Speed (RPM) | Drive Loss (%) | Operating Power (kW) | Motor Size NEMA (hp) | SE (%) | Pts within Peak TE (%) | FEG | Wheel Diameter (mm) | Inlet dBA (dB) | Best Lead Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AFDW-18 | 1.39 | 7,374 | 26.520 | III | 3598 | 3865 | 651 | 4.6 | 27.8 | 40 | 43 | 18 | 80 | 464 | 97 | Standard |
| AFDW-20 | 1.33 | 5,821 | 22.100 | III | 2864 | 3526 | 536 | 4.7 | 21.95 | 30 | 55 | 6 | 80 | 508 | 94 | Standard |
| AFDW-22 | 1.00 | 5,098 | 17.870 | II | 2271 | 2575 | 434 | 4.7 | 19.22 | 30 | 62 | 1 | 75 | 565 | 90 | 10 Day |
| AFDW-24 | 1.00 | 4,540 | 14.733 | II | 1832 | 2192 | 397 | 4.8 | 17.03 | 25 | 70 | 0 | 80 | 622 | 86 | 10 Day |
| AFDW-27 | 1.10 | 4,478 | 12.134 | II | 1564 | 1989 | 364 | 4.8 | 16.79 | 25 | 71 | 1 | 80 | 686 | 85 | 10 Day |
| AFDW-30 | 1.14 | 4,305 | 9.827 | I | 1316 | 1348 | 355 | 4.8 | 16.14 | 25 | 74 | 3 | 85 | 762 | 83 | 10 Day |
| BIDW-18 | 1.55 | 8,007 | 26.520 | III | 3285 | 3530 | 594 | 4.6 | 30.31 | 50 | 39 | 22 | 80 | 464 | 99 | Standard |
| BIDW-20 | 1.30 | 6,629 | 22.100 | III | 2643 | 3219 | 496 | 4.6 | 24.99 | 40 | 48 | 15 | 80 | 508 | 95 | Standard |
| BIDW-22 | 1.02 | 5,539 | 17.870 | II | 2091 | 2294 | 424 | 4.7 | 20.88 | 30 | 57 | 8 | 80 | 565 | 91 | 10 Day |
| BIDW-24 | 1.04 | 4,818 | 14.733 | II | 1717 | 2045 | 387 | 4.8 | 18.07 | 25 | 66 | 1 | 75 | 622 | 87 | 10 Day |
| BIDW-27 | 1.12 | 4,634 | 12.134 | II | 1458 | 1855 | 344 | 4.8 | 17.38 | 25 | 69 | 0 | 75 | 686 | 84 | 10 Day |
| BIDW-30 | 1.12 | 4,800 | 9.827 | I | 1258 | 1279 | 333 | 4.8 | 18 | 25 | 67 | 3 | 75 | 762 | 83 | 10 Day |

## 8.5 $m^3/s$, 1345 Pa, Sea Level, Density 1.2 $kg/m^3$

Fan selection data and fan curves courtesy Greenheck

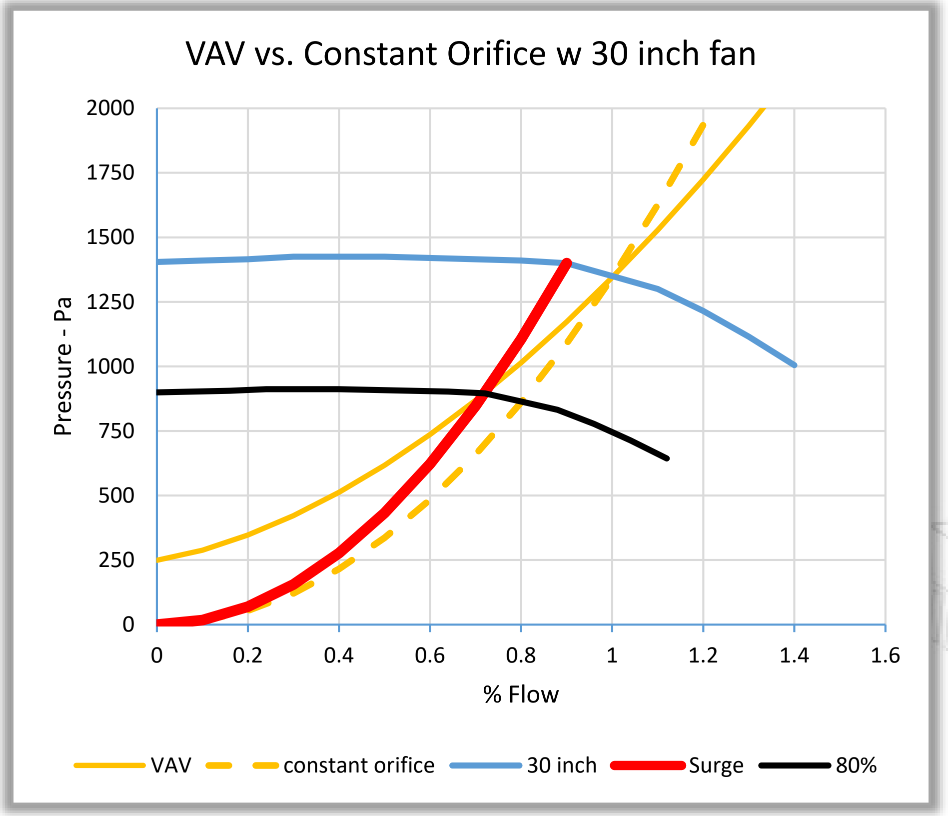
# Characteristic Curve and Fan Stall Regions for 686 mm fan

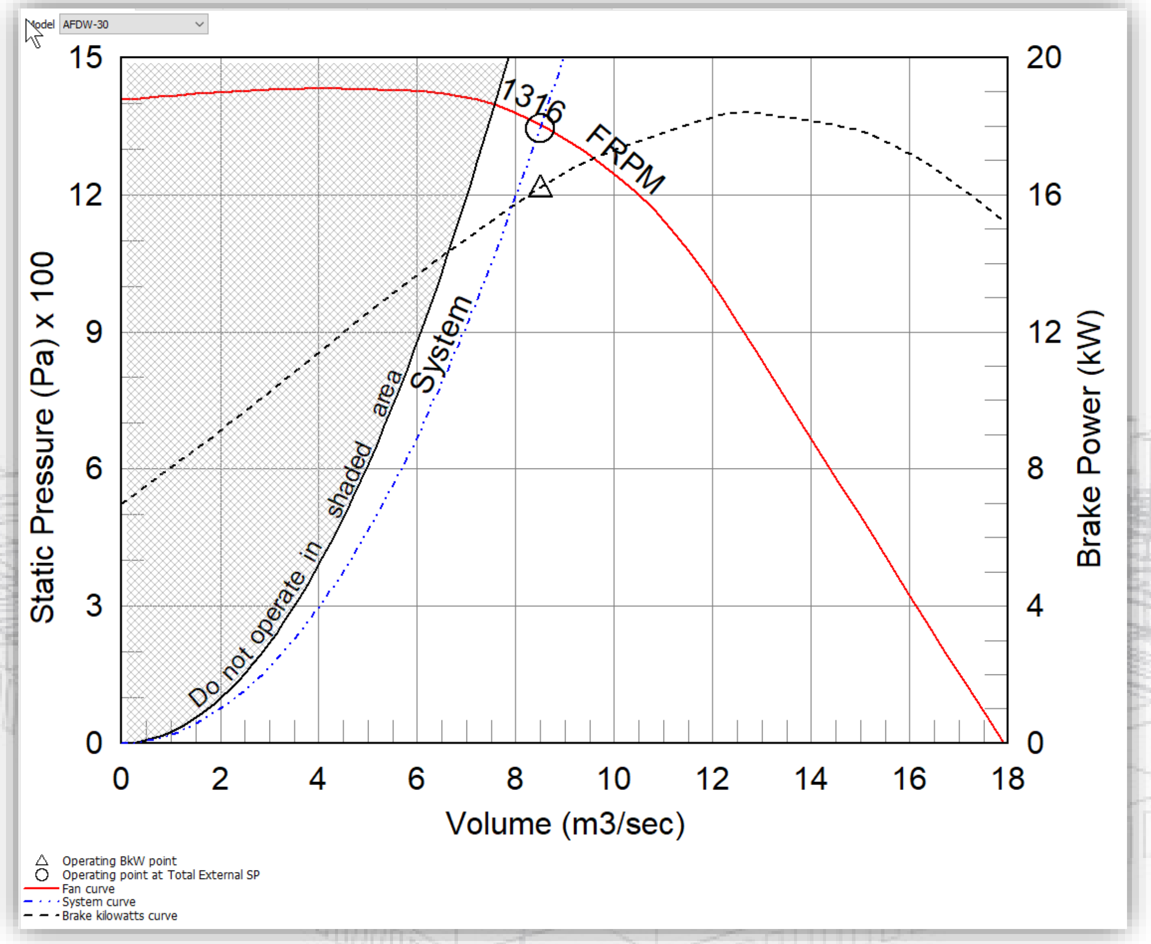



Minimum speed is limited to 60%!

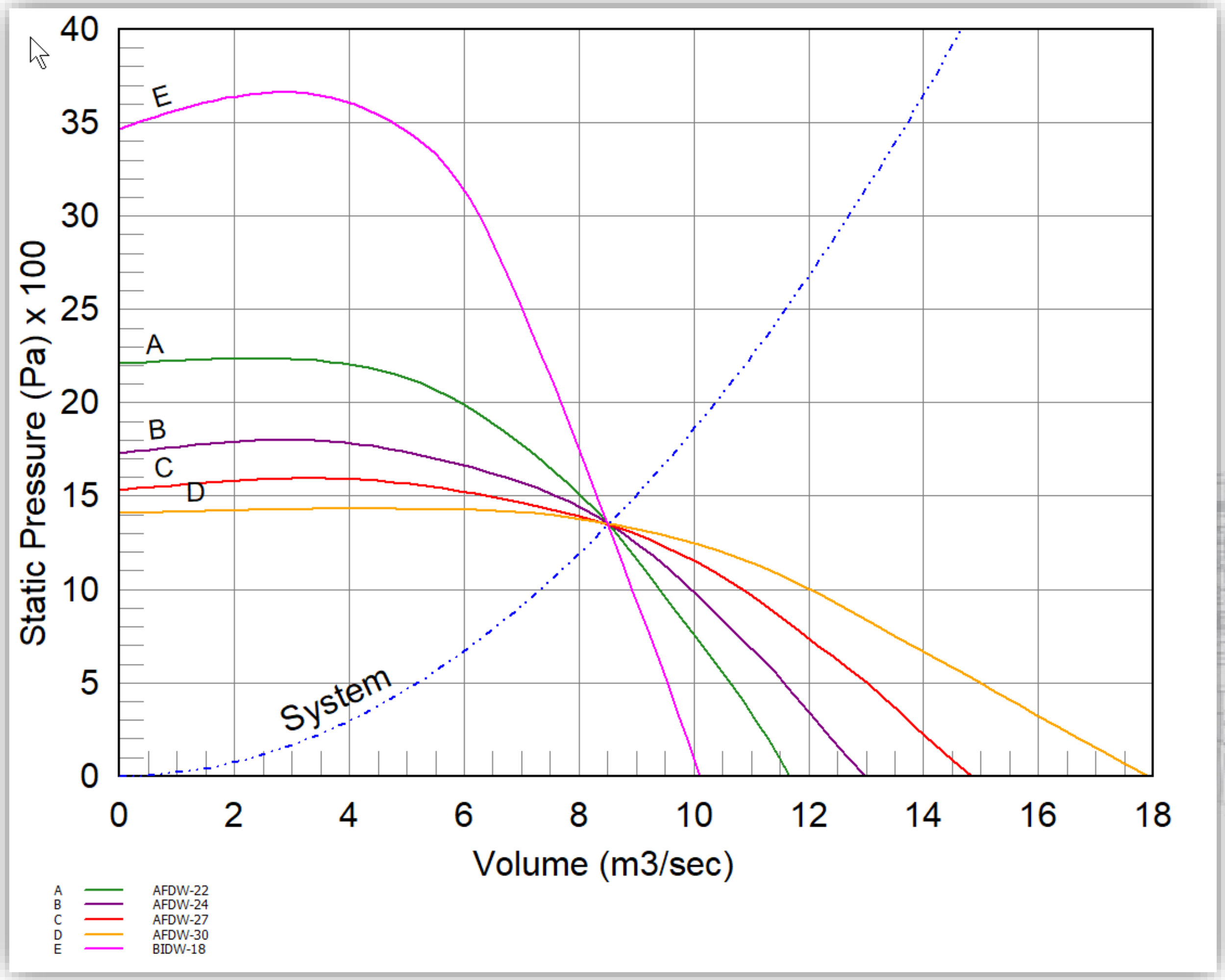
# Characteristic Curve and Stall Regions for 762 mm Fan




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:

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

# Questions?

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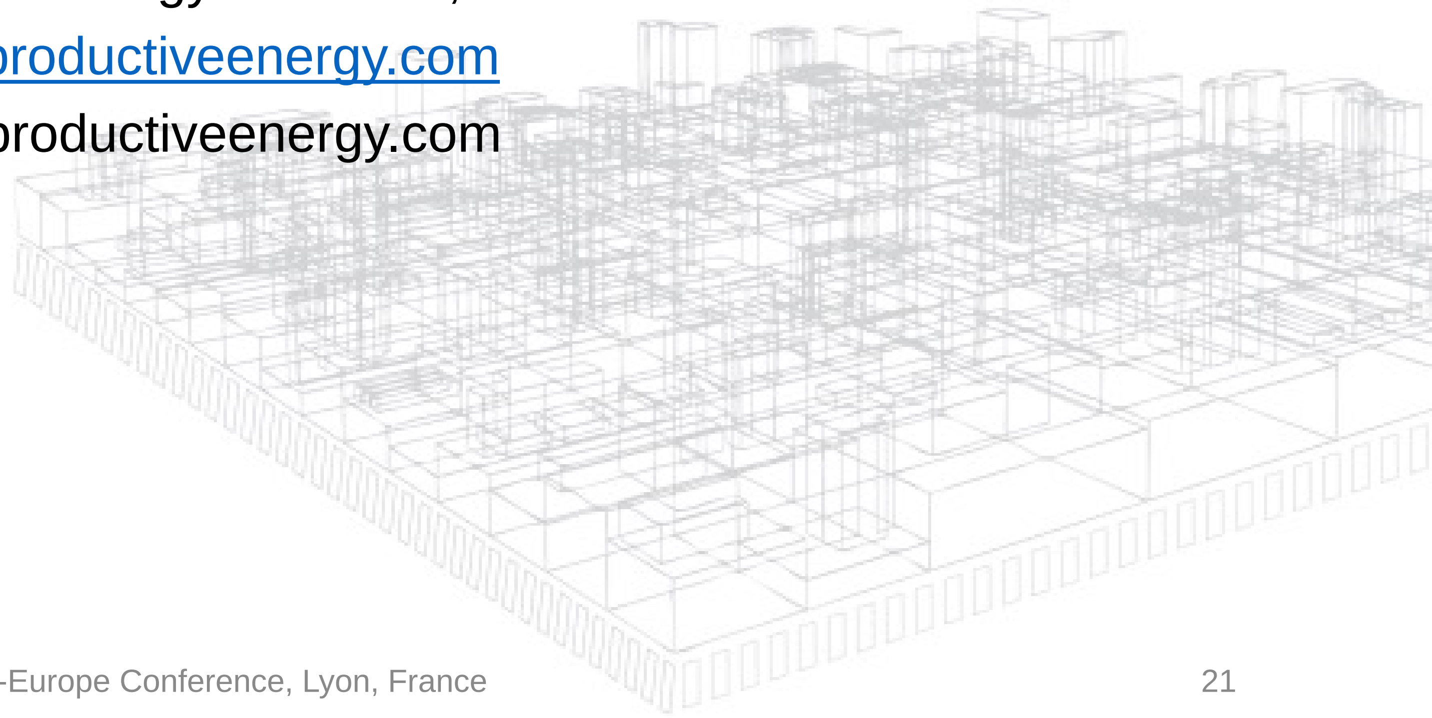

# Cooling Coil Pressure Loss (Imperial)

| | Pressure loss | | |
|---|---|---|---|
| Face velocity | Catalog | Calculated w exponent 1.6 | Calculated w exponent 2 |
| Feet per minute | Inches w.g. | Inches w.g. | Inches w.g. |
| 200 | 0.26 | | |
| 400 | 0.77 | 0.79 | 1.04 |
| 500 | 1.08 | 1.13 | 1.63 |
| 600 | 1.48 | 1.51 | 2.34 |

## Coil Selection criteria

- Wet Coil
- 5 rows
- 12 fins/inch

Courtesy McQuay

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

# Actual Fan Selections

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