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Seminar 37 - Selection & Application Considerations of Fans Used in Variable Air Volume Systems

Selection Considerations for Fans Used in Variable Air Volume Systems

Mark W. Fly, P.E., Fellow ASHRAE
Executive Director of R/D and Laboratory Services
AAON, Inc.
mfly@aaon.com

Learning Objectives

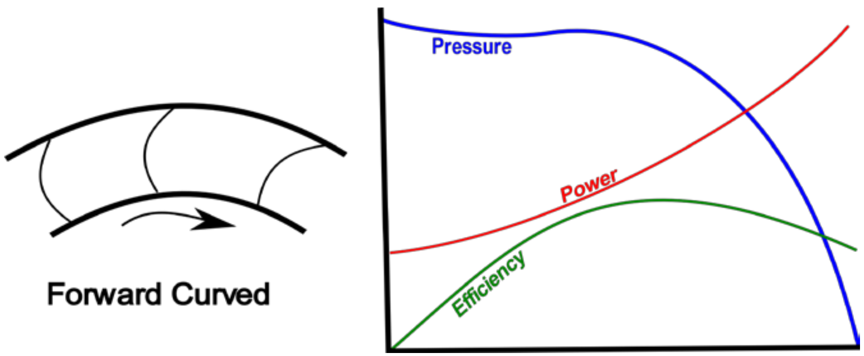
1. Explain the difference between systems with constant duct pressure set points and those with variable duct pressure set points for fan speed control
2. Use VAV system characteristics to estimate system efficiency and power at full- and part-load
3. Evaluate the effect of duct control type and setting on the fan energy consumption of variable air volume systems
4. Explain how the proposed FEG and FEI energy metrics are affected as a fan modulates speed in a VAV system application

Outline

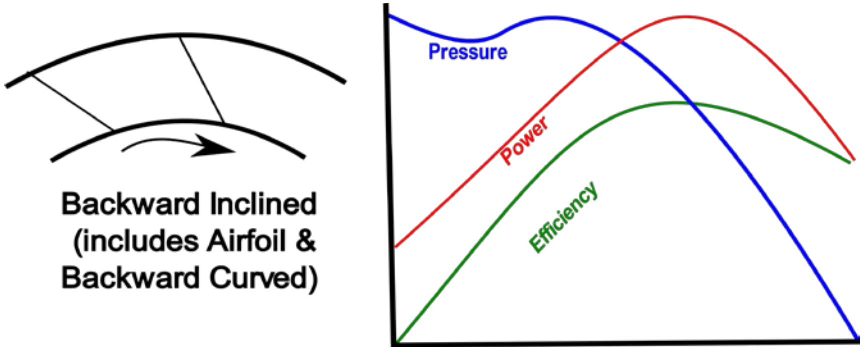
1. Fan types
2. Fan curves
3. Fan laws and family of curves
4. Surge or stall
5. Control static
6. Selecting fans at points of operation
7. Dynamic reset of control static set point
8. FEG metrics
9. FEP/FEI metrics
10. Conclusions

Fan Type Characteristics

- Forward curve fans are designed for high volume low pressure applications.
- Power increase continuously with flow.
- Forward curve fans can run in stall without physical damage to the fan.



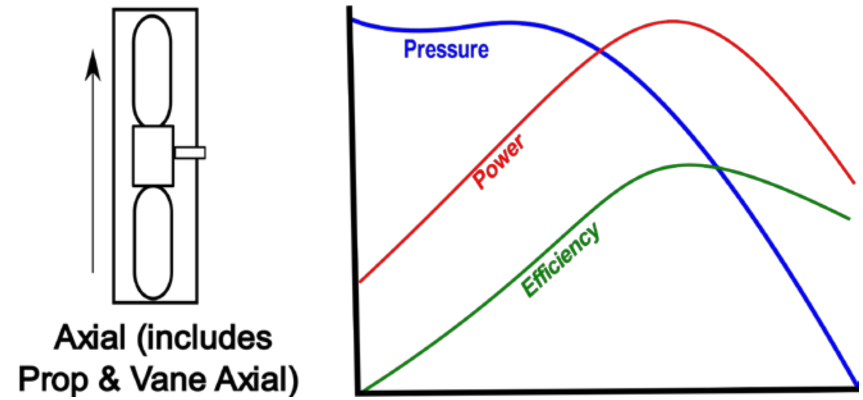
- Backward incline fans include backward curved and air foil designs and are suitable for medium pressure applications.
- Efficiency peaks with power.

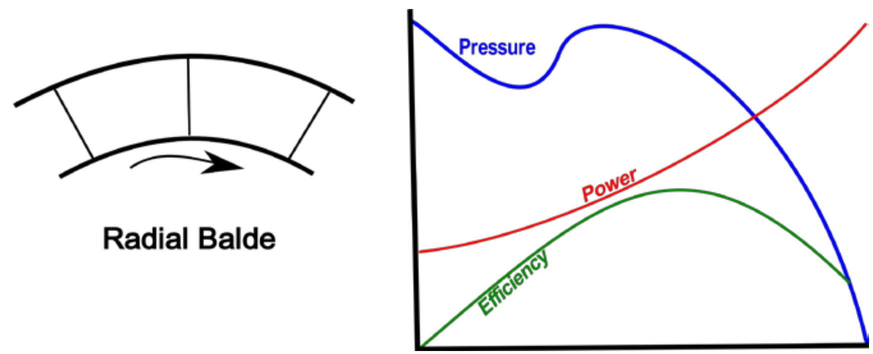


Fan Type Characteristics

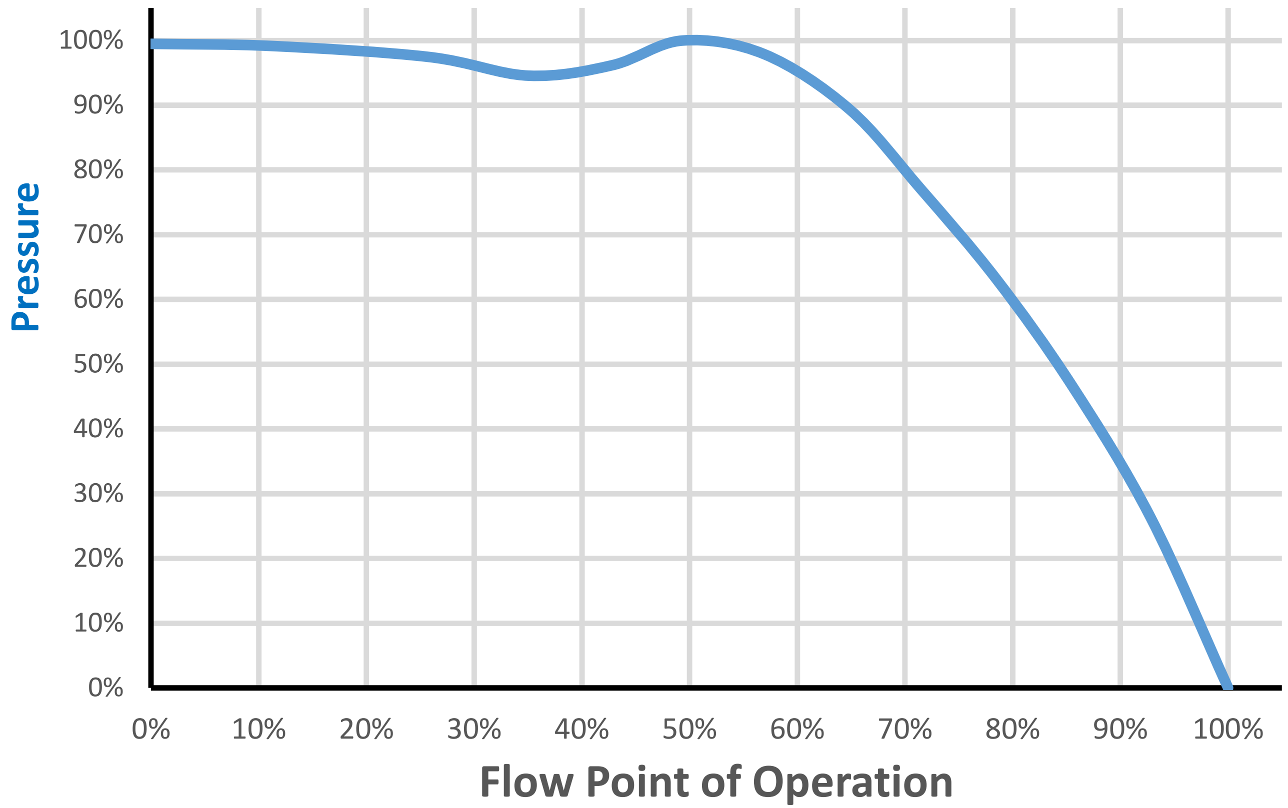
- Axial fans include prop and vane axial types.
- Prop fans are suitable for low pressure high volume applications.
- Vane Axials fans are designed for high axial velocity and high pressure applications.
- Efficiency peaks with power.

- Radial Blade fans are seldom used in HVAC applications and suitable for material handling or high pressure applications.
- Power continuously increases with flow.

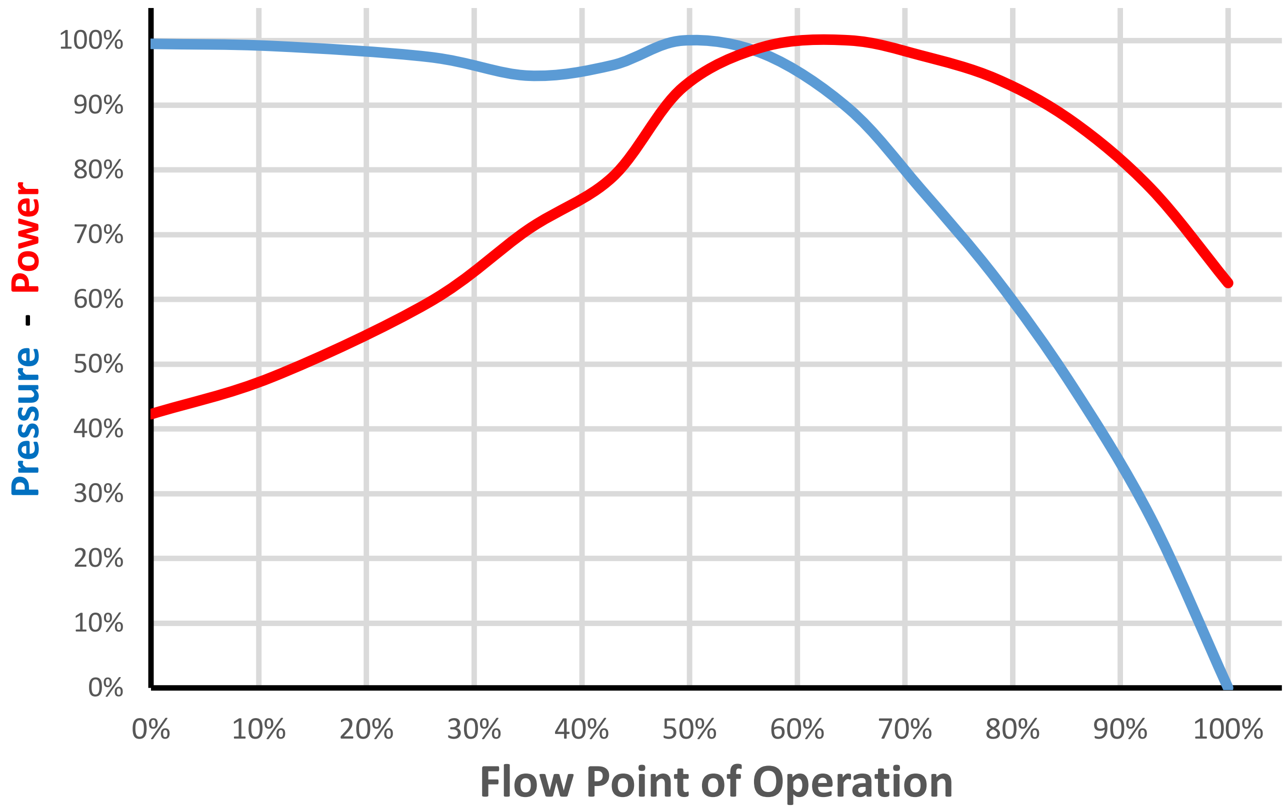




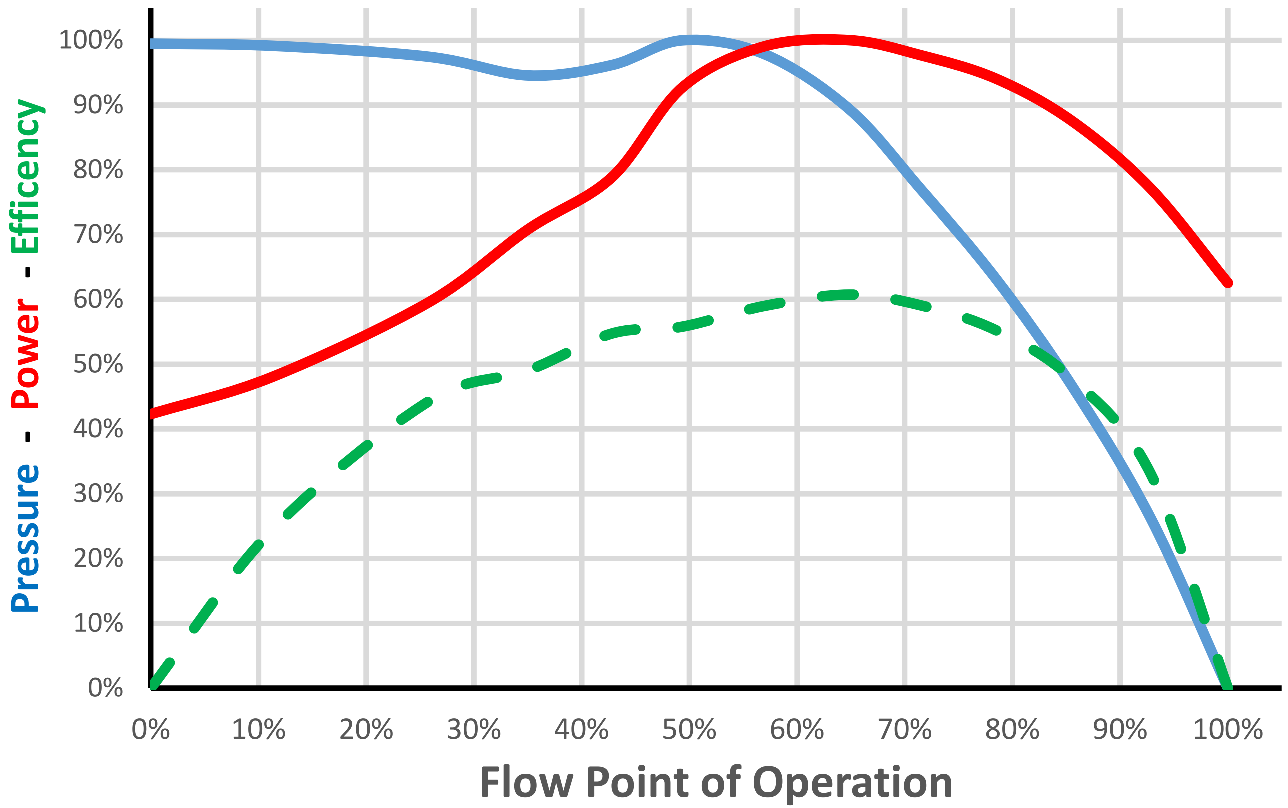
Fan Curve Basics - Pressure Vs Flow



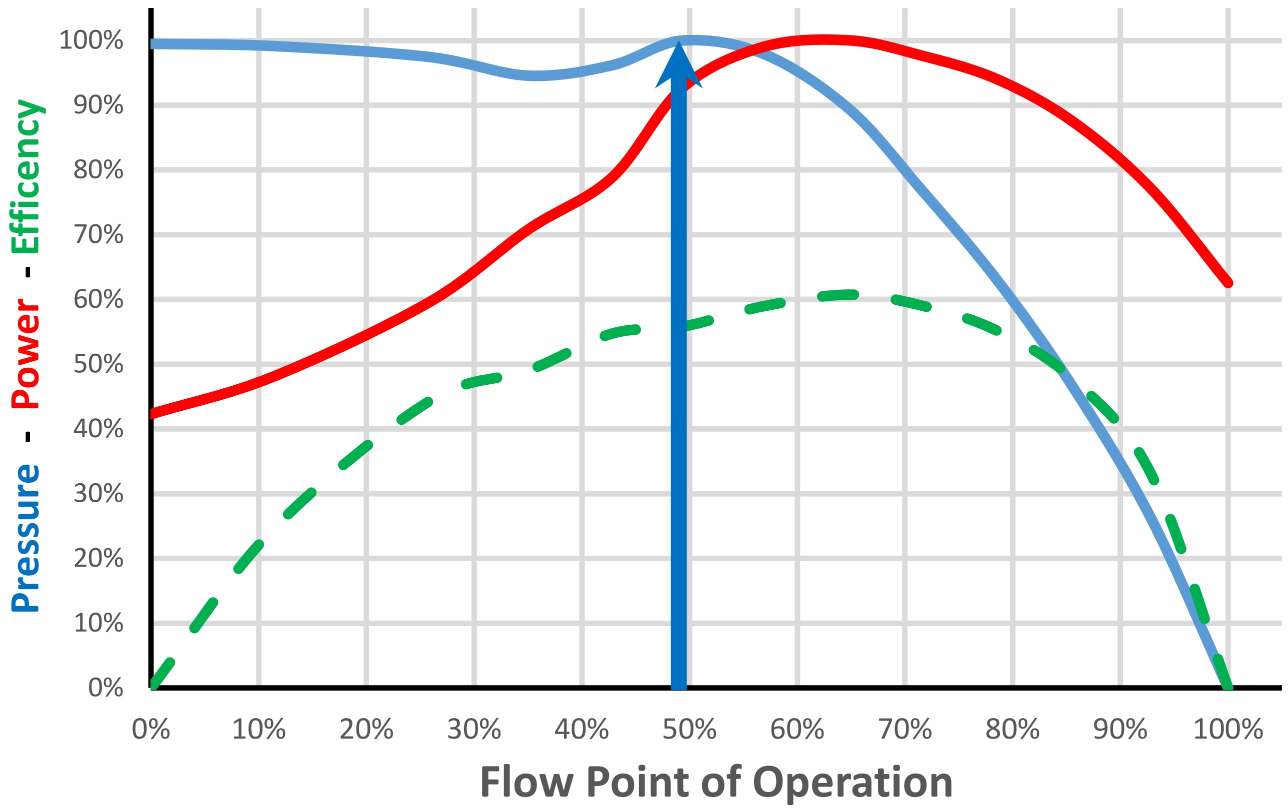
Fan Curve Basics - Power Vs Flow



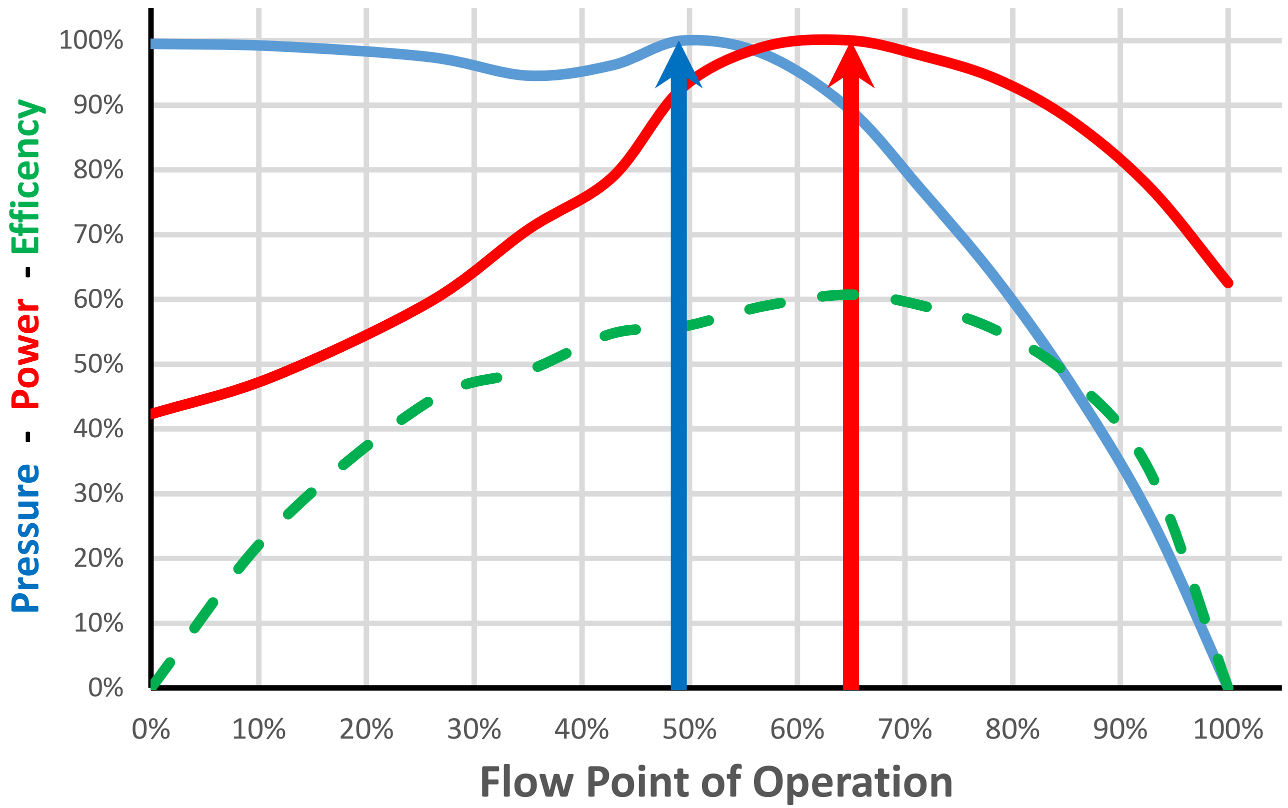
Fan Curve Basics - Efficiency Vs Flow



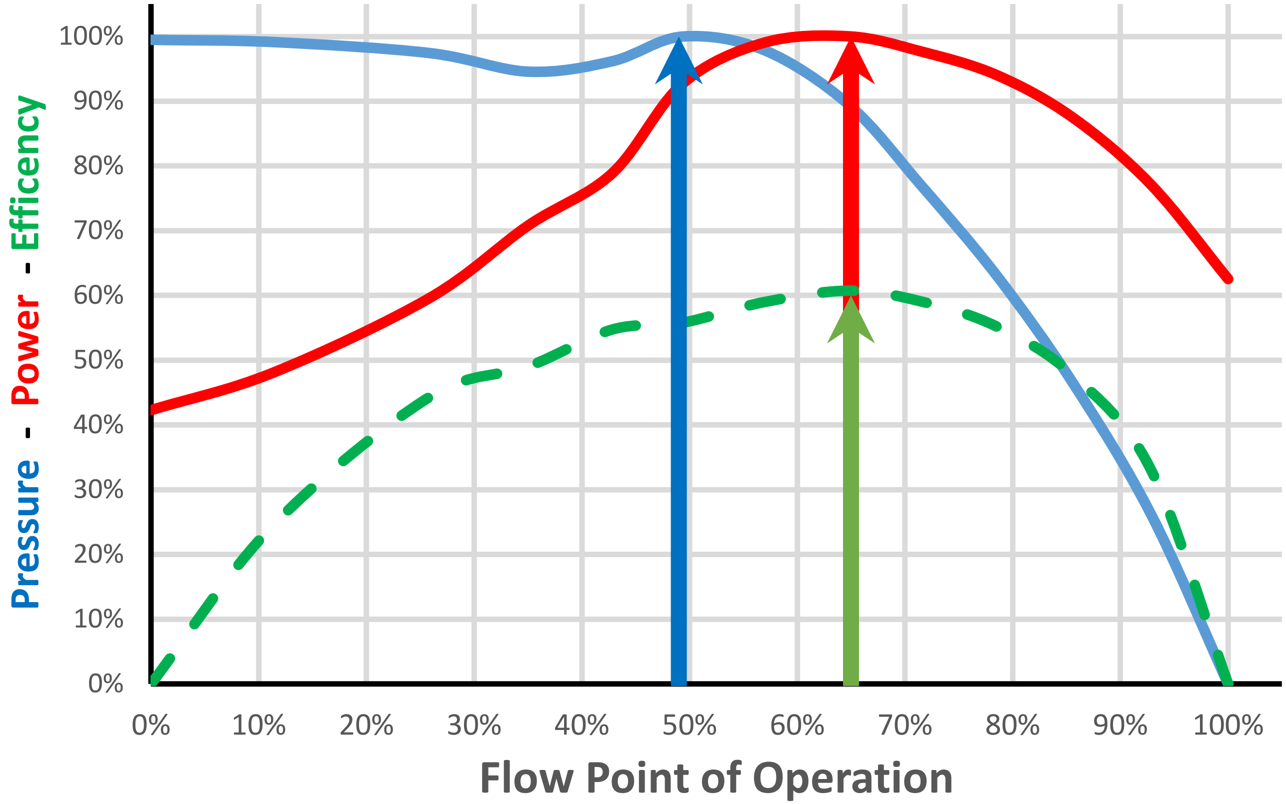
Fan Curve Basics - Peak Pressure



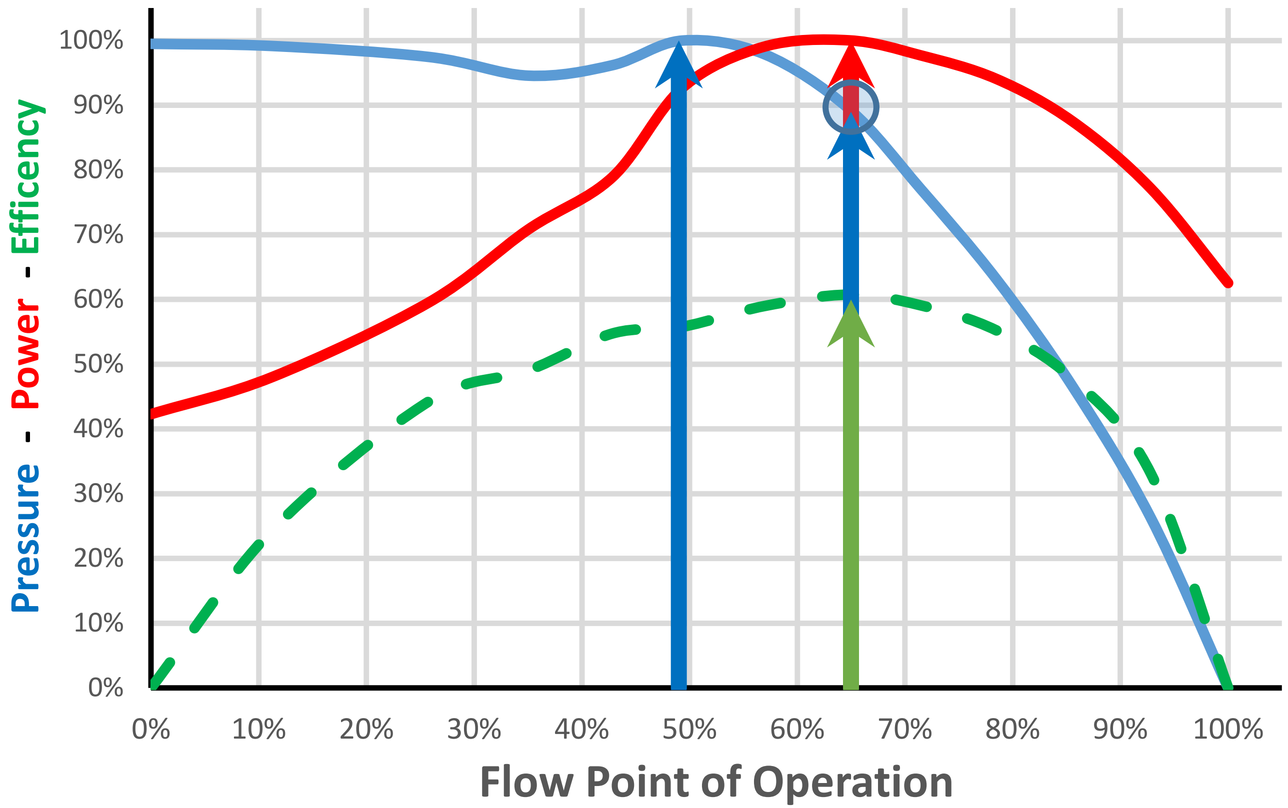
Fan Curve Basics - Peak Power



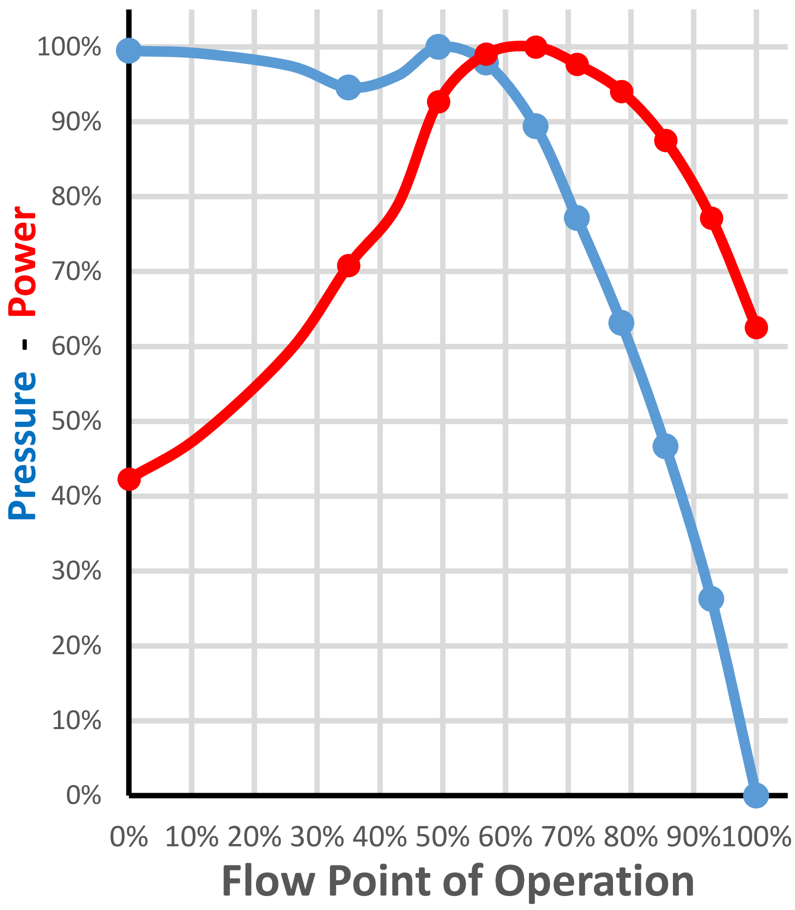
Fan Curve Basics - Peak Efficiency



Fan Curve Basics - Selection at Peak Efficiency

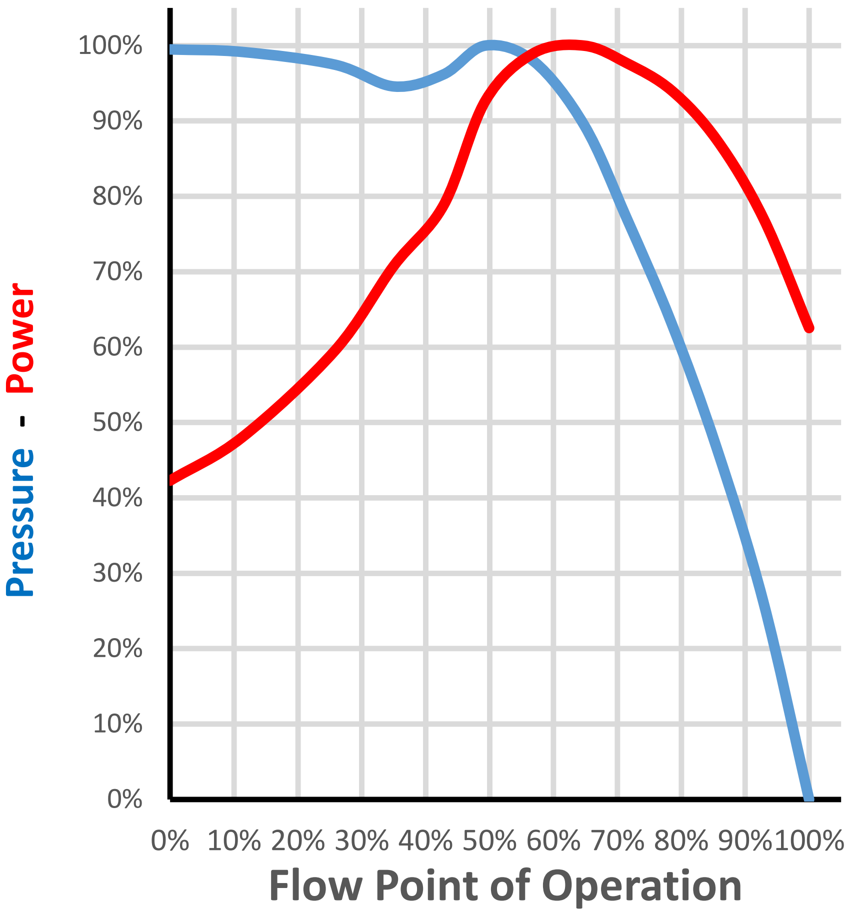


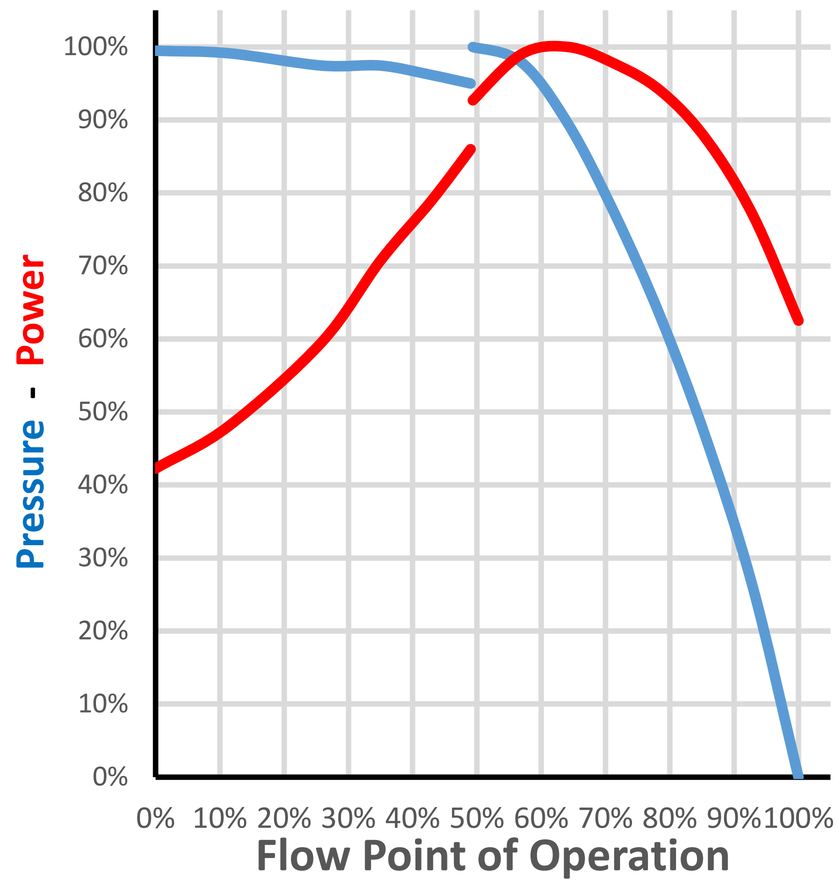
How Curves Are Drawn



- Fan curves are drawn with spline curve fit of measured data.
- Some may not extend to the left past the stall area.
- If the fan construction is very precise, then stall has a sharp discontinuity in the curve.

Precise Actual Fan Curve





Fan Laws Can Be Used To Develop Curves At Other Speeds

Fans are Volumetric machines!

Air Flow $$Q_2 = Q_1 \times \left(\frac{n_2}{n_1}\right) \times \left(\frac{d_2}{d_1}\right)^3$$

Pressure $$P_2 = P_1 \times \left(\frac{n_2}{n_1}\right)^2 \times \left(\frac{d_2}{d_1}\right)^2 \times \left(\frac{\rho_2}{\rho_1}\right)$$

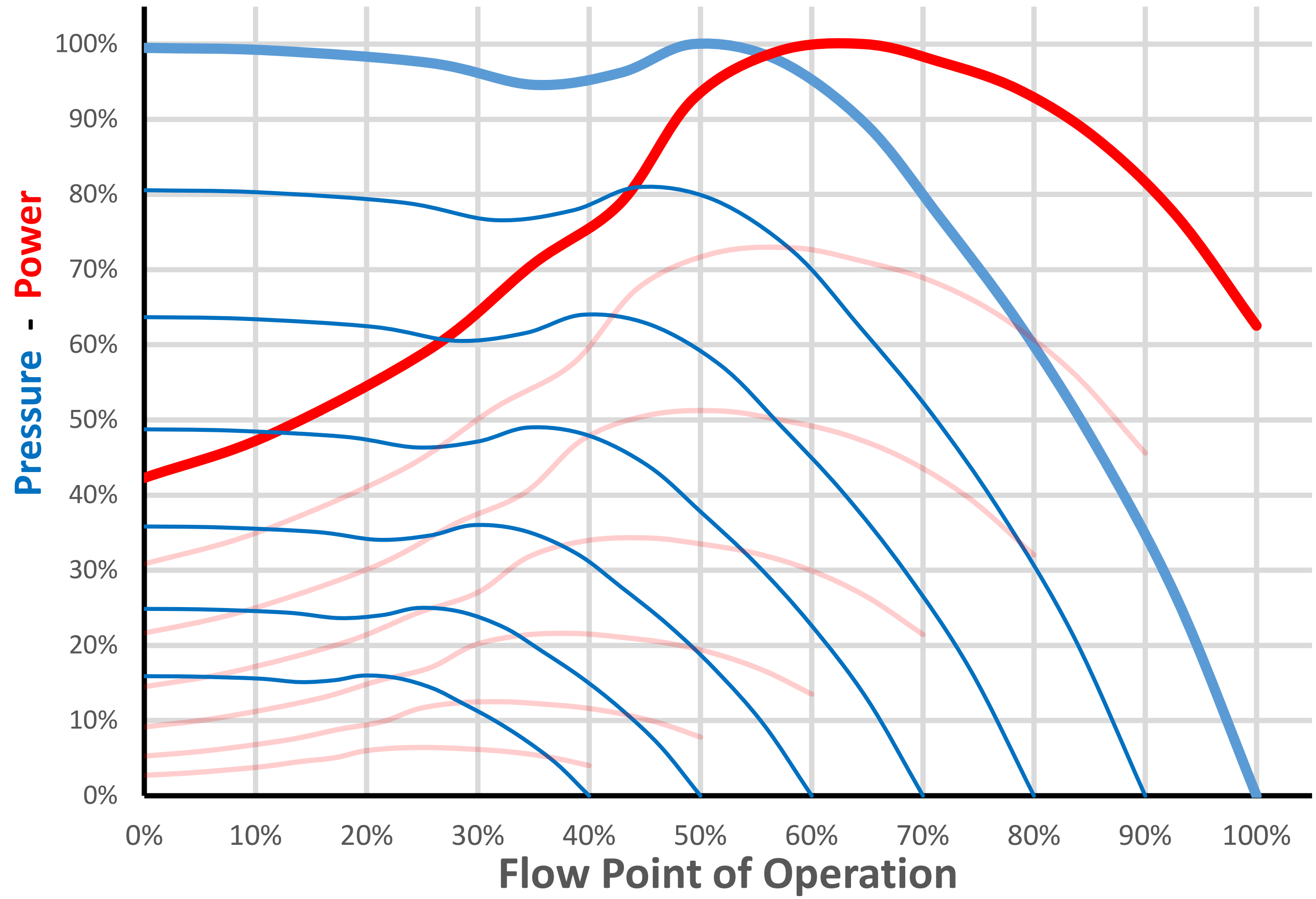
Power $$W_2 = W_1 \times \left(\frac{n_2}{n_1}\right)^3 \times \left(\frac{d_2}{d_1}\right)^5 \times \left(\frac{\rho_2}{\rho_1}\right)$$

Where: Q = Air Flow
P = Pressure
W = Power
n = RPM
d = Fan Diameter
ρ = Air Density

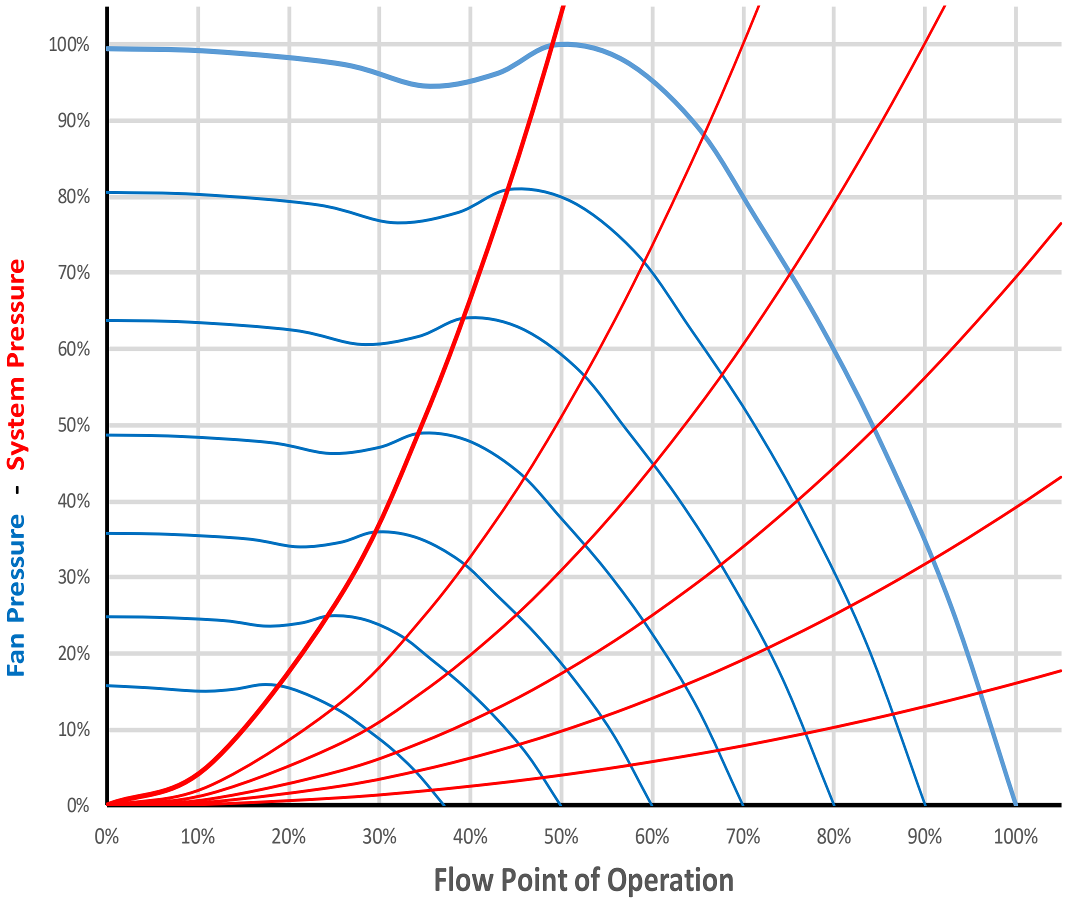
d can be used only for fans that are precisely geometrically proportional

Fan Laws only operate on the system curve

VAV Systems Using Variable Speed Fans



System Curves

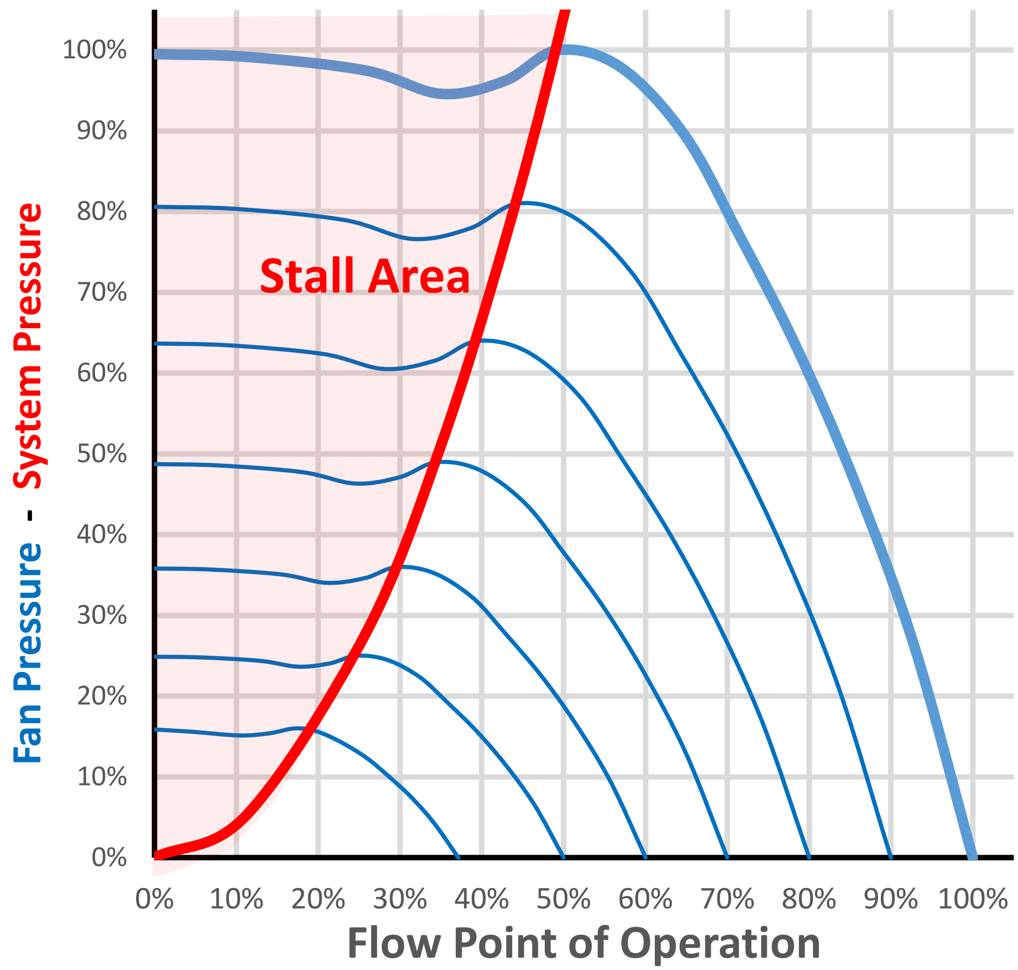


- System curves represent fixed te internal and external losses within the unit, ducts, and diffusers. System curves are valid for developing turbulent flow where:

$$P = c \cdot Q^2$$

The system curve is a <u>characteristic of the system</u> and the fan operates at the intersection of the pressure (@ RPM) curve and the system curve.

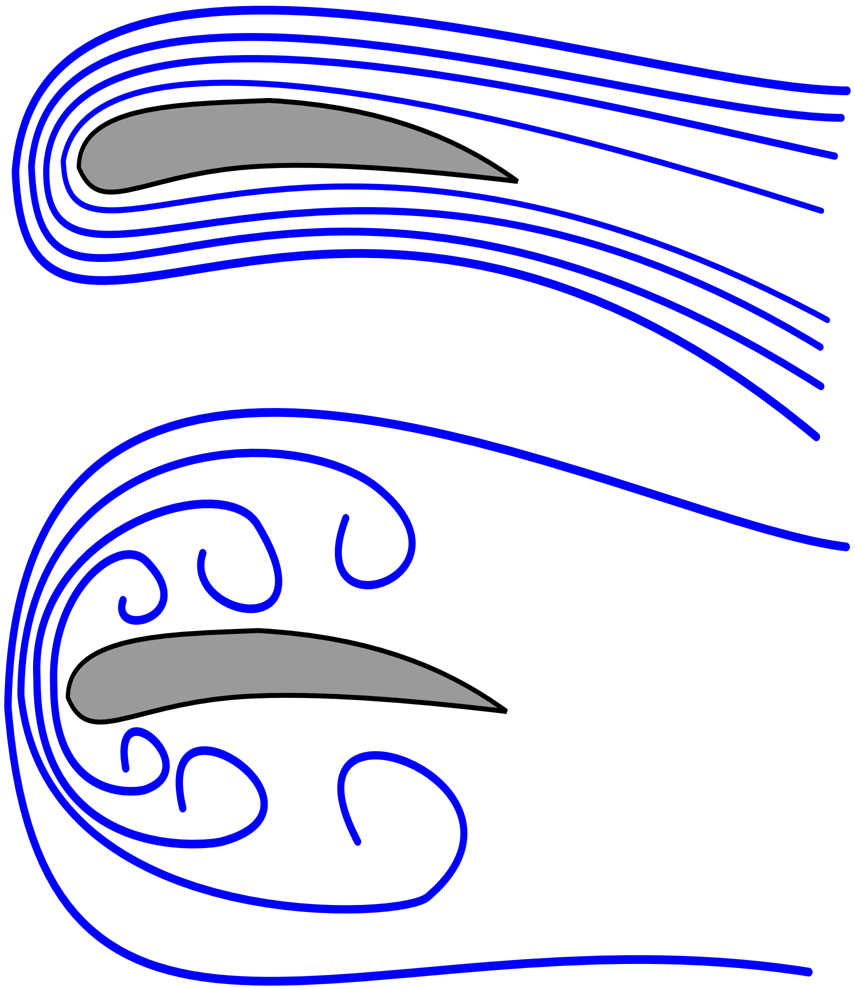
Fan Stall or Surge



- The area to the left of the peak static point on a fan curve is referred to as the Stall or Surge area.
- This is an area of unstable operation that can cause physical damage to the fan in many fan designs.
- With or without physical damage, this area of operation is noisy and unstable.

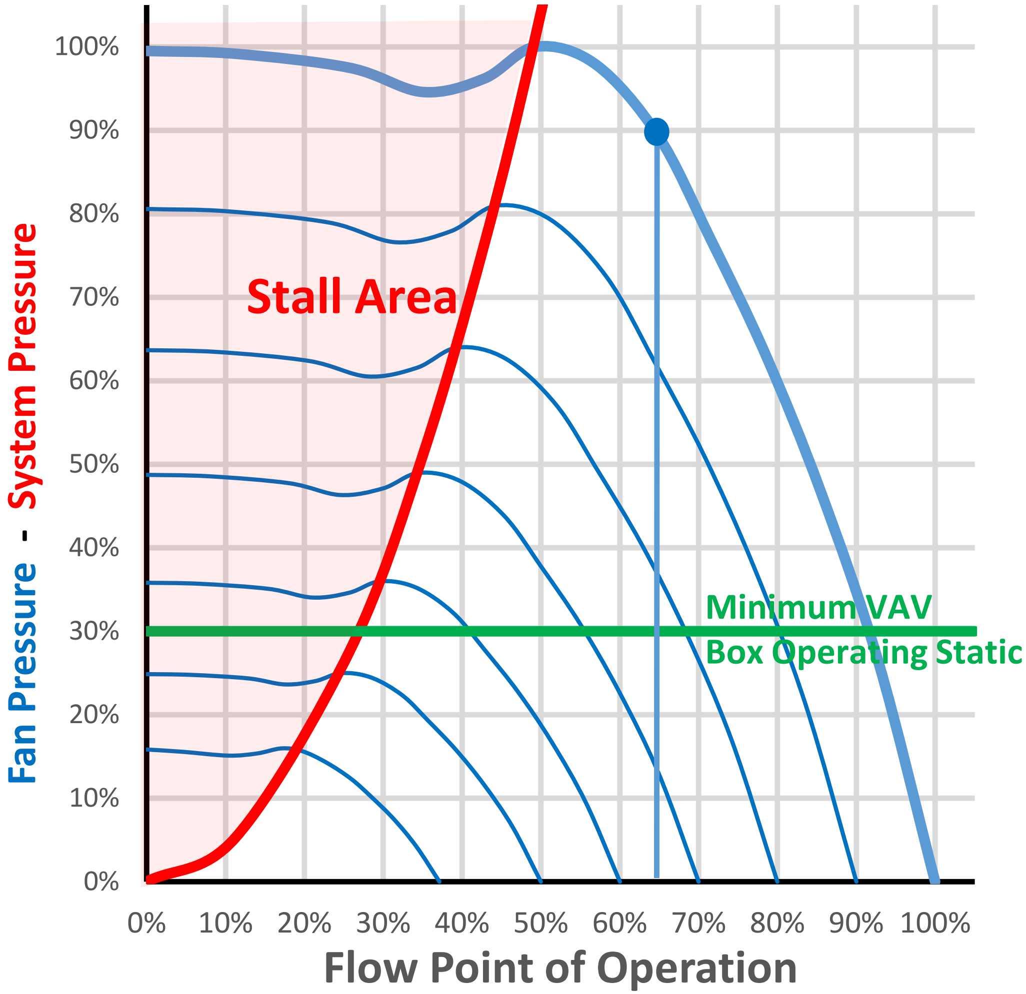
What is Stall or Surge?

- At acceptable operating points, right of peak, air flow smoothly “attaches” to every fan blade creating aerodynamic lift.
- When operating in the stall area, left of peak, the air will “separate” and vortex on some or all of the blades. Air flow and pressure can drop drastically in this condition.



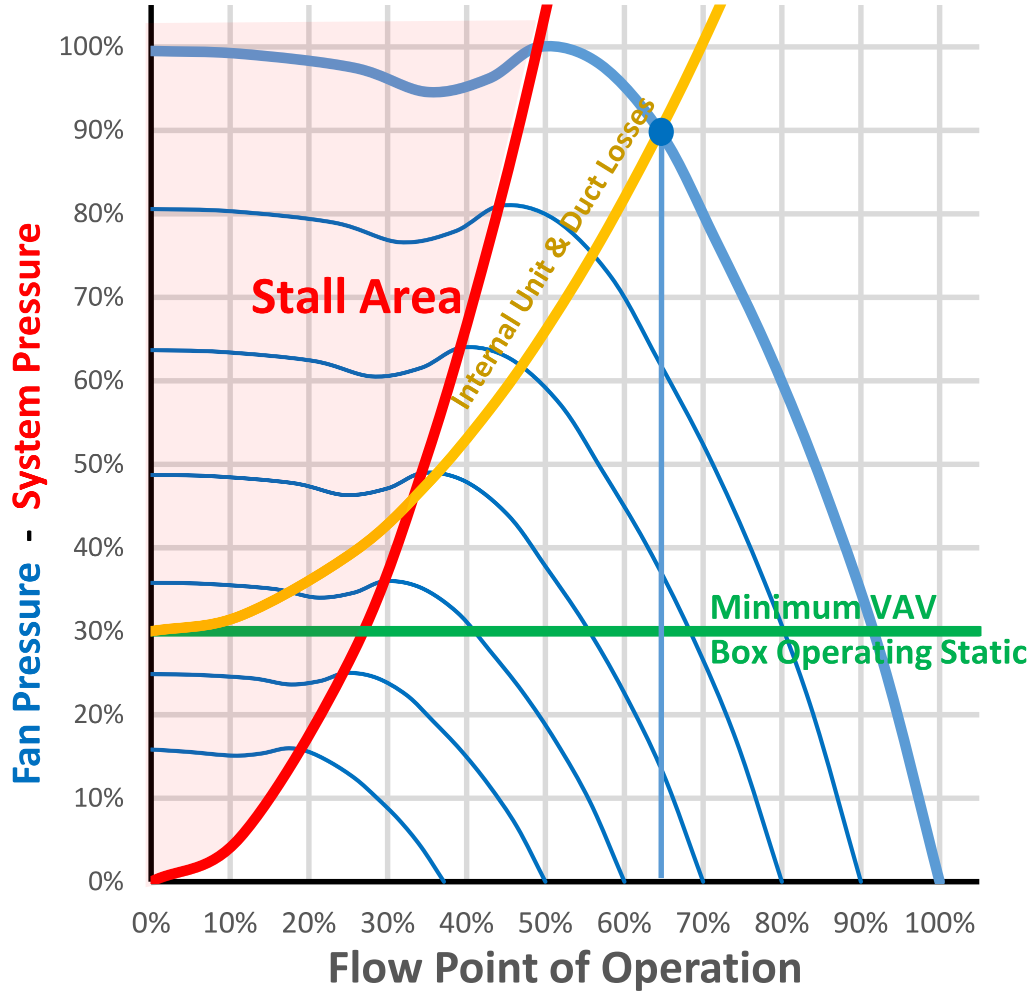
- Once the flow slows over a blade, the localized pressure drops and flow will reattach and resume working for a short period of time.
- Stall will occur one blade after the other, resulting in surging of air flow and random uneven loading on the fan wheel.

Selection Of A Fan For Multi Zone VAV Operation



- With Multi Zone VAV Systems (containing multiple VAV boxes served by a common fan), a minimum static pressure must be maintained at all boxes in order for the box control damper to throttle properly.
- In most systems this minimum pressure is controlled by maintaining a “control static” pressure at a sensor located about 2/3rd of the way down the duct system to the furthest box.

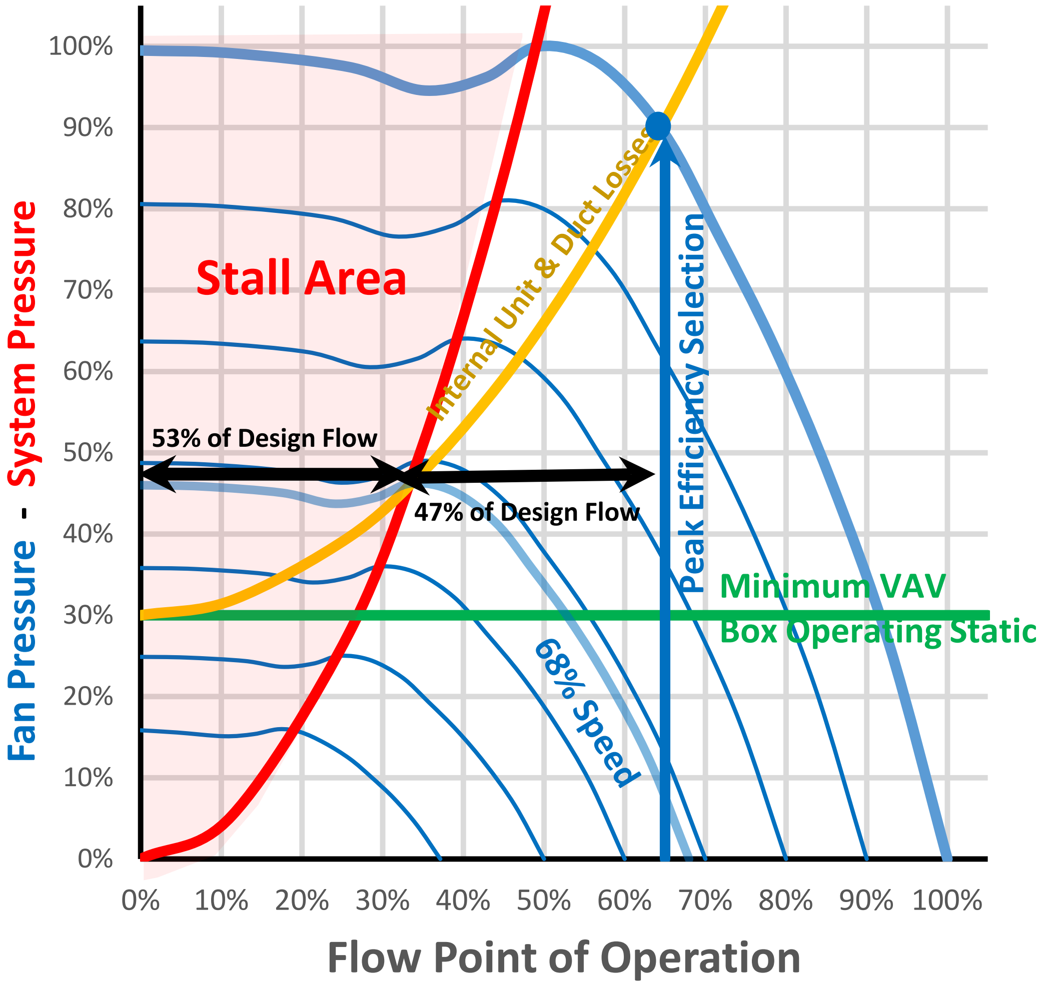
Selection Of A Fan For Multi Zone VAV Operation



- By controlling the fan speed to maintain a "control static" and due to the fact that the system losses dynamically change as the VAV boxes throttle, the system curve actually starts at 0 flow and a pressure equal to the control static setpoint.

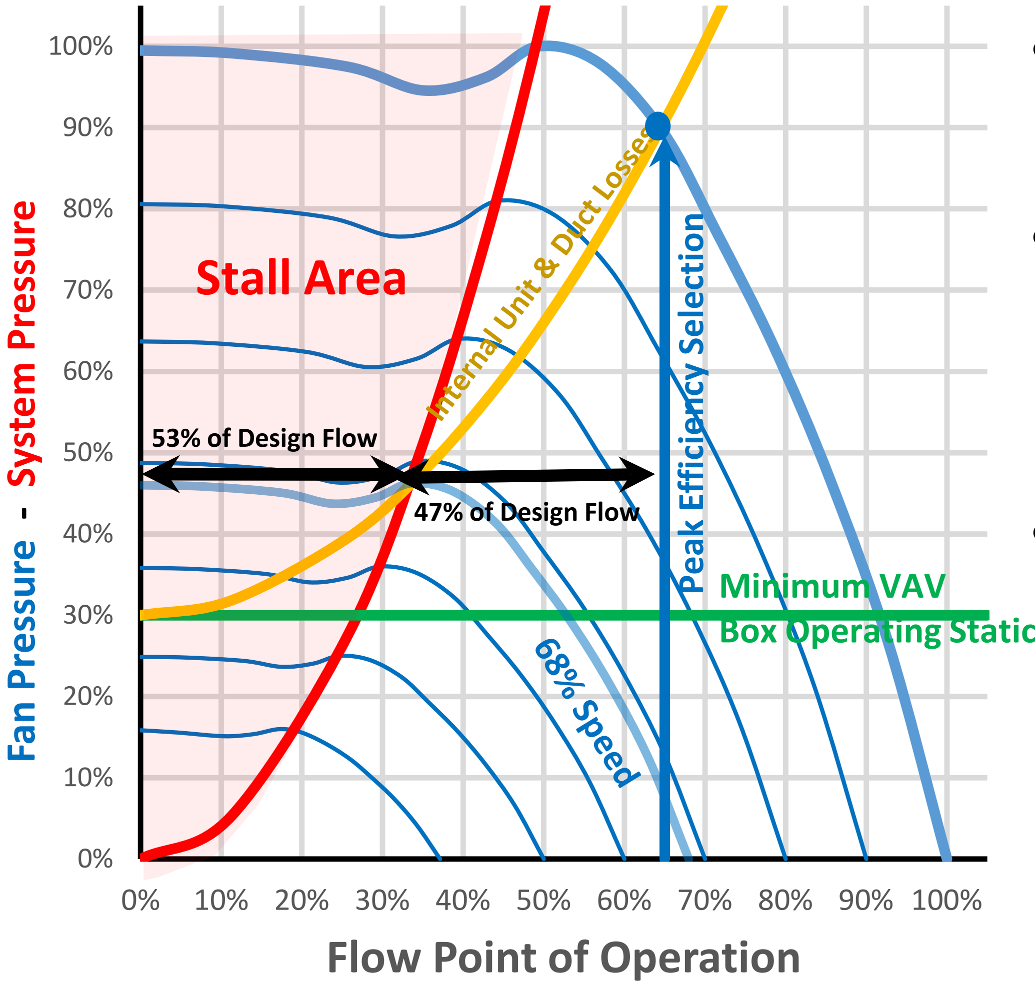
$$P = c \cdot Q^2 + P_{ctl}$$

Selection Of A Fan For Multi Zone VAV Operation



- To keep the fan from entering stall, the system turndown must be limited.
- In this example the max turn down of the fan would by limited to 47% of design flow with a fan speed of 68% of design before going into stall.
- Since both fan curves and system design have tolerances, some safety factor needs to be applied.

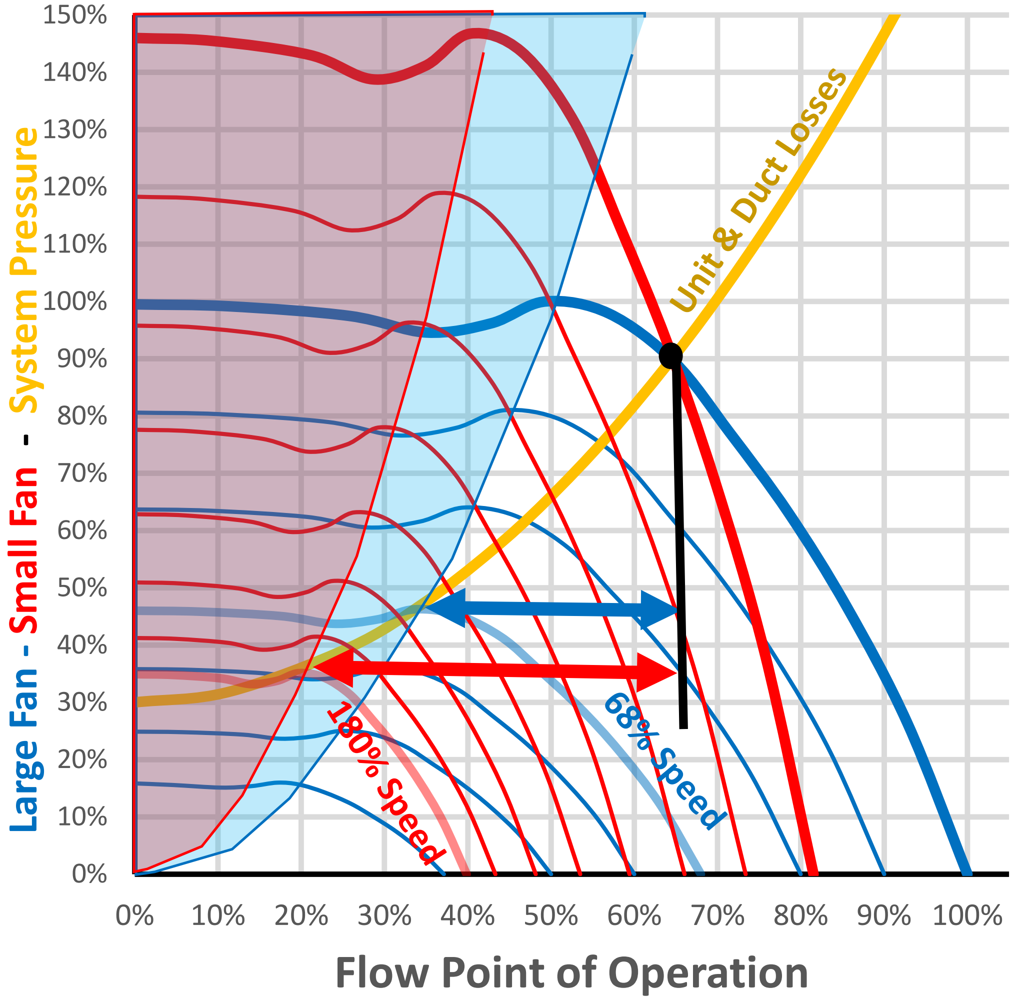
Selection Of A Fan For Multi Zone VAV Operation



- Fan peak efficiency is usually close to the peak of the pressure curve.
- Higher efficiency fans tend to have steeper efficiency curves that peak closer to the peak static.
- By selecting a fan that would operate farther to the right and down on the pressure curve, would enable a lower minimum speed and greater turndown.

How To Move The Selection To The Right

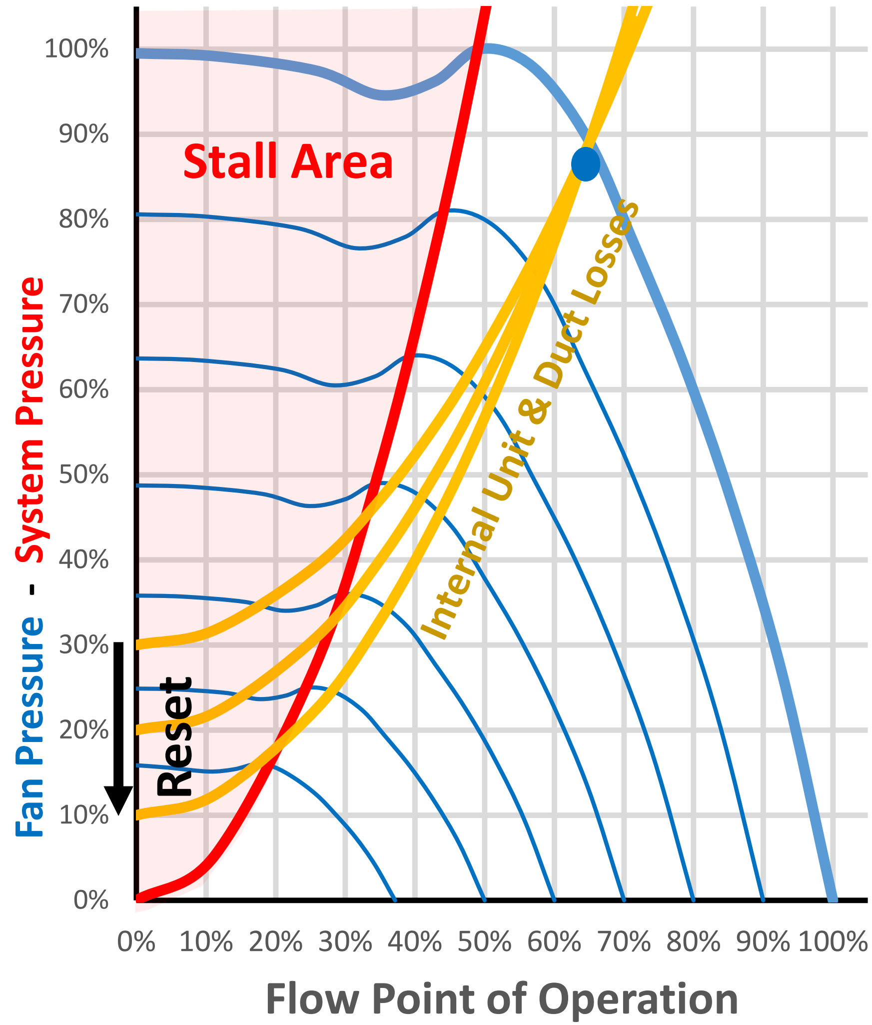
- To move the fan selection to the right, select a smaller fan running faster.
- In this example a 25% smaller wheel running 80% faster enabled a much greater throttling range.
- This selection gives a greater turn down in speed but operates at lower full load efficiency.



Dynamic Reset Of The Static Setpoint

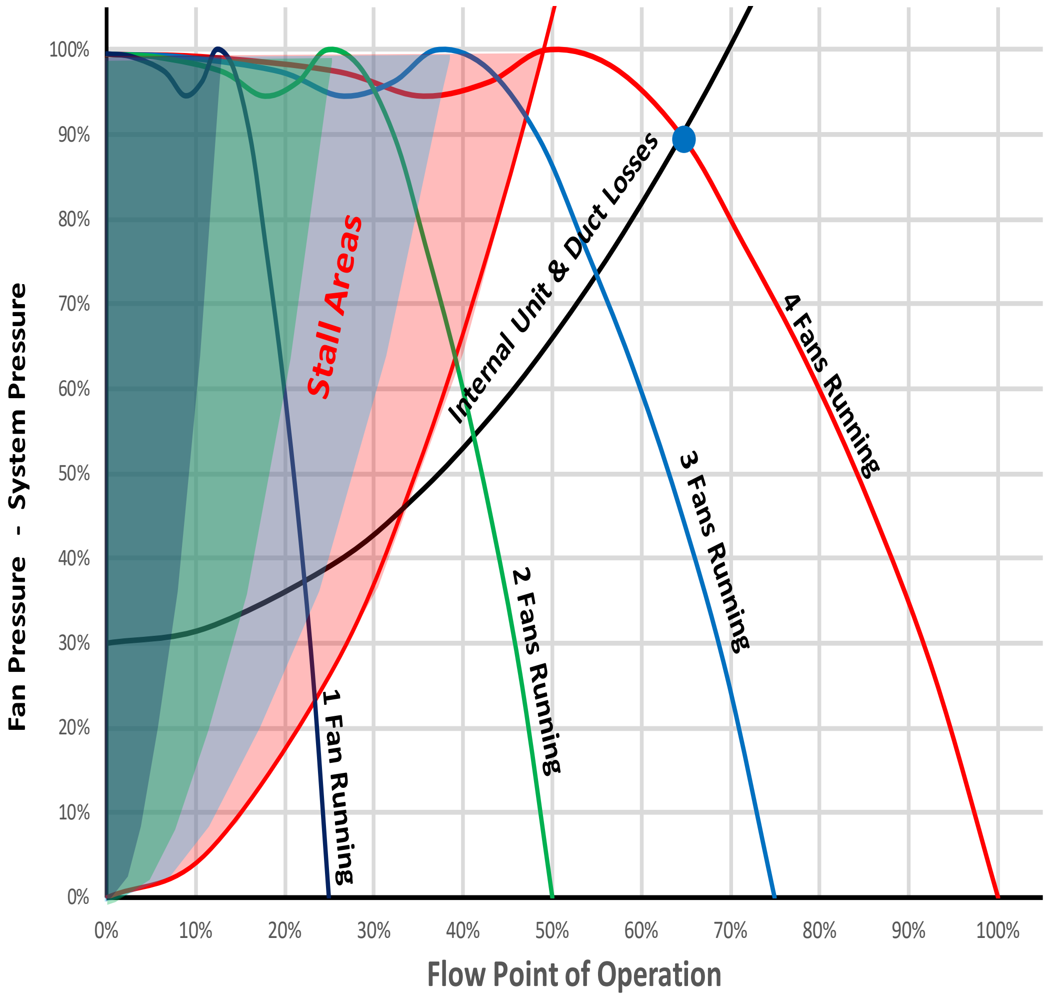
- Additional turn down can be achieved by intelligent controls resetting the controlling duct static pressure set point.
- The duct static setpoint can be lowered as long as the box with the highest demand is still satisfied.
- This requires communicating VAV box controls so that each can be surveyed to insure all VAV boxes are satisfied at the reduced pressure.
- This can increase the turn down range, but to avoid fan stall it may require a more complex control system.
- Power is reduced almost proportional to pressure since:

$$W = \frac{Q \cdot P}{k \cdot \eta}$$



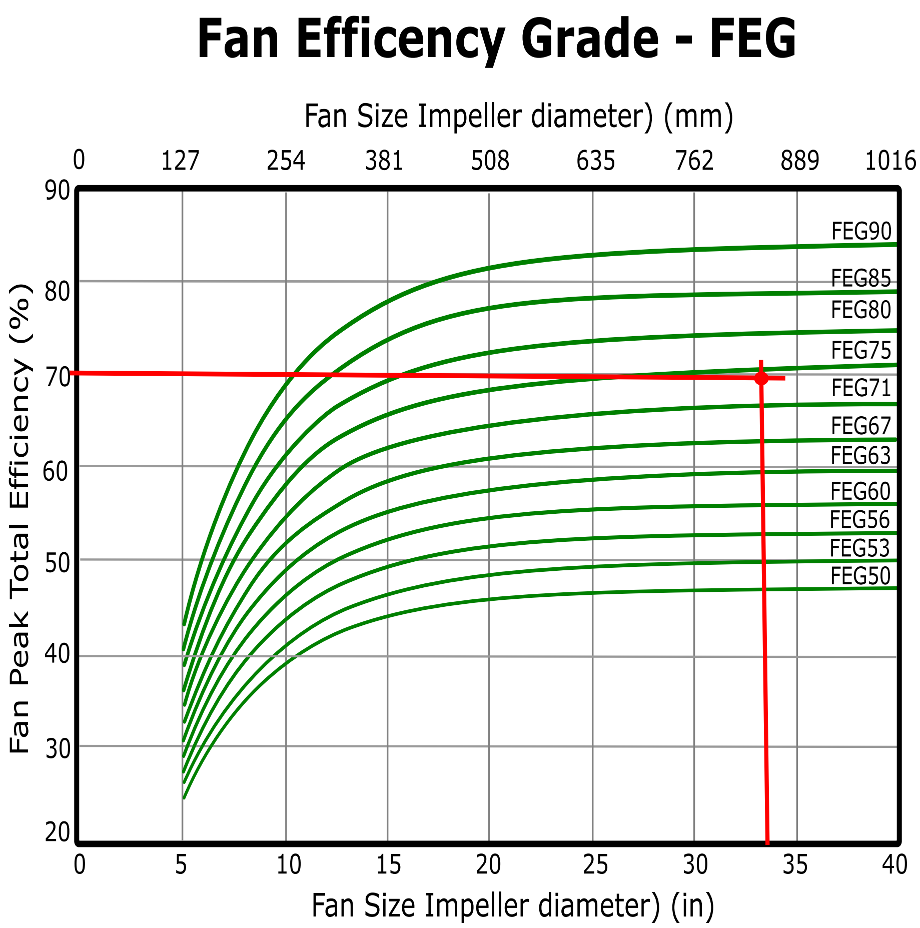
Multiple Fans in Parallel (Fan Arrays)

- Multiple staged fans in parallel (fan arrays) can be used to obtain very low turndown in VAV systems.
- Each fan must be equipped with a backdraft damper to prevent backflow through staged off fans.
- All operating fans must run at the same speed to keep higher speed fans from imposing a stall condition on lower speed fans.
- The fan drive ramp up speed time should be kept as short as possible when staging on fans to minimize the time the fan runs through stall.



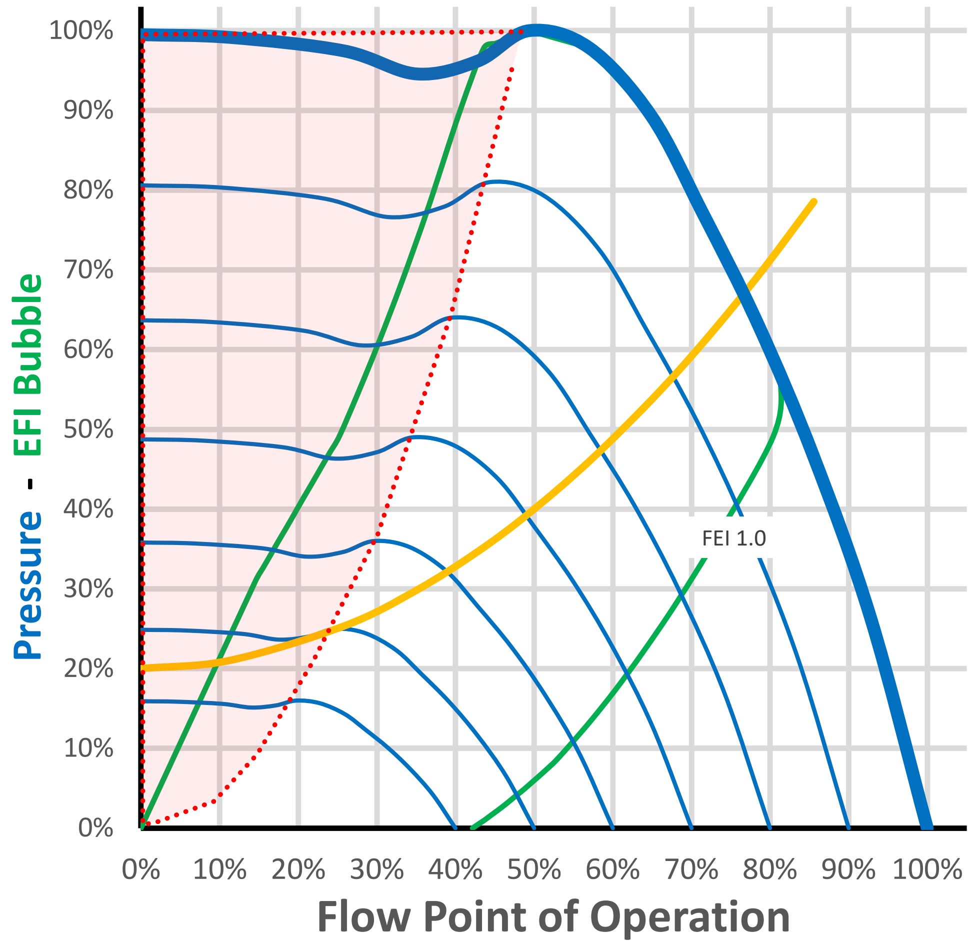
Fan Efficiency Grade (FEG)

- The FEG metric is referenced in AMCA Standard 205.
- FEG looks at total efficiency for housed fans and static efficiency for unhoused fans.
- FEG considers fan <u>shaft input power</u> only.
- It is recommended that fan be selected at points within 15% of the peak efficiency.
- FEG is based on the peak efficiency of the fan and <u>regulates the fan design</u>.
- With FEG a minimum allowable level is set for each fan type.
- FEG has been previously referenced in ASHRAE Standards, 90.1, 189, and the International Green Construction Code.



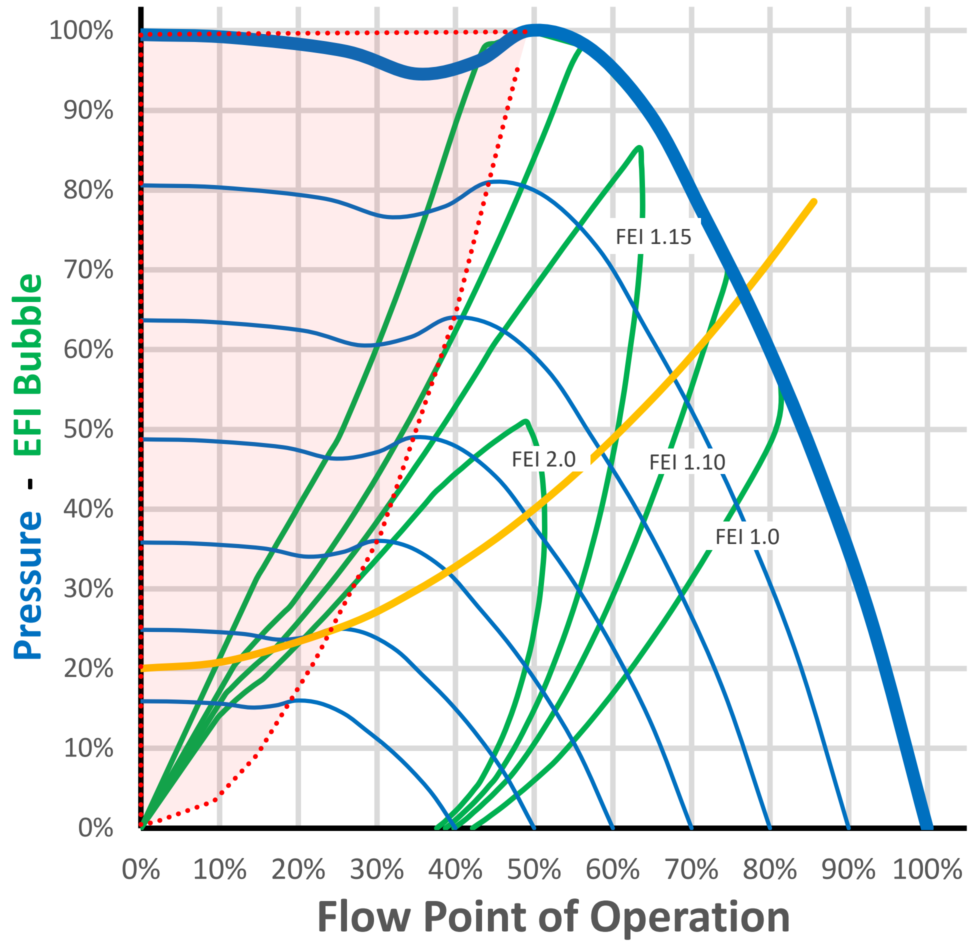
Fan Efficiency Index - FEI

- The newer FEI metric is based on AMCA Standards 207 and 208 and is considered a wire-to-air metric.
- FEI is derived from FEP (fan electrical power) and is the ratio of the fan electrical input power to standardized reference fan and motor power input at the flow and pressure.
- The input power used in FEP can be directly measured or can be derived by prescribed methods that account for typical motor part load performance and losses from belt drives, VFD's and our sources.
- FEI constrains operation to an acceptable "bubble" and <u>regulates the point of selection and operation of the fan.</u>



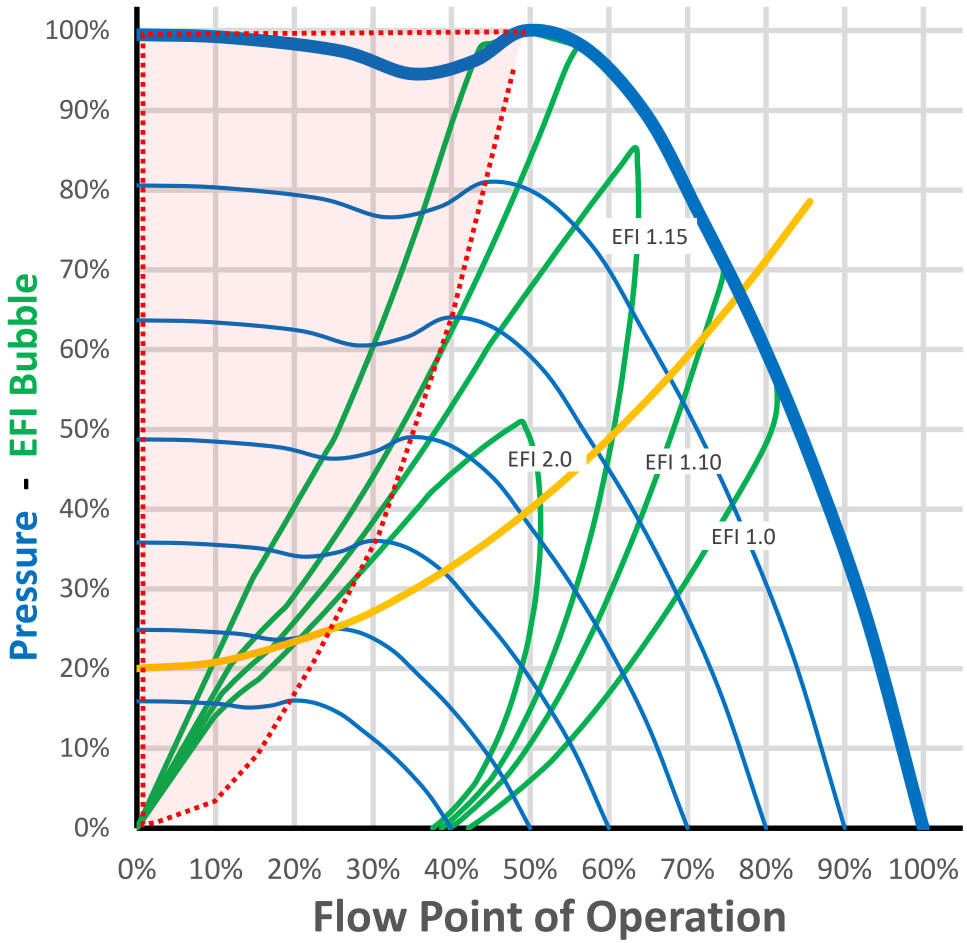
Fan Efficiency Index - FEI

- Higher Efficiency levels can be regulated by increasing the ratio by greater than 1.0.
- As the Index increases the bubble shrinks and limits both the speed and point of operation allowed to be within compliance.
- Depending on the fan's efficiency curve which in turn defines the application bubble, this may limit the what fans can be selected and may limit the VAV fan turndown.



Fan Efficiency Index - FEI

- FEI only regulates the fan manufacturer if they know the design point of operation of the fan.
- It also regulates the designer and building operator who must know the limits of operation to remain within the FEI criteria bubble.
- Determining this allowable operation envelope of a given fan efficiency curve is a very complex calculation.
- FEI does not regulate the fan's design since all fans will pass a given FEI metric if run slow enough.



Conclusions

- Designers for multi-zone VAV applications must have a full understanding of the expected operating range VAV system.
- Fan must be carefully selected so that they can turndown to the minimum required flow without going into stall.
- Selecting the largest fan with the highest peak efficiency limits the turndown available in a multi-zone VAV system.
- Dynamic reset of the control static can result in large energy savings as well as lower turn down as the shaft power is reduced almost proportional to pressure reduction.
- Multiple fans in parallel can be used to achieve lower turndown by staging, if they are all ran at same speed and are equipped with backdraft dampers.
- The new FEI metric can drive designers to larger fans that operate at higher efficiencies but could limit the turndown range in multi-zone VAV Systems and it may not result in lower annual energy use based on load profile.

References

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Questions?

Mark W. Fly, P.E.
mfly@aaon.com