ENGINEERING WHITE PAPER

Internal use only

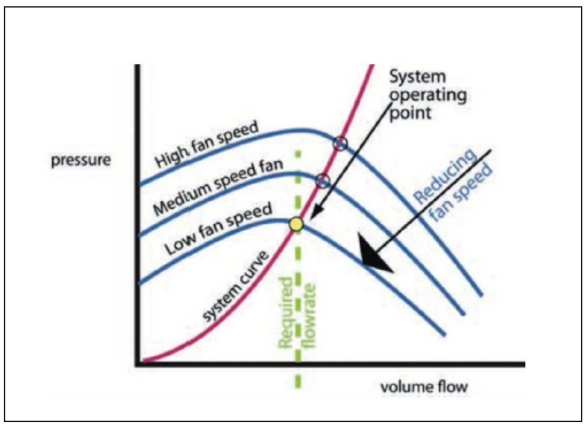
April 6, 2020

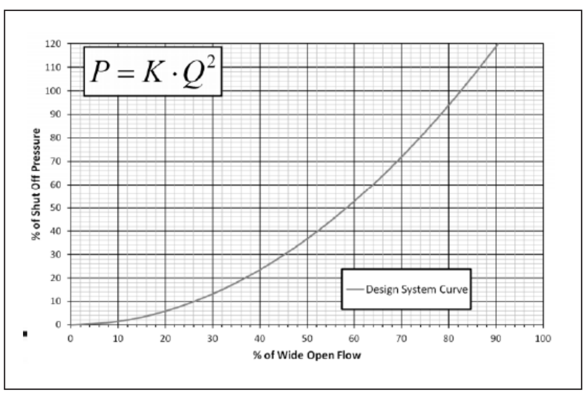
Fan Laws, System Curves, Elevation, & Selecting Fans

When designing airside systems (selecting fans) or troubleshooting installed airside systems (fans) it is critical to understand fan curves, system curves, the fan laws, & the effects of change in elevation.

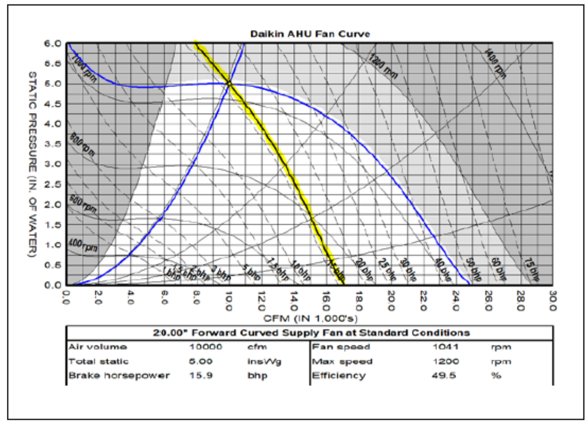
Fan curves, system curves, & the operating point:

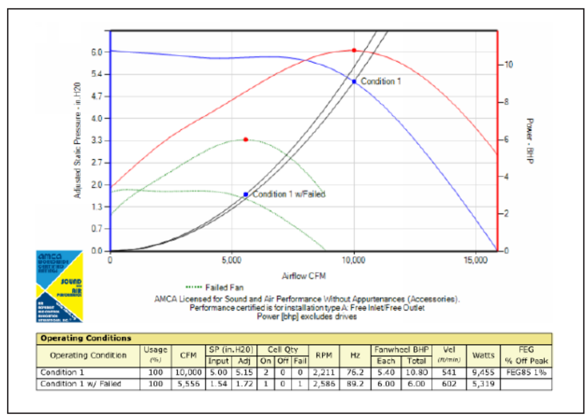
The system curve governs the operation of the duct system. The fan curve governs the operation of the fan. The interaction of these two curves determine the operating point for the system. For each speed of a fan there are unique fan speed (rpm) curves (see below). System curve relates pressure to the square of the velocity. A duct system has one system curve but changing something in the duct (filters loading) will change the system curve.





Below are two typical fan curves with system curve, operating point, & brake horsepower (bhp) curves. Daikin on the left & Nortek on the right. Daikin fan curve is fairly typical to most fan manufacturers, while Nortek's is a bit less common.





Nortek provides less information on their curves than most manufacturers, as they want reps to rely on their Design Assistant software for fan selections. Fan curves (blue, left y axis) and system curves (black) are presented similarly, but the BHP curve (red, right y axis) is scaled along the y-axis instead of the x-axis. To find BHP, draw a line vertically from the intersection of your fan and system curves – the operating point. The intersection point of the vertical line on the BHP curve will indicate BHP at your operating point. Adding a failed fan condition will display a second set of curves (dashed) to show your operating point with a failed fan(s).

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When dealing with field issues or questions about whether an operating fan is performing to specs simply gather the following information and you can analyze the operation of the installed system correctly:

- A single field measured point in the ducted air system, static pressure (insWg) & airflow (cfm)
- Amp draw of the fan motor
- Tachometer reading (revolutions rpm) of the fan shaft

You will build the system curve from this single operating point from the equation P=K*Q2 and you can derive any other point on the curve with this same equation once you solve for K (constant). Amp draw of the motor will tell you which bhp curve you are running on. Convert amp draw to bhp by knowing the volts, motor efficiency, & power factor of the motor. Conversely, if you know the speed of the fan shaft you can determine which fan (rpm) curve you are running on. Fan speed is often simpler to derive than bhp but knowing both is the most certain way to validate your operating point when troubleshooting. You must have a single operating point for analysis while it is helpful (not required) to have the amp draw or fan shaft speed.

Fan Laws:

Fan Law 1

Airflow delivered by a fan varies in direct proportion to the change in its rotational speed

$$CFM_2 = \frac{RPM_2}{RPM_1} \times CFM_1$$

Fan Law 2

Static Pressure developed by a fan varies with the square of the change in its rotational speed

$$SP_2 = \left(\frac{RPM_2}{RPM_1}\right)^2 \times SP_1$$

Fan Law 3

Power required by a fan varies with the cube of the change in its rotational speed

$$BHP_2 = \left(\frac{RPM_2}{RPM_1}\right)^3 \times BHP_1$$

Fan Laws are the relationship between variables involved with performance and power. These relationships between performance & power for centrifugal fans are known as the Affinity laws.

In general terms, when looking at speed (rpm) changes, when doubling the fan speed:

- The airflow will double
- The pressure will increase by 4 times
- The power will increase by 8 times

Put another way, if you decrease your fan speed by ½ you will decrease your power to 1/8th its original power

A given fan is operating in a fixed system with constant density:

CFM_1 = 10,000 cfm
SP_1 = 1.50 in. wg
BHP_1 = 5.00 BHP
RPM_1 = 1,000 rpm

25% more air is desired. By using and rearranging the Fan Laws, we can calculate:

CFM_2 = 12,500 cfm $(1.25)^1$ increase
SP_2 = 2.34 in. wg $(1.25)^2$ increase
BHP_2 = 9.77 BHP $(1.25)^3$ increase
RPM_2 = 1,250 rpm $(1.25)^1$ increase

In order to obtain 12,500 cfm using the original fan, the speed must be increased from 1,000 to 1,250 rpm and the motor must be changed from 5 to 10 hp. This may be not be possible, depending on the fan design and its construction. Increasing airflow in a fixed system is not as simple as it may first appear!

Below is a good example of how to use these fan laws

Use this link to easily calculate the changes in your fan systems

Change in Temperature / Change in Elevation:

Any temperature other than 70°F affects the air/gas density. Fan pressure and horsepower vary directly with the ratio of the air/gas density at the fan inlet to the standard density; however, fan air volume (cfm) is not affected by the air density. Fans operating at some altitude above sea level are similar to fans operating above 70°F.Use this link for correction tables and examples for both temperature & elevation

Efficiency and Stability:

When selecting a fan, it's important to check the fan curve for stability at part load. In Daikin Tools, be sure to check the Variable Volume button and enter the static pressure at minimum flow.

Often, the most efficient fan at the full load design conditions is the least stable at part load. This fan curve

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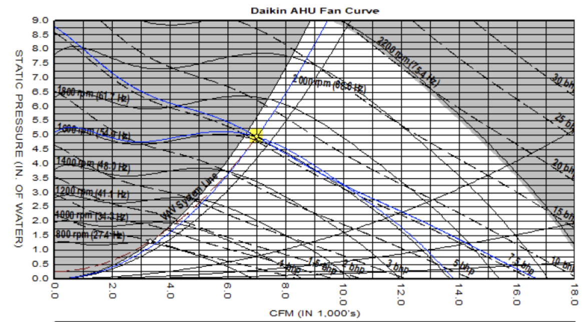
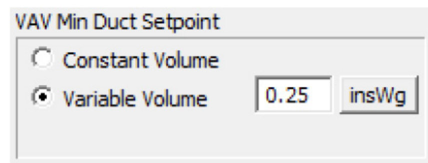
shows the minimum airflow is just short of 50% of the design airflow. If you need to operate below this, then you'll want to find a fan with a full load point shifted more to the right.

You'll note this DDPF is operating at a speed of 55.4 Hz. When a motor operates below 60 Hz, the motor HP is limited proportional to the speed. For example, if we have a 10 HP motor operating at 55.4 Hz, the maximum HP this motor could generate is 55.4/60 x 10 = 9.2. In this case, with a 7.8 BHP it's not an issue. But if you're wondering why a fan selection with a 3.6 BHP is giving you a minimum motor size of 7.5 HP, it's most likely due the RPM of the motor.



AF 24 DD PLENUM 9BL (100% Width) 1x1 Supply Fan at Standard Conditions					
Air volume	7000	cfm	Fan speed	1616	rpm
Total static	4.95	insWg	Max speed	2183	rpm
Brake horsepower	7.8	bhp	Efficiency	70.2	%
Minimum CFM	3317	cfm	Minimum Fan Speed	814	rpm
Approx VFD Setting	55.4	Hz	Motor Speed	1750	rpm



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