HVAC: Fans

According to a recent study, more than 25 percent of the energy consumed in commercial buildings is used for heating and air-conditioning. Of that, a good portion (anywhere from 20 to 60 percent) is consumed by the fans and pumps that transfer heated (or cooled) air or water from central heating and cooling plants to conditioned spaces. Supply and exhaust fans are the major players, primarily because most fans operate continuously while the building is occupied. There is a wide variation in efficiency between different fan designs (from as low as 40 to as high as 80 percent). In light of their long operating hours and wide-ranging efficiencies, HVAC fans are often good candidates for energy-efficiency retrofits.

In addition to the efficiency of the fan itself, the low cost and wide availability of variable-frequency drives in all horsepower ranges make this technology an important part of most energy-efficiency upgrade strategies.

What Are the Options?

Two basic types of fans are used in HVAC applications, classified according to the direction of the airflow through the impeller: axial and centrifugal.

Axial-flow fans. Axial-flow fans are the familiar propeller-type fan (similar in many ways to residential fans that get plugged into the wall for space cooling); the air is passed straight through. Axial fans are often directly connected to their motors, avoiding losses associated with a drive belt. They also have a central hub that allows the motor to fit neatly behind the fan with little penalty in efficiency. The weight distribution of their blades allows for low starting torque.

Axial fans can be subdivided into three categories (see Figure 1): propeller fans (used to move high air volume against low or no static pressure), tube-axial fans (fans that encase the propeller in a duct section), and vane-axial fans (fans that use straightening fins to convert circular, twisting air to get the fan moving). Vane-axial fans tend to be the most efficient fans available for HVAC air-handling units—with efficiencies in the high 80s—largely because the direction of the airflow is little changed as it passes through the fan.

The pitch of axial fan blades can be fixed, adjustable, or "variable pitch in flight," meaning that the blade angle can be varied as the fan rotates. Fixed-pitch blades are the norm for low-efficiency propeller fans and for constant-volume fans. Adjustable-pitch fans allow the user to manually adjust blade pitch to tune the flow—a useful feature for commissioning or for building in a safety factor without penalizing efficiency. Variable-pitch blades can be adjusted "in flight" by pneumatic or electric actuators; they provide efficient volume control without changing the speed of the fan. The mechanism that enables blade pitch to be varied in flight must be diligently maintained in order to maintain proper operation.

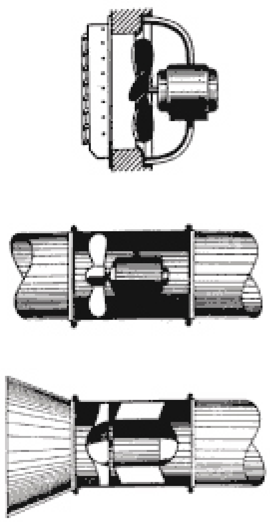
Centrifugal fans. Centrifugal fans, also known as "squirrel cage" or "utility" fans, have an entirely different design. Instead of passing straight through, the air makes a 90-degree-angle turn as it travels from the inlet to the outlet and is "thrown" from the blade tips. Centrifugal fans have more mass farther from the axle, which requires more starting torque, but they're generally quieter than axial fans.

There are several arrangements of fan blades for centrifugal impellers. The highest-efficiency centrifugal fans use airfoil or backward-curved impeller blades (Figure 2). Airfoil blades are curved backward and have an airfoil shape (similar to a cross section of an airplane wing), while backward-curved blades are of a single thickness of metal. Straight radial fan blades are used mostly in industrial applications. The main advantage of radial blades is that they permit the passage of foreign objects in the airstream such as sawdust, metal filings, and other debris. They have no advantages for HVAC use, however, and should not be used for handling ventilation air in buildings. Forward-curved fan blades have low efficiency and are typically used to move high volume against low pressure in applications such as window air conditioners and hotel unitary packages. Low purchase cost and compactness are the principal advantages of fans with forward-curved blades; they are still being built and installed in great quantities. Forward curved fans are usually used for smaller HVAC units; more efficient fan types are usually only available for larger packaged units (15 tons and higher) or from semi-custom manufacturers.

Despite their lower efficiencies, centrifugal fans greatly outnumber axial fans—anecdotal estimates indicate that centrifugals make up 80 to 90 percent of the HVAC supply fans currently used in the U.S. and nearly 100 percent of fans in smaller packaged air handlers.

Figure 1: Types of axial fans

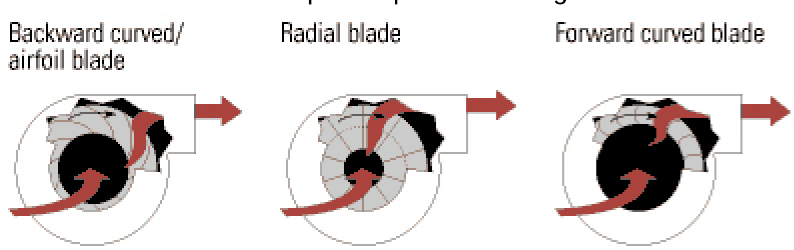
Top to bottom: the propeller, the tube-axial, and the vane-axial.



Source: Modern Heating, Ventilating, and Air Conditioning

Figure 2: Centrifugal fan impeller blades

Backward-curved airfoil impellers provide the highest efficiencies for centrifugal fans.



Source: Platts

How to Make the Best Choice

Pick a size that's just right. There is broad anecdotal evidence that many fans and motors are larger than necessary for their intended use. One investigator concluded after making field measurements on about 1,000 motors that about half operated at less than 60 percent of their rated load and a third operated at less than half their rated load. Probably the fans whose motors were attached were similarly oversized. That's bad news for those who pay the energy bills, because fans operate at their highest efficiency within a relatively small range. Outside of that range, efficiency drops off dramatically.

To pick the appropriate size, use a fan chart such as that shown in Figure 3. For new construction, carefully calculate the airflow and pressure drop and then add a safety factor. In a retrofit case, use the chart with data from actual measurements of flow and pressure to determine the optimum size, rather than looking for a like replacement.

Check the cost-effectiveness of high-efficiency options. Axial fans are the most efficient, but consider backward-curved fans where centrifugal design must be used. To evaluate the cost-effectiveness of high-efficiency fans, estimate the time spent in full- and part-load operation and calculate the potential savings as shown in Table 1. In addition, consider how variable-frequency drives (VFDs) might figure into the equation, especially if there are a significant number of operating hours spent at part load. A VFD provides significant benefit during part-load operation for airfoil and fixed-pitch axial fans, but less benefit when applied to a forward-curved fan (horsepower requirements for forward-curved fans drop off more steeply with reduced airflow than for other fan designs, so the VFD provides less of an efficiency improvement). A VFD should not be employed on a variable- or adjustable-pitch axial fan. Such fans are designed to operate at a constant speed, and varying fan speed can cause it to operate at a resonant frequency, causing excessive vibration that can actually make the fan blades break free from the hub (potentially causing substantial damage to surrounding equipment).

Pay attention to entrance and exit conditions.The conditions at the entrance and exit to a fan greatly influence fan system efficiency. Following these guidelines can help you get the most out of your fan system:

• Use long, straight duct runs upstream and downstream of the fan.

• Use gradual slopes when ducts expand or contract. A slope of 1:7 usually works well.

• For single-inlet centrifugal fans, place the drive system opposite the inlet to keep the inlet clear of obstructions.

• Avoid spinning the air into the impeller of centrifugal fans. Bringing the air in axially produces the best efficiency unless the impeller is specifically designed for either pre-rotation or counter-rotation. For example, inlet guide vanes, sometimes also called pre-rotation vanes, which are used to vary the air delivery of centrifugal fans.

• If duct elbows must be used near a fan inlet or outlet, install turning vanes. If an elbow is installed near the outlet of a centrifugal fan, have it turn in the same direction as the fan impeller. Doing the opposite—turning the air in the opposite direction from the impeller—is colloquially known as "breaking the back of the velocity profile" and leads to substantial pressure drop.

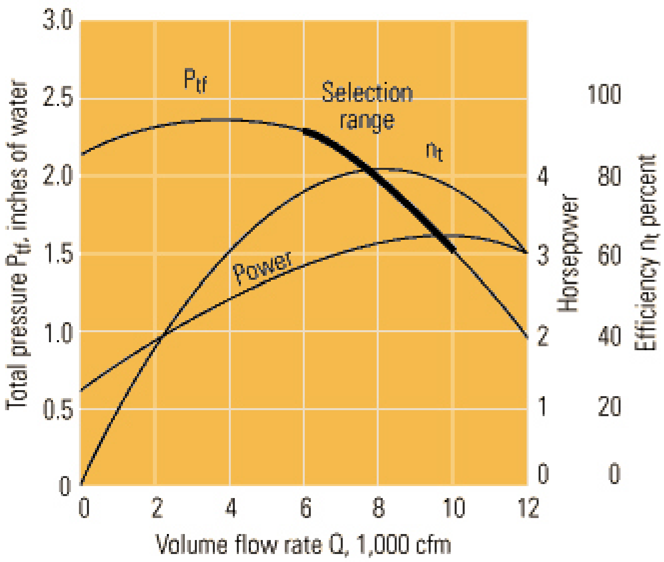
• If a centrifugal fan with inlet guide vanes is to be retrofitted with a VFD, remove the inlet vane assembly from the fan inlet and replace it with a smooth bell mouth in order to improve efficiency.

• For axial fans, use bell mouths, spinner cones, and tapered outlet sections for maximum efficiency.

Consider VFDs for variable flows. Variable-frequency drives—also known as variable-speed drives or variable-frequency inverters—use electrical waveform modification to vary the voltage and frequency of the alternating current that drives the motors. By controlling motor speed so that it closely corresponds to varying load requirements, VFDs can reduce energy consumption (in some cases, energy savings can exceed 50 percent), improve power factor, and provide other performance benefits such as soft-starting and overspeed capability. They also can eliminate the need for expensive and energy-wasting capacity control mechanisms such as outlet dampers or inlet guide vanes. VFDs require a small amount of power to operate, and so fans with a VFD consume more power at full load than single-speed fans—typically 2 to 3 percent more—but it takes very little time operating at part load to make up the difference. VFDs can be cost-effective in cases with average loads as high as 90 percent, but an analysis should be performed for each individual case based on the time spent at part-load conditions and the efficiency of the fan with and without the VFD. The price of VFDs has continued to decrease, while performance and reliability have increased. As a result, energy codes in some states now require VFDs on almost all fans employed in HVAC systems. (For more information about VFDs, see Motors: Adjustable Speed Drives.)

Figure 3: Sample fan curve

Fan curves show the relation between the quantity of air that a fan will deliver and the pressure against which it can discharge the air. The curves also indicate the horsepower required from the drive motor for the corresponding airflow, and the fan efficiency. For a given application, pick a fan that operates most of the time at the highest part of the efficiency curve. As shown, choosing a fan too far to the right will ensure plenty of airflow, but at a penalty in efficiency.



Source: 1996 ASHRAE Handbook

Table 1: Sample savings calculation for high-efficiency fans

This table illustrates the calculations required to evaluate the cost-effectiveness of a high-efficiency fan. The calculations assume a full load of 10 kilowatts and a part load of 5 kilowatts, operating time of 3,000 hours per year at full load and 1,000 hours per year at part load, and an electricity cost of $0.08 per kilowatt-hour. Use a fan curve (see Figure 3) to find the efficiency at the desired operating conditions. Note that the heat generated by the fan adds to the cooling load—the energy required to remove that heat is calculated assuming a cooling coefficient of performance of 3.4.

Characteristic	Centrifugal fan, forward- curved	Axial fan with vanes
Fan efficiency, full load (percent)	63	78
Power requirement, full load (kilowatts)	15.9	12.8
Fan efficiency, part load (percent)	47	63
Power requirement, part load (kilowatts)	10.6	7.9
Annual fan energy use (kilowatt-hours)	58,300	46,300
Annual cooling energy required (kilowatt-hours)	17,147	13,618
Annual energy use (kilowatt-hours)	75,447	59,918
Annual energy cost ($)	6,036	4,793
Annual energy savings ($)	NA	1,242
Incremental fan cost ($)	NA	600
Simple payback period (years)	NA	0.5

NA = not applicable
Source: Platts

What's on the Horizon?

Research and development in fan design is generally focused not on efficiency improvements but on increasing the mechanical strength of fan blades or extending airfoil performance into uncharted regions of speed, pressure, and temperature.

However, opportunities do exist for improving the aerodynamics of HVAC-duty fans. These include adding airfoils to support struts, tapering inlet cones to centrifugal fans, cleaning up the aerodynamics of small details such as axial fan blade roots and centrifugal fan blade-wheel connections, improving tolerances, and reducing clearances. One NASA engineer believes that the best opportunities for improved HVAC fan performance lie in reduced tip clearance, better blade shaping, and eliminating the use of non-airfoil blades.