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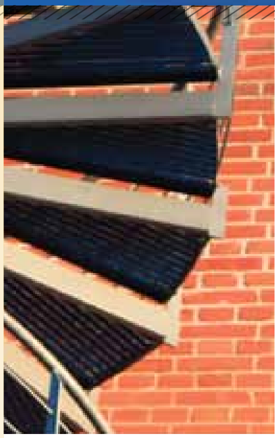

The Role of Fan Efficiency in Achieving Energy Reduction Goals

Energy consumption of commercial buildings continues to be a major focus of attention as non-renewable energy sources are depleted and overall energy costs increase. The current ASHRAE Standard 90.1 released in 2010 provides a 30% reduction in building energy consumption as compared to the same standard issued back in 2004. A large portion of a building's energy budget is consumed by the HVAC system. This article explores the role that fan energy efficiency plays in ASHRAE Standard 90.1 and how a proposed revision to that standard will help promote further energy reductions.

Building HVAC systems are designed to provide occupant comfort through a combination of heating, air conditioning, and ventilation. Thermal loads and ventilation requirements determine the amount of airflow necessary to achieve HVAC performance targets. A fan provides continuous airflow and overcomes system resistance by increasing the total energy of the airstream. The rate at which energy is added to the airstream is called the air power and it is simply the product of the airflow rate and the fan total pressure rise. In turn, the fan total efficiency is the ratio of the delivered air power to the shaft power supplied to the fan – output power over input power. Clearly, a high efficiency fan will consume less energy than a low efficiency fan, but fan efficiency alone is not a sufficient metric to ensure reductions in fan energy consumption.

For example, consider an application using a single AHU (air-handling unit) with a design capacity of 20,000 cfm and an internal total pressure drop of 2 in-wg. Two alternative systems are designed. System A has a total pressure drop of 3.5 in-wg while System B has a total pressure drop of 5 in-wg. Now suppose that the fan selected for System A has a total efficiency of 65% while the fan selected for System B has a total efficiency of 70%. At first glance we might expect that System B would consume less energy than System A because of the higher efficiency fan. However, a simple calculation would reveal that this is not the case. The fan input power, or shaft power, required by System A is 26.6 hp while the fan in System B requires 31.4 hp, an 18% difference. This example is summarized in Table 1 in accordance with Figure 1.

It is the higher external total pressure drop imposed by System B that is driving the difference, not the fan efficiency. The key point is that the system resistance must be minimized and a high-efficiency fan must be selected to ensure the lowest energy consumption.

Existing Requirements

Several existing energy standards recognize both system pressure drop and fan efficiency as key factors in reducing energy consumption, although not in an obvious way. For many years, ASHRAE 90.1 has imposed a fan power limitation that has implications for both system pressure drop and fan efficiency. One form of the fan power limitation, Option 2 in the 2010 version of ASHRAE 90.1, states that the combined net shaft power for all applicable fans within a system must be less than a specified value. Written in a generic form, the requirement states:

$$H \leq \alpha Q + A$$

where H is the fan power limit (bhp), Q is the supply air flowrate (cfm), A is a pressure drop adjustment factor that provides

Table 1: Energy consumption of fans.

	AHU System A	AHU System B
Required Flowrate	20,000 cfm	20,000 cfm
Internal Resistance	2 in-wg	2 in-wg
External Resistance	3.5 in-wg	5.0 in-wg
Total System Resistance	5.5 in-wg	7.0 in-wg
Fan Total Efficiency	65%	70%
Shaft Power	26.6 hp	31.4 hp

allowance for certain system configurations and/or special components, and α is a coefficient that depends on the type of system involved – constant volume or variable volume. In practice, all fans in the HVAC system that supply or exhaust conditioned air are combined in the fan power calculation. In this article we will consider a simplified system consisting of a single supply fan to illustrate the implications of the fan power limitation on duct design and fan efficiency.

Dividing by the flowrate, Q, results in the Specific Fan Power (SFP). From the relationship between fan flowrate, fan pressure, and shaft power, the SFP is equivalent to the ratio of fan pressure to fan efficiency, as shown in the following equation:

$$\frac{H}{Q} = \frac{P}{\eta} \leq \alpha + \frac{A}{Q}$$

In order to have low values of H/Q (SFP), the fan static pressure, P, must be small, and/or the fan static efficiency, η, must be large. Note that the ratio of fan static pressure to fan static efficiency is identical to the ratio of fan total pressure to fan total efficiency. The observations discussed below apply for both cases as long as the ratio contains like quantities, total or static. In other words, the fan static pressure cannot be used in combination with the fan total efficiency. System resistance is always in the form of a total pressure drop. This conflicts with the common practice of selecting fans on the basis of fan static pressure, which is generally not known in advance. The reader is directed to a recent article by Cermak and Murphy[1] for more information on the subject of fan selection.

In any event, the fan efficiency is always less than 100%, so the fan power limitation effectively places an upper limit on the fan pressure – static or total. This is a key point because it encourages best practices to ensure that the system resistance is kept to a minimum.

Ignoring any pressure drop adjustments, A = 0, and using the VAV coefficient, α, of 1.3 hp/kcfm as found in the standard, the maximum system resistance allowed for various fan efficiencies can be calculated. For our single fan example, a system with a fan static pressure of 5.3 in-wg requires a minimum fan static efficiency of 65% to meet the SFP. Likewise, a system with a 2 in-wg fan static pressure requires a minimum fan static efficiency of only 25%.

So the existing standard does contain an implicit fan efficiency requirement as a function of fan pressure – related to the system resistance. The higher the system resistance, the higher the fan efficiency needs to be in order to satisfy the fan power limitation. The 1.3 hp/kcfm limit used in this example would be higher if any pressure drop adjustments were applicable. For example, a 0.5 in-wg pressure drop credit is given for systems with fully ducted returns.

In general, meeting the fan power limitation can be satisfied with careful system design and existing fan technology. The fan power limitation is especially easy to meet when the system resistance is low.

Further energy reductions can be realized by requiring fans to meet a minimum energy efficiency–especially those applications where low efficiency fans can meet the existing fan power limitation by a large margin. However, a requirement based on a single value of fan efficiency would not be practical because small fans tend to be less efficient than large fans. This is due to a variety of factors including air viscosity, lack of proportional manufacturing tolerances, and other effects that do not scale with traditional fan laws. Consequently, a fan with a 10 in. impeller will be less efficient than a 25 in. fan that is geometrically similar. A minimum fan efficiency set too high could potentially eliminate smaller fans and the equipment that uses them.

Figure 1: System diagrams showing differently configured 20,000 cfm air handlers, System A and System B, as characterized in Table 1.

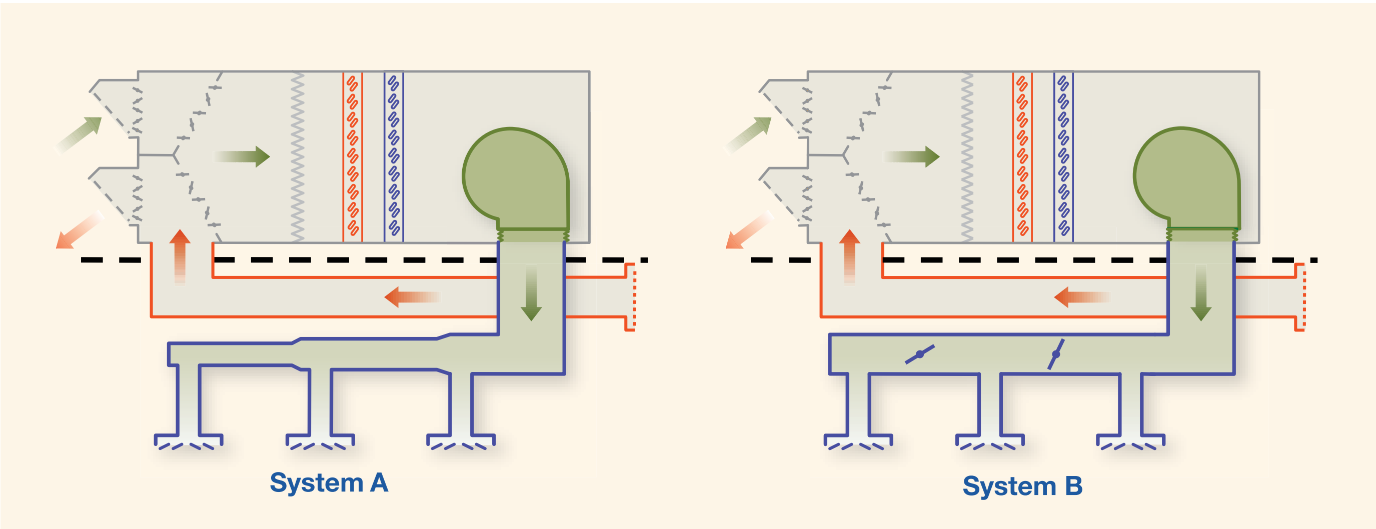

Table 2: Examples of fan selections showing pass/fail analysis results.

Example	Flowrate (cfm)	Fan Total Pressure (in-wg)	Shaft Power (hp)	Fan Total Efficiency (%)	Peak Fan Total Efficiency (%)	Efficiency Difference	FEG	SFP (hp/kcfm)	Result
1	20,000	6.0	23.9	79	84	5	85	1.20	PASS
2	20,000	4.0	22.5	56	60	4	63	1.13	FAIL
3	20,000	6.0	27.0	70	75	5	80	1.35	FAIL
4	20,000	8.0	31.5	80	84	4	85	1.58	FAIL
5	20,000	4.0	25.7	49	65	16	67	1.29	FAIL

Fan Efficiency

The Fan Efficiency Grade (FEG) is a new energy metric that recognizes the relationship between impeller diameter and peak total efficiency. FEG is defined by both ANSI/AMCA 205-12, *Energy Efficiency Classification for Fans*, and ISO 12759, *Fans – Efficiency Classification for Fans*. The FEG is based on the peak total efficiency and is a measure of the aerodynamic quality of the fan. Total efficiency is used because it represents the total energy imparted to the airstream by the fan. For a given impeller diameter, a fan rated FEG85 is capable of greater aerodynamic efficiency than a fan rated FEG67, but it does not represent the operating efficiency when used in any particular application.

Introducing the FEG into ASHRAE 90.1 is in process. The proposal would place a minimum FEG67 on all fans with the exception of fans included in certain energy rated equipment, fans with motors 5 hp and less, power roof ventilators, and emergency-only fans. In addition, the proposal would require fans to be selected to operate within 15 points of their peak total efficiency to ensure good energy efficiency.

A minimum FEG67 will impact systems with relatively low-pressure requirements where the current fan power limitation can be met with a low efficiency fan. As demonstrated above, systems with high pressure drop already require high efficiency fans to meet the fan power limitation and these applications are not likely to be affected.

To illustrate the impact, Table 2 shows several fan selections for the simplified case of a single fan VAV system without additional pressure drop adjustments. Per the standard, the

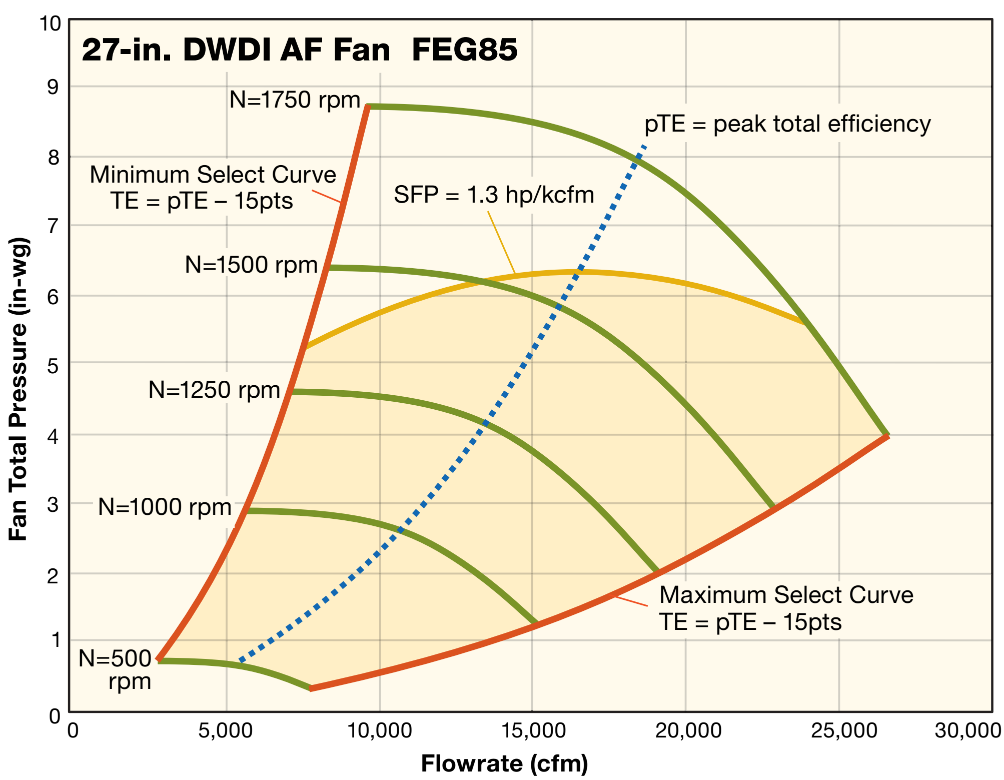

Figure 2. Example double-wide housed centrifugal fan characteristic with an FEG of 85. The maximum and minimum select curves shown correspond to a fan total efficiency 15 points below the peak fan total efficiency (pTE). Selecting within this range ensures compliance with the ASHRAE Standard 90.1 proposal. A VAV system using a single fan would be further limited to selections below the 1.3 hp/kcfm curve in order to comply with the existing fan power limitation.

largest SFP is 1.3 hp/kcfm. The proposed addition of FEG67 requires no additional steps or calculations, but simply to ensure that the selected fan is FEG67 or greater and that the operating-point efficiency condition is met. The FEG, operating total efficiency, and peak total efficiency are supplied by the fan manufacturer through catalog data or selection software.

The size and type of fan chosen in these examples is not important, only the performance parameters and the published FEG. In Example 1, a fan rated FEG85 operating from 5 points from peak total efficiency is selected. The calculated SFP is 1.2 hp/cfm, so the FEG, fan power limitation, and efficiency criteria are met.

In Example 2, the fan total pressure is 4 in-wg, but a fan having an FEG63 is selected, which is immediately disqualified. Under the existing standard, this fan would have satisfied the fan power limitation since the SFP is only 1.13 hp/kcfm.

Examples 3 and 4 meet the FEG requirement, but fail due to excessive SFP. In these cases the system pressure requirement is driving the selection toward more efficient fans, much higher than the proposed FEG limit.

In Example 5, the fan is selected too far from the peak total efficiency point, and the selection fails under the proposed criteria. This should rarely happen because the 15-point spread is generous and often covers the entire selection range that manufacturers recommend for a given fan.

Figure 2 shows the characteristic operating envelope for a typical DWDI airfoil fan with a rating of FEG85. The minimum and maximum system curves correspond to the peak total efficiency less 15 points as required by the proposed revision to the standard. For this particular example, the 15 point restriction is relatively broad and covers a large portion of this fan's performance envelope. In fact, it is not too much different from the performance envelope that would be presented by the manufacturer in print catalogs or selection software. Also shown in the figure is a curve indicating the specific fan power of 1.3 hp/kcfm. For a single VAV fan, and in the absence of any pressure adjustments, selections can only be made in the shaded region below the line to meet the current standard. This again stresses the fact that the fan power limitation encourages system designs with low resistance.

Summary

Energy reductions required by standards and regulation will continue to challenge building designers and equipment manufacturers for the foreseeable future. Reducing energy consumption of fans requires a combined effort from HVAC system designers and fan manufacturers. The current ASHRAE Standard 90.1 encourages good system design and the use of high efficiency fans to achieve energy goals. The proposed addition of a fan efficiency requirement (i.e., FEG) complements the existing standard and offers a path for future energy reduction improvements.

References

Cermak, J., and J. Murphy, *Select Fans Using Fan Total Pressure to Save Energy*. ASHRAE Journal, July 2011. Available at www.amca.org/feg/best-practices.aspx.

Learn More about Fan Efficiency Grades

For more information about fan efficiency grades, including technical papers, progress on adoption into ANSI/ASHRAE/IES 90.1, and a hyperlink to a free PDF download of ANSI/AMCA 205 Energy Classification for Fans, visit www.amca.org/feg.