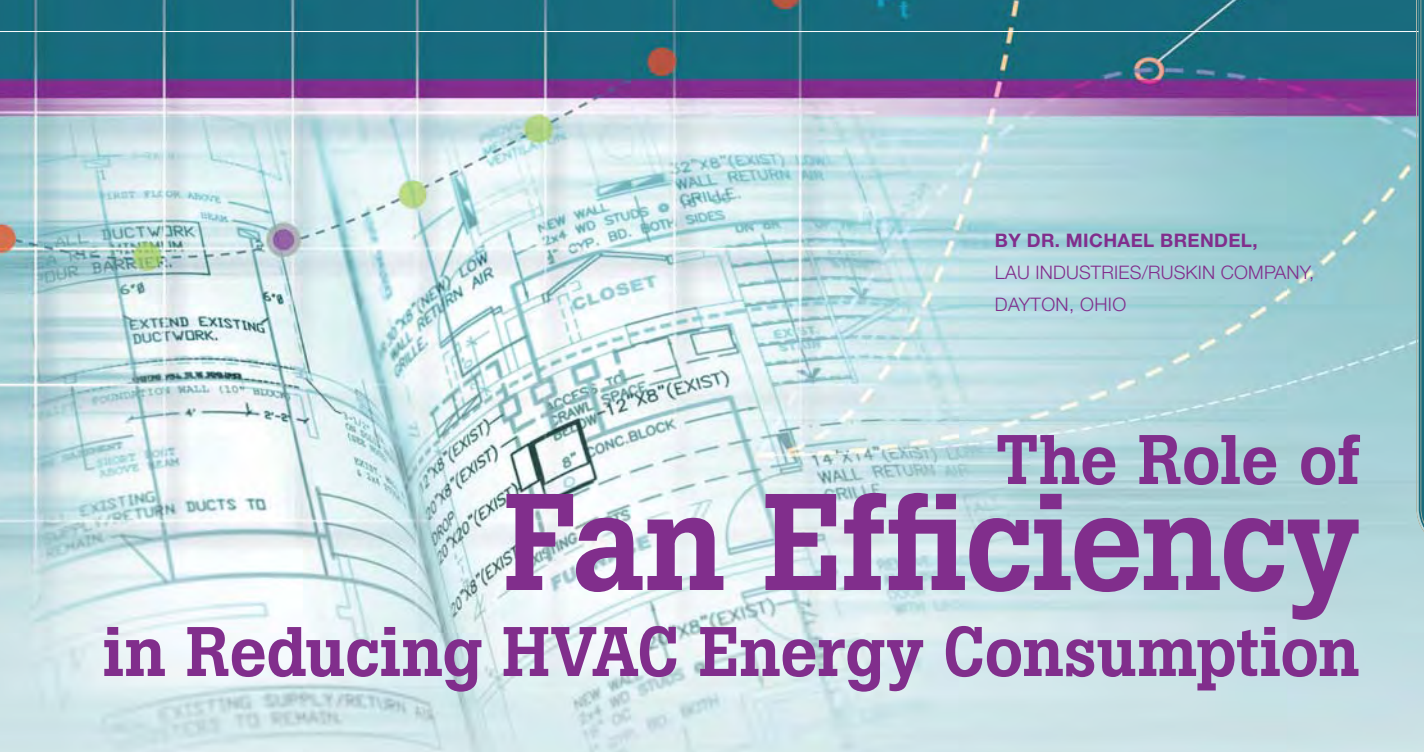

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The Role of Fan Efficiency in Reducing HVAC Energy Consumption

A new fan efficiency grading system can help designers select high-efficiency fans to help reduce overall energy use.

In 2008, the United States consumed about 100 quadrillion BTU (106 EJ) of source energy to power everything from lightbulbs to automobiles. That is the equivalent of over 29 million kWh, or a per capita energy consumption rate of 11 kW. The vast majority of this energy comes from a limited supply of nonrenewable resources. This has led many industries to implement far-reaching initiatives and policies to address energy conservation, and the HVAC industry is no exception.

The annual energy consumption for heating and cooling of commercial buildings is estimated at 5 quadrillion BTU (5.3 EJ). About one-third of this energy is used by the supply, return, and exhaust fans. While this estimate represents a small fraction of overall energy consumption, responsible energy awareness and management at all levels is necessary to achieve long-term energy reduction goals. This article reviews the energy requirements of HVAC air distribution systems and shows how a new fan efficiency grading system, embodied in standard AMCA 205, will play a role in assuring energy-smart fan selections. See the related news story on the recent passage of AMCA 205 on Page 4.

ENERGY REQUIREMENTS

A typical HVAC distribution system includes a network of ductwork, coils, filters, dampers, diffusers, and many other specialized components. Airflow through these devices encounters resistance, in the form of a pressure drop, which must be overcome by adding energy to the flow. This energy can be separated into potential and kinetic components, corresponding to the static and velocity pressure. The total energy, or total pressure (P_t) by analogy, is the sum of the two components: potential plus kinetic. Static pressure (P_s) and velocity pressure (P_v) can be traded back and forth in a duct system, so both need to be correctly accounted for when considering energy consumption. Ignoring compressibility effects, the rate at which energy must be added to maintain a prescribed airflow rate is the total pressure drop multiplied by the flow rate. This is called the air power and in I-P units it is calculated as $H_o = PtQ/6362$ where H_o is the air power (hp), P_t is the total pressure drop (in-wg), and Q is the flow rate (cfm). Although the air power must be provided by the fan, it is important to recognize that the required air power is a result of system design and does not depend on the fan selection. A clear goal in reducing HVAC system energy consumption is to minimize the required air power through proper design of the air distribution system; that is, minimize the system pressure drop and/or the flow rate. This responsibility rests with the system designer and is the first step in achieving energy reduction.

Specifying an energy-efficient fan can go a long way toward reducing energy consumption, but it is not a sufficient requirement. A poorly designed air distribution system with a high total pressure drop might utilize a high-efficiency fan, but the net energy consumption could be higher than a properly designed system with low total pressure drop, utilizing the same fan. One way to assure good system design is to specify a maximum allowable air power per unit flow rate, H_o/Q. This effectively places an upper limit on the system pressure drop, P_t. A variation of this approach is currently used in the ASHRAE 90.1-2007 standard to encourage good system design.

FAN EFFICIENCY

Figure 1 is a Sankey diagram showing the energy flow through a fan system. A typical fan system consists of a motor,

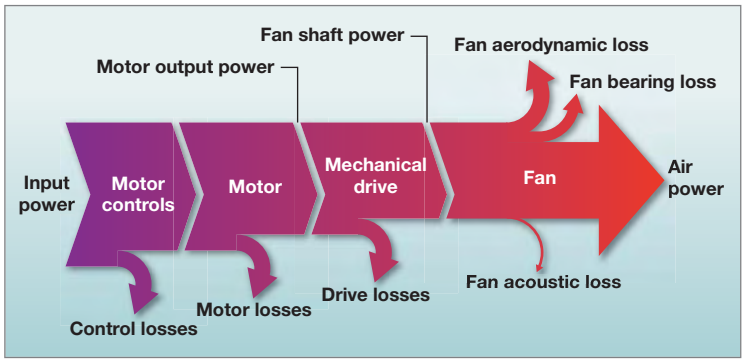

Figure 1. Fan energy flows from left to right through a typical fan system.

motor control, mechanical drive, and the fan. Power flows from left to right, with each component rejecting a portion of the input energy as a result of inefficiencies. Energy efficiency of each component is the ratio of the output power to the input power. The fan imparts energy to the air stream by converting mechanical power at the fan shaft to air power at the outlet. Some of the input energy is rejected due to aerodynamic losses, mechanical losses (e.g., bearings), and, to a much lesser extent, acoustic losses. The total efficiency of the fan is given by the ratio of air power to fan shaft power.

Establishing energy-efficiency goals for fans presents a number of challenges. Fan total efficiency is a function of many variables including fan type, airflow, speed, and impeller size. For example, HVAC fans are often designed as a product series that includes multiple sizes to meet different airflow requirements. Fans within the series generally have geometric similarity whereby key dimensions scale in direct proportion to the fan impeller diameter. However, it is well known that smaller HVAC fans do not perform as well as larger fans from the same series. This is due to practical limits in manufacturing tolerances, aerodynamic effects, and disproportionate mechanical losses that occur as the fan size is reduced.

Over the past several years, fan industry leaders within the AMCA and ASHRAE communities have developed a simple metric to classify fans by their energy efficiency: the Fan Efficiency Grade (FEG). The FEG has been proposed in draft standards AMCA 205 and ISO 12759, and offers code/regulatory bodies a tool for specifying fan energy-efficiency targets.

The FEG for a given fan is determined from the peak total efficiency (pTE) and the impeller diameter using the curves shown in Figure 2. These curves are constructed so that fans in a given geometric series should all have the same FEG regardless of fan size. The FEG is established by plotting the impeller diameter and peak total efficiency, then reading the associated FEG band in which this point falls. For example, a fan with an impeller diameter of 15 in and a peak total efficiency of 71% would have an FEG of 80.

The FEG applies to a fan without any drive components. It is customary in many parts of the world for manufacturers to sell fans without motors or drives. Selection of efficient motors, controls, and drive systems is left to the buyer, which provides flexibility in designing custom HVAC products. This also places the responsibility for achieving higher FEGs directly in the hands of the fan manufacturers. More details concerning the

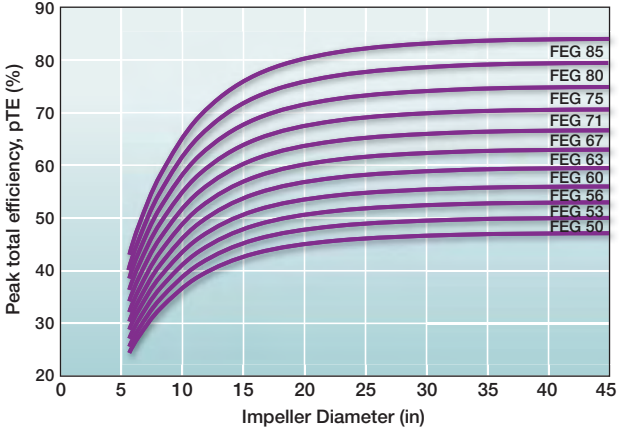

Figure 2. Fan Efficiency Grade curves are used to classify fans by their energy efficiency.

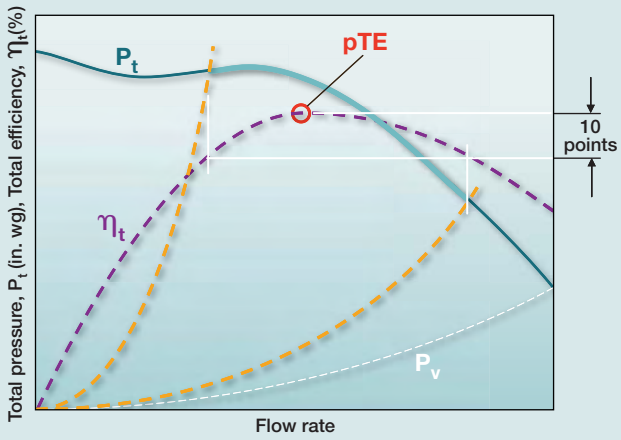

Figure 3. This diagram depicts a typical fan curve and the proposed 10-point total efficiency band.

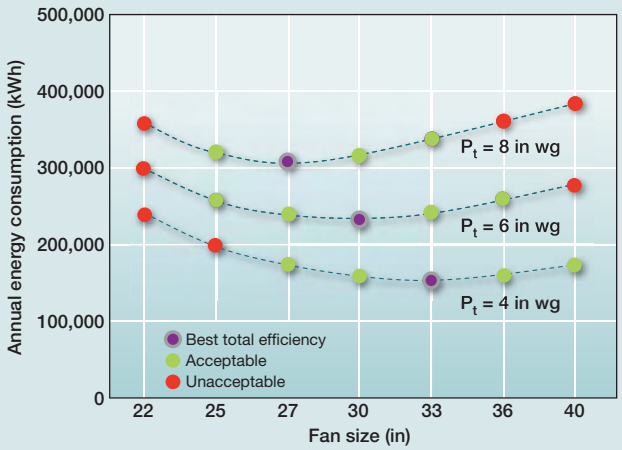

Figure 4. This chart shows examples of fan selections in terms of annual energy consumption.

Table 1. Selections for 25,000 cfm @ 6 in-wg (total pressure)

FAN SIZE	SPEED (RPM)	SHAFT POWER (HP)	TE	pTE	DIFFERENCE
22	2507	36.1	65.6%	78.0%	12.4%
25	1992	31.7	74.6%	80.0%	5.4%
27	1656	29.2	80.9%	82.0%	1.1%
30	1399	28.3	83.5%	83.5%	0.0%
33	1247	29.4	80.3%	83.5%	3.2%
36	1138	31.6	74.7%	84.0%	9.3%
40	1044	33.8	69.9%	84.0%	14.1%

history, development, and scope of the FEG may be found in a previous article.

The FEG is not the fan efficiency. It is a classification that represents the energy efficiency potential of a fan. It is the responsibility of the system designer to properly select fans to best suit the needs of the application. Future regulations may place a lower limit on acceptable FEG as part of an overall strategy to reduce fan energy consumption. However, this alone will not guarantee that fans are properly selected. Per AMCA 205, codes that specify a minimum FEG must also require that fan selections be within 10 points of the peak total efficiency. This additional requirement assures high-efficiency operation and helps place emphasis on total operating cost, rather than first cost.

But how restrictive is the 10-point limit on fan selection?

FAN SELECTION

Figure 3 shows a typical fan curve with both the total pressure and efficiency characteristics as well as the proposed 10-point total efficiency band. For most common fan types (DWDI Airfoil, plenum, DWDI forward curved, etc.), approximately 50% of the fan capacity is available for selection. This is often comparable to the manufacturer's recommended selection range.

By way of example, consider an air handler that delivers 25,000 cfm (42,500 m^3/h) at 6 in-wg (1,500 Pa) total pressure. Selections were obtained from a series of belt-drive double-wide airfoil fans having a FEG of 85. Table 1 shows several selections meeting the performance target along with required shaft power and total efficiency. Five of the seven selections are acceptable based on the 10-point efficiency requirement.

Taking this one step further, Figure 4 shows the selections in terms of annual energy consumption. Here it is assumed that the motor and mechanical drive efficiencies are both 90%

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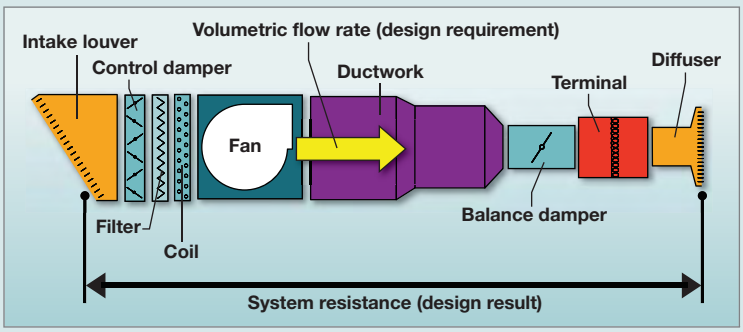

A typical HVAC air distribution system consists of a variety of a/c and air control elements. The flow rate is a design requirement, while the system resistance is the result of component selection and design calculations.

and that the duty cycle for the fan is continuous. This plot also shows the importance of minimizing the system restriction by considering the same 25,000 cfm flow requirement for 8 in-wg (2,000 Pa) and 4 in-wg (1,000 Pa) systems. In both cases, several fan sizes meet the 10-point restriction, although the fan size for best performance increases with decreasing pressure requirement.

The number of available selections offers the system designer reasonable flexibility in selecting a fan size to meet other design requirements. For example, further energy reductions are possible with a VAV (variable air volume) system where fan speed is modulated based on a duct pressure signal. The fan must be selected to assure efficient operation and acceptable turndown to meet multiple flow conditions. This requires careful consideration of the fan operating schedule to determine the net energy consumption at each operating point. In some instances, this may lead to a fan size that is smaller than that selected for continuous operation.

SUMMARY

Energy consumption of HVAC systems is garnering much attention on both national and international fronts. Achieving energy reduction goals in HVAC air distributions systems can be accomplished on several levels. Designing systems that minimize pressure drop for a given flow requirement must be the first priority in reducing energy consumption. Selection of high-efficiency fans that operate near peak efficiency complements good system design and contributes to overall energy reduction.

The FEG, a new fan energy-efficiency classification that has been proposed in AMCA 205 and ISO 12759, offers a simple metric for code and regulatory bodies to formulate new energy standards for fans. The added requirement for selecting and operating fans within 10 points of peak total efficiency assures meaningful energy conservation without over-restricting system design options.

REFERENCE

1. Annual Energy Review. DOE/EIA-0384. U.S. Energy Information Administration. 2009.
2. Westphalen, D., and S. Koszalinski. Energy Consumption Characteristics of Commercial Building HVAC Systems, Vol. II: Thermal Distribution, Auxiliary Equipment, and Ventilation. DOE/BTX. October 1999.
3. ASHRAE/ANSI/IESNA Standard 90.1: Energy Standard for Buildings except Low-Rise Residential Buildings. ASHRAE. Atlanta, 2007.
4. Brooks, J., J. Cermak, and J. Murphy. Fan Industry Meeting Energy Challenges. AMCA Inmotion Spring 2009.