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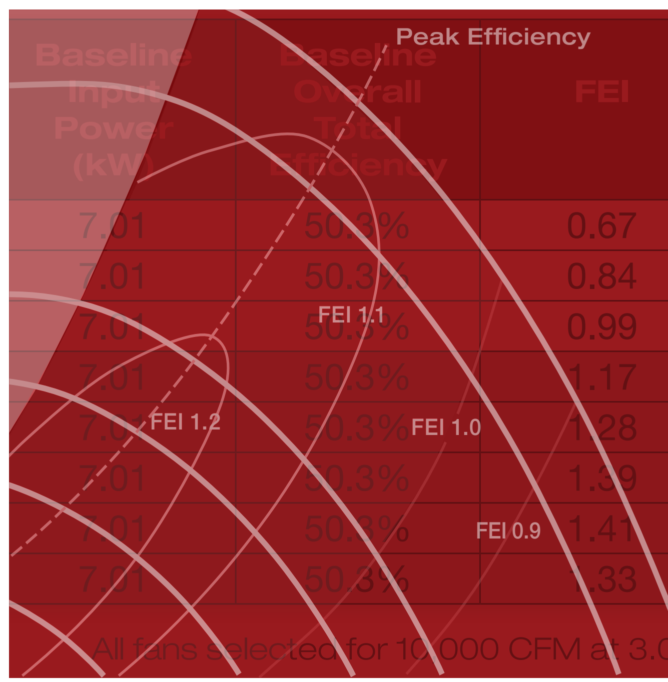

Introducing the Fan Energy Index

An AMCA International White Paper

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Introducing the Fan Energy Index

for Fan Efficiency Codes, Standards, Regulations and Incentive Programs

ABSTRACT

This document defines the fan energy index (FEI), an energy efficiency metric for fans first developed by AMCA International. This metric is further defined in the U.S. Department of Energy (DOE) Term Sheet,[1] a document approved by the DOE that resulted from public negotiations on what a DOE-fan-efficiency regulation would contain. The FEI is a ratio of the actual fan efficiency to a baseline fan efficiency, both calculated at a given airflow and pressure point. Since these efficiencies are each calculated at the same airflow and pressure, FEI is also defined as the ratio of the baseline electrical power to the actual electrical power of a fan.

The FEI was designed to encourage responsible application of fans and drive significant and quantifiable energy savings through energy codes, utility rebate programs and federal regulations. This is accomplished by establishing the minimum fan efficiency or maximum fan electrical input power at design airflow and pressure.

INTRODUCTION

Fan energy consumption is receiving much attention worldwide. Commercial fan efficiency provisions began appearing in U.S. standards in 2013 (ASHRAE 90.1 and ASHRAE 189.1) and in the International Energy Conservation Code in 2015.[2] European Commission efficiency regulations for many types of commercial fans became effective in January 2013, and preset increases known as Tier 2 requirements became effective January 2015. Tier 3 requirements are currently being set.[3] Meanwhile, China, Malaysia, Taiwan, Thailand and other Asian countries have passed federal regulations for fan efficiency.[4] The DOE has been developing an efficiency regulation for commercial and industrial fans and blowers since June 2011, with a draft test procedure rulemaking expected in the fourth quarter of 2016 and a draft energy conservation standard expected some time in 2017. Efforts to develop U.S. utility rebate programs are underway as well, but DOE regulations must become more defined before program creators can commit to specific approaches. AMCA International, as an advisor to interested parties worldwide, plays a key role in establishing appropriate fan efficiency metrics for codes, standards, U.S. and European regulations and non-mandatory incentive programs. As part of a continuing effort to create metrics that can be used to reduce fan energy use, AMCA has developed the fan energy index, or FEI, which addresses both fan design and fan application (sizing and selection).

The FEI can be used by

- Regulators to improve the efficiency of fan designs and limit market availability of less efficient fans
- Utilities to establish rebate programs to incentivize the efficient use of fans
- Code bodies to drive building owners and contractors to using more energy efficient fans for ventilation and process applications
- Purchasing agents to evaluate the fan selections and their suitability for specific applications

"The FEI discourages the unintended consequences of adverse selection behavior in a market driven by first cost."

PROBLEM DEFINITION

Fans are unique from other appliances in that their operating efficiency varies significantly based on how they are applied and where they are selected within their operating envelope. Fan application and selection is therefore far more influential than peak fan efficiency in determining the actual energy consumed by a fan. Since fans are not typically sold to building owners (who pay electric bills), market pressures push system designers and purchasing agents toward smaller fans with a lower first cost. This market dynamic works against the effectiveness of regulations focused on raising fan peak efficiency requirements. If minimum mandated peak efficiencies result in higher product costs, selection and application decisions may shift to compensate, negating at least a portion of the efficiency gains expected from the regulation. A fan efficiency metric that addresses both product efficiency and product selection can use natural market pressures to influence behaviors in both fan manufacturers and air system design professionals. In order to best accomplish this, the metric must address each of the following issues.

FAN SIZE

Fan size has an impact on achievable efficiency levels. It is well documented that smaller diameter impellers cannot attain the peak efficiency levels of larger diameter impellers with the same aerodynamic design. This can be addressed in a number of ways. The FEG metric of ANSI/AMCA Standard 205[5] relates fan peak efficiency to impeller diameter. The FMEG metric of ISO 12759[6] takes slightly different approach by relating fan peak efficiency to absorbed input power. A third alternative detailed in this document, FEI, relates fan efficiency to both airflow and pressure. An efficiency metric that varies with airflow not only accounts for the size impact, but it also directly addresses fan selection.

FAN PRESSURE

Fan pressure also has an impact on achievable efficiency levels. Fans designed for lower pressure applications generally have lower peak efficiencies than those designed for higher pressures. The same aerodynamic features that increase fan pressure (number of blades, turning vanes, housing shapes, etc.) also tend to increase fan peak efficiency. These same features, however, make fans designed for higher pressure less efficient when applied at low pressures. A fan designed for low pressure offers lower energy consumption when applied at these low pressures. Other fan efficiency metrics address this issue by varying efficiency requirements based on fan type. The FEI efficiency metric that varies with flow and pressure instead of fan type can be applied universally using a single baseline target efficiency to impact both fan design and fan application. The FEI can thus be applied to a broad range of products, encouraging best practices in aerodynamic design.

PROPER APPLICATION

Proper application of fans also requires the correct use of fan static and total pressure. Although system resistance is properly calculated in terms of duct total pressure, fan performance specifications and resulting fan selections are nearly always made using fan static pressure. Fans with ducts attached to the fan discharge should be selected using fan total pressure, since both the static pressure and fan velocity pressure are available to overcome system resistance. However, a fan without a duct connected to its discharge should always be selected using fan static pressure, since the velocity pressure cannot be used to overcome system resistance. The fan energy index recognizes the value of velocity pressure in ducted applications and encourages the proper use of fan pressures.

DRIVES

Direct drive fans can offer a significant improvement in efficiency over belt driven fans. However, belt driven fans are commonly used because they provide a flexible solution to match the fan speed to design conditions, provide a means to modify fan performance in the field and enable the use of large, low speed fans where motors matched to these speeds are either not available or are cost prohibitive. Direct drives should be evaluated based on their ability to save energy. To accomplish this, an efficiency metric must be applied to the entire fan, motor and drive. This is often called a “wire-to-air” or “extended product” approach.

SPEED CONTROL

Speed control and inlet vanes also offer energy savings. Fan power consumption is related to fan speed by a cubic equation; reducing fan speed cubically reduces power consumption. However, when considered in a wire-to-air metric, the use of a speed controller or inlet vanes will always reduce the efficiency of the fan system at the full load design point because each control method has an energy penalty. The size of the penalty varies with the method of control and the load at which the fan is operating — part load and full load. “Wasted energy” from speed control penalties, however, is often much less than the energy savings from using them. Therefore, some adjustment is warranted, either to the design point efficiency metric or to the required efficiency levels, in order to eliminate the “penalty” and encourage the use of fan speed control. This is where the new FEI metric offers state-of-the-art, elegant opportunities for calculating, regulating and incentivizing fan efficiency.

INTRODUCING THE FEI METRIC

FEI encourages the proper use of fan total pressure for fans applied with outlet ducts and recognizes that fan static pressure and static efficiency are correct measures to drive energy savings for non-ducted fans. FEI is a wire-to-air metric that encourages the use of direct driven fans — but only as a means to save energy, since there are some applications in which belt drives better match the fan speed to the application. By making an adjustment for capacity control, FEI encourages the use of variable speed and inlet vanes, taking advantage of energy savings at reduced fan loads. Finally, FEI discourages the unintended consequences of adverse selection behavior in a market driven by first cost.

The FEI takes advantage of the large energy savings available from an “application dependent” requirement, while accommodating the “application independent” sales that occur through distributors.

HIGH-LEVEL SOLUTION

The fan energy index is superior to other fan efficiency metrics that are based on peak fan efficiency. With so many different fan designs on the market, a peak efficiency approach requires the categorization of fans in the market with a different minimum peak efficiency requirement for each product category. As mentioned earlier, with operating efficiency so dependent on fan selection, a peak efficiency metric that does not address fan selection could result in increased energy consumption.

Instead of specifying a minimum peak efficiency level for the each of the various fan types, the FEI establishes a baseline efficiency and resulting baseline power that varies with both airflow and pressure, universally applied to all fan categories. The ratio of fan efficiency to this baseline efficiency at design conditions is used to package the metric and make it easier to use for customers, owners, regulatory bodies and utility rebate programs. The baseline represents a reasonable efficiency level that is common to all fan types as they are normally applied.

With this baseline efficiency established for all fan types and applications, the simple FEI ratio carries significant value. For a given application (airflow and pressure), different fan types and sizes can all be compared using the same baseline. An FEI equal to one means the actual fan efficiency meets the baseline efficiency. In other words, the power consumed is equal to the baseline power consumption. An FEI greater than one means the fan efficiency exceeds the baseline, while an FEI less than one does not meet the baseline. Higher values of FEI for the same airflow and pressure will always equate to energy savings.

Since the baseline has been chosen to represent a reasonable efficiency, it is expected that code bodies and the DOE will establish 1.0 as a minimum FEI requirement. However, there may be exceptions to this. For example, fans used for variable air volume (VAV) systems should have a lower FEI requirement to encourage use of VAV systems. Fans used infrequently, such as emergency fans or fans used for material handling, could also have lower FEI requirements. On the other hand, high-performance-building standards and ratings systems (such as ASHRAE 189.1 and LEED) or utility rebate programs could have a higher FEI requirement to increase efficiency over baseline codes and regulations. The FEI metric also supports the expected increased stringency in codes and regulations over time as fan technology improves.

The fan energy index is calculated as a ratio of the baseline electrical power over the fan's actual electrical input power. The calculation method of AMCA Publication 207[7] and the measurement method of ANSI/AMCA Standard 210[8] are available to establish FEI as a wire-to-air metric. While code authorities and the DOE will establish minimum FEI (or maximum fan power) levels as they deem appropriate, fan suppliers and users have the freedom to meet these requirements in any manner they choose. A fan user can utilize any combination of fan, transmission, motor and speed control, as long as the combined FEI level meets the minimum requirement.

INDUSTRY BENEFITS

FEI is designed to address the wide efficiency variability of every fan by concentrating on the energy consumed by a fan as it is applied: at the design point of operation. By focusing on application, the FEI can effectively impact both fan design and fan selection. For example, to meet an energy efficiency goal at the design conditions, one could either use a very efficient fan design selected at some distance off-peak or a fan with lower aerodynamic efficiency selected closer to its peak efficiency. Either way, the goal of energy savings will be achieved. The customer — a contractor who is principally concerned about first cost — will actually force manufacturers to design a more efficient product so it can be applied in an efficient manner and still be cost effective.

While driving significant energy savings and technological improvements, the FEI will also teach proper fan selection. Everywhere a consumer makes a fan selection decision, be it performance tables, fan curves or electronic selection software, the value of FEI for that selection will be shown. Consumers will know immediately how their fan selection compares to the maximum allowable fan electrical input power. They will know how the energy consumption of one product compares to another, regardless of product type, category, size or drive method.

Even though the FEI was developed to focus on fan energy as applied, it can also be used as an application-independent metric when the design operating point is not known. In this case, the FEI is evaluated at the best efficiency point (BEP) at the maximum published fan speed. By considering this single point, the metric establishes a restricted speed range while remaining consistent with its use at the design point of operation.

SOLUTION DETAILS

GENERAL DEFINITION

The general definition of FEI is this:

$$FEI = \frac{\text{Fan Efficiency}}{\text{Baseline Fan Efficiency}} \qquad \textbf{Eq. 1}$$

Since these efficiencies are both calculated at the same airflow and pressure, this ratio can also be written as follows:

$$FEI = \frac{\text{Baseline Fan Electrical Input Power}}{\text{Fan Electrical Input Power}} \qquad \textbf{Eq. 2}$$

This second equation is equivalent, but it is easier to work with and has the added benefit of working along the entire fan curve. Since the static efficiency is always zero at free air (zero pressure), there is no way to regulate efficiency at this point on the fan curve. However, with the ratio in terms of fan electrical input power, there is a solution for baseline power (and the resulting FEI), even at zero pressure.

Note that the FEI is an overall efficiency, wire-to-air metric that includes not only the impact of the fan efficiency but also each of the drive components used to operate the fan. This will be expanded upon later in this paper.

BASELINE EFFICIENCY CALCULATION

The first step in establishing the overall baseline efficiency is to calculate the baseline fan efficiency, which is traditional fan efficiency based on fan shaft power. In order to encourage the appropriate use of fan pressures, the baseline efficiency is calculated in terms of total efficiency for fans tested with outlet ducts and static efficiency for fans tested with no outlet duct.

Fans tested with ducted discharge:

$$\eta_{t,baseline} = \eta_{t,target} \times \left(\frac{Q}{Q + Q_0}\right)\left(\frac{P_t}{P_t + P_0}\right) \qquad \textbf{Eq. 3}$$

Fans tested without ducted discharge:

$$\eta_{s,baseline} = \eta_{s,target} \times \left(\frac{Q}{Q + Q_0}\right)\left(\frac{P_s}{P_s + P_0}\right) \qquad \textbf{Eq. 4}$$

The values $\eta_{t,target}$ and $\eta_{s,target}$ are constants based on the expected efficiency for very high airflow and pressure applications. Q_0 and P_0 are constants that control how the expected efficiencies are reduced at low airflows and pressures. Note that all pressures shown refer to standard air density. In order to use the equations at other air densities, each of the pressures (P_t, P_s and P_0) must be corrected to the actual density. The resulting power will also be at the actual density.

This baseline efficiency can be plotted to show its relationship to airflow and pressure, as in Figure 1. It can also be shown as a contour surface that increases at high airflow and pressure while approaching the target efficiency, as in Figure 2

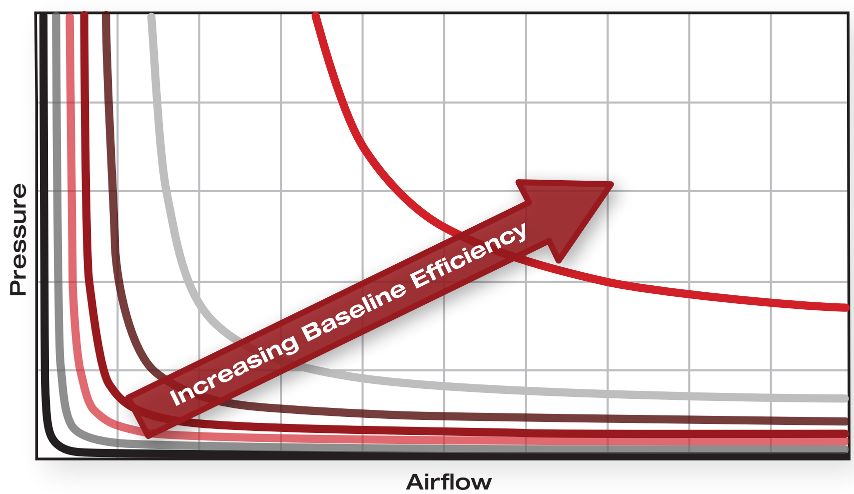


Figure 1. Baseline fan efficiency with lines of constant efficiency varying with airflow and pressure

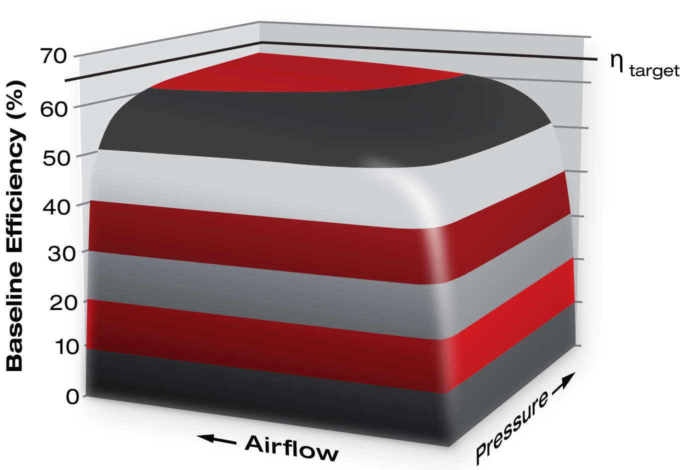


Figure 2. Contour plot of baseline fan efficiency as a function of airflow and pressure. This baseline approaches the target efficiency

	1 in. wg			2 in. wg			3 in. wg			4 in. wg			5 in. wg			6 in. wg		
CFM	**RPM**	**BHP**	**FEI**	**RPM**	**BHP**	**FEI**	**RPM**	**BHP**	**FEI**	**RPM**	**BHP**	**FEI**	**RPM**	**BHP**	**FEI**	**RPM**	**BHP**	**FEI**
6000	830	1.39	1.65	1051	2.79	1.41												
7000	900	1.72	1.55	1092	3.18	1.44	1267	4.83	1.34									
8000	979	2.14	1.41	1142	3.64	1.43	1306	5.41	1.36	1458	7.34	1.30						
9000	1064	2.66	1.28	1209	4.28	1.36	1358	6.13	1.35	1499	8.15	1.31	1633	10.3	1.27			
10000	1152	3.28	1.15	1280	4.95	1.30	1411	6.86	1.34	1550	9.11	1.30	1674	11.3	1.28	1798	13.8	1.25
11000	1242	3.98	1.04	1359	5.79	1.22	1479	7.84	1.28	1597	10.0	1.31	1722	12.5	1.28	1835	14.9	1.27
12000	1336	4.82	0.94	1441	6.73	1.15	1549	8.82	1.24	1660	11.1	1.27	1770	13.6	1.28	1883	16.3	1.26
13000	1431	5.80	0.84	1528	7.86	1.06	1627	10.1	1.18	1728	12.4	1.23	1828	14.9	1.26	1932	17.6	1.26
14000	1527	6.94	0.76	1617	9.09	0.99	1707	11.3	1.12	1799	13.8	1.19	1897	16.6	1.22	1987	19.1	1.25
15000	1625	8.23	0.68	1706	10.4	0.92	1791	12.8	1.06	1878	15.5	1.14	1964	18.1	1.20	2054	21.1	1.21
16000	1724	9.68	0.62	1798	12.0	0.86	1879	14.6	1.00	1957	17.2	1.09	2038	20.0	1.16			
17000	1823	11.3	0.56	1892	13.7	0.80	1967	16.4	0.94	2041	19.1	1.04						
18000	1923	13.1	0.51	1986	15.6	0.74	2056	18.4	0.89									

Selections highlighted in gray indicate FEI ≥ 1.0

Non-highlighted selections indicate FEI < 1.0

Figure 3. Fan selection tables commonly found in product catalogs showing FEI levels at each point

Fan Size (in.)	Fan Speed (rpm)	Fan Power (bhp)	Fan Total Efficiency	Electric Input Power (kW)	Overall Fan Efficiency	Baseline Input Power (kW)	Baseline Overall Total Efficiency	FEI
18	3238	11.8	40.1%	10.4	33.9%	7.01	50.3%	0.67
20	2561	9.56	49.5%	8.38	42.1%	7.01	50.3%	0.84
22	1983	8.02	59.0%	7.04	50.1%	7.01	50.3%	0.99
24	1579	6.84	69.1%	6.00	58.8%	7.01	50.3%	1.17
27	1289	6.24	75.8%	5.47	64.5%	7.01	50.3%	1.28
30	1033	5.73	82.5%	5.03	70.1%	7.01	50.3%	1.39
33	887	5.67	83.4%	4.97	71.0%	7.01	50.3%	1.41
36	778	6.01	78.7%	5.27	66.9%	7.01	50.3%	1.33

Selections highlighted in gray indicate FEI ≥ 1.0

All fans selected for 10,000 CFM at 3.0” Pt

Figure 4. Fan selection page of an electronic catalog for a single point of operation. Note that FEI is inversely proportional to fan power

BASELINE POWER CALCULATION

The baseline power of Equation 2 starts with a calculation of the baseline fan shaft power. This can be calculated from the general equation for fan efficiency at the same airflow and pressure:

$$\eta = \frac{Q \times P}{6343 \times H} \quad \text{or} \quad H = \frac{Q \times P}{6343 \times \eta}$$

In these equations, *H* is fan shaft input power (bhp in I-P units, kW in SI units) at standard density, and the constant *6343* is omitted when using SI units.

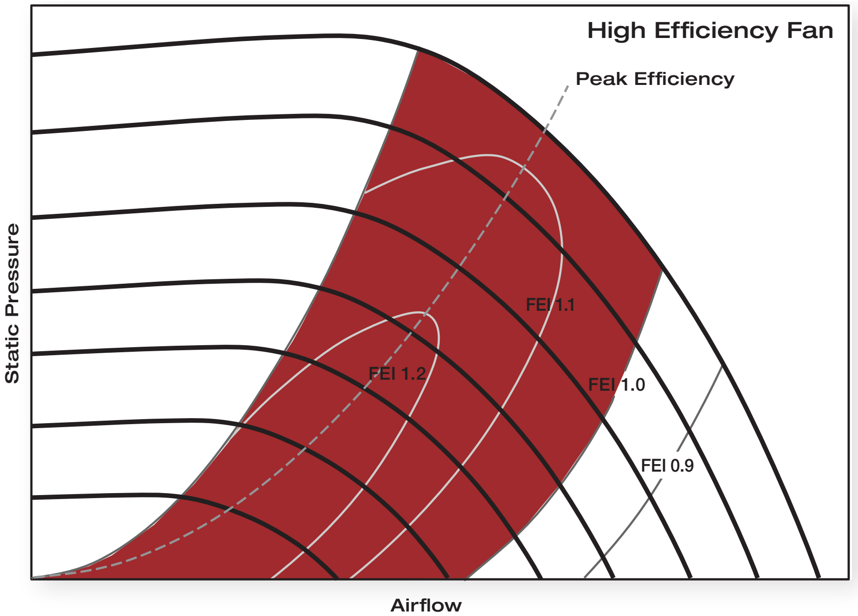
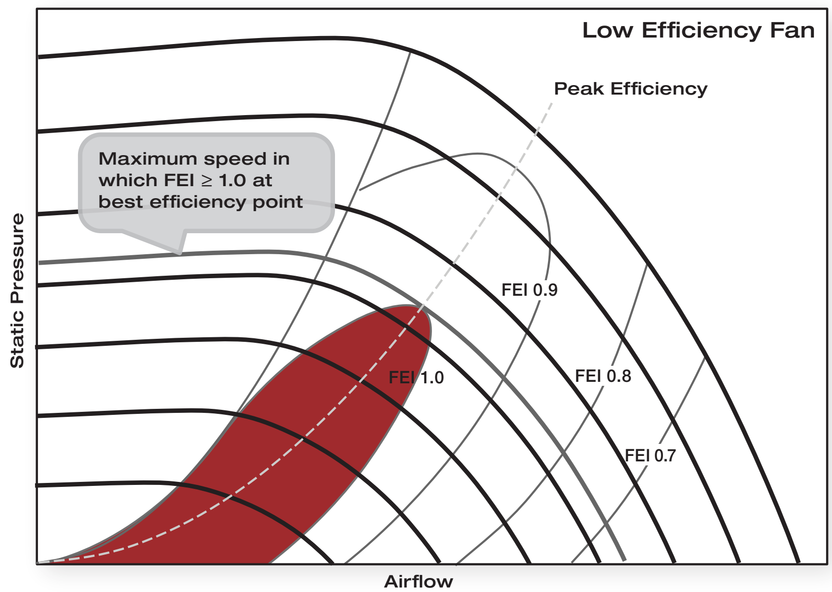


Figure 5. Multiple speed fan curves for a high efficiency fan have a large allowable selection range (FEI ≥ 1)

Figure 6. Multiple speed fan curves for a low efficiency fan have a smaller allowable selection range (FEI ≥ 1).



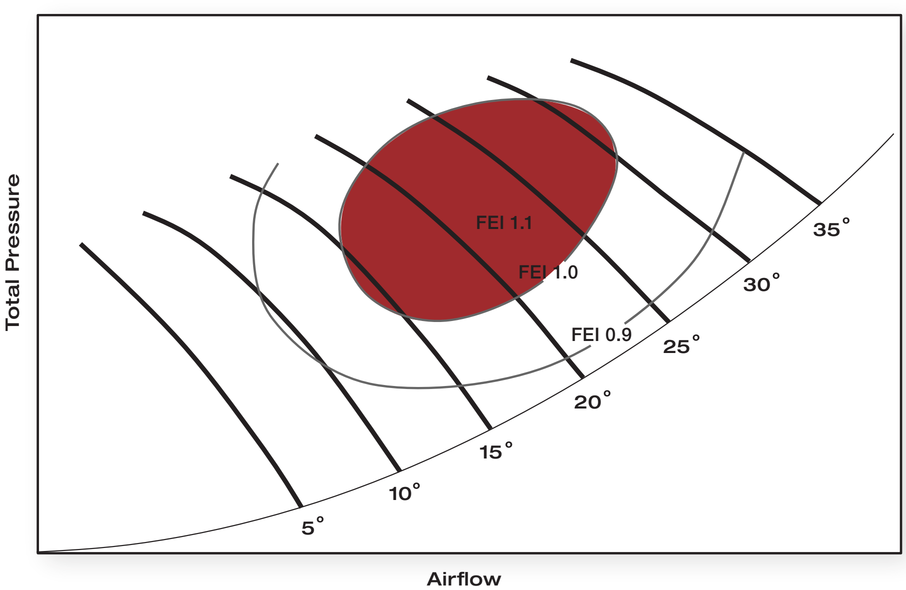


Figure 7. Concentric FEI *curves for adjustable pitch axial fans show highest efficiency areas and allowable selection range (FEI ≥ 1)*

By combining the baseline efficiency of Equations 3 and 4 into the general equation for fan efficiency, the baseline fan shaft power can be calculated as follows:

For fans tested with ducted discharge:

$$H_{baseline} = \frac{(Q + Q_0)(P_t + P_0)}{6343 \times \eta_{t,target}} \qquad \textbf{Eq. 5}$$

For fans tested without a ducted discharge:

$$H_{baseline} = \frac{(Q + Q_0)(P_s + P_0)}{6343 \times \eta_{s,target}} \qquad \textbf{Eq. 6}$$

Again, the conversion constant *6343* is not used with SI units.

Figure 3 is a fan selection table that would be found in a product catalog. FEI values greater than 1.0 would be clearly differentiated from those less than 1.0 in order to direct customers to proper selections. Figure 4 shows how this differentiation could look on the fan selection page of an electronic catalog.

Families of fan curves are also useful during fan selection. Figures 5 and 6 show multiple speed fan curves for fans with high and low efficiency levels. In these figures, higher FEI levels occur closer to the peak fan efficiency.

Finally, Figure 7 shows how adjustable pitch axial fans have FEI levels that form concentric curves.

WIRE-TO-AIR CONCEPT

In order to address the electrical energy consumed by the fan and drive, the fan energy index is expressed in terms of electrical input power and overall fan efficiency. Figure 8, taken from the 2016 edition of ANSI/AMCA Standard 210, shows how the power flows into the fan:

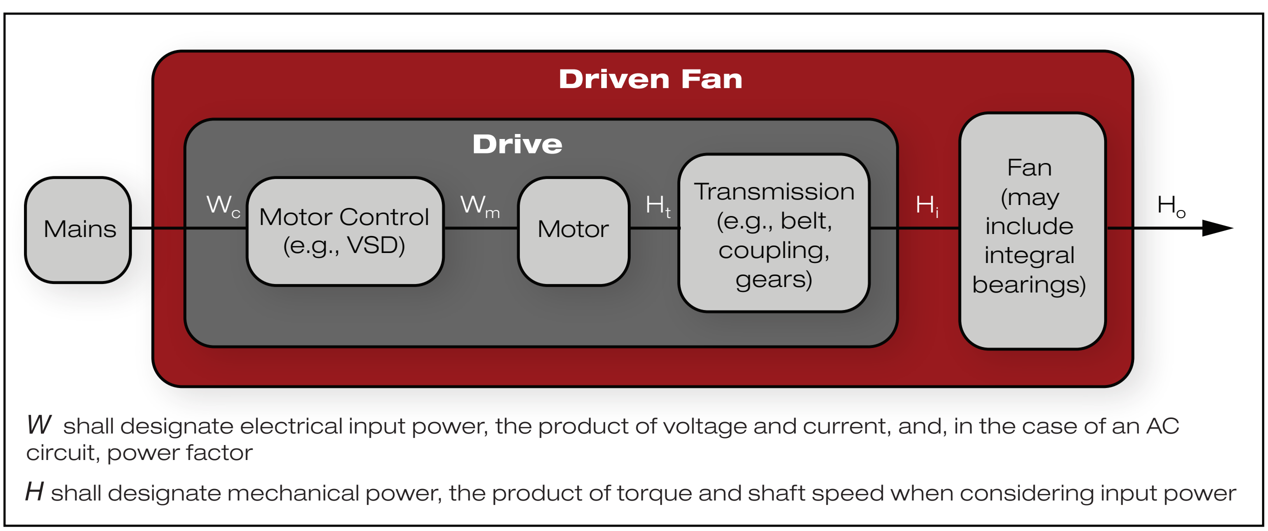


Figure 8. Power flow into fan and identification of losses associated with each component

The general definition of FEI from equations 1 and 2 can more accurately be expressed in terms of overall wire-to-air efficiency of the driven fan system (Equation 7) and electrical power input to the driven fan (Equation 8):

$$\text{FEI} = \frac{\text{Overall Fan Efficiency}}{\text{Baseline Overall Fan Efficiency}} \qquad \textbf{Eq. 7}$$

$$\text{FEI} = \frac{\text{Baseline Electrical Input Power}}{\text{Fan Electrical Input Power}} \qquad \textbf{Eq. 8}$$

These overall values can either be measured using electrical input power or they can be calculated from the combination of individual components:

$$\text{Overall Efficiency} = \text{Fan Efficiency} \times \text{Trans Efficiency} \times \text{Motor Efficiency} \times \text{Controller Efficiency}$$

$$\text{Overall Input Power} = \text{Fan Shaft Power} + \text{Trans Loss} + \text{Motor Loss} + \text{Controller Loss}$$

In practical terms, this equation can also be shown using component efficiencies:

$$\text{Overall Input Power} = \text{Fan Shaft Power} \times \frac{1}{\text{Trans Efficiency}} \times \frac{1}{\text{Motor Efficiency}} \times \frac{1}{\text{Controller Efficiency}}$$

The baseline electrical input power, $W_{baseline,}$ is calculated from the baseline power of Equations 5 and 6 and a baseline drive system efficiency:

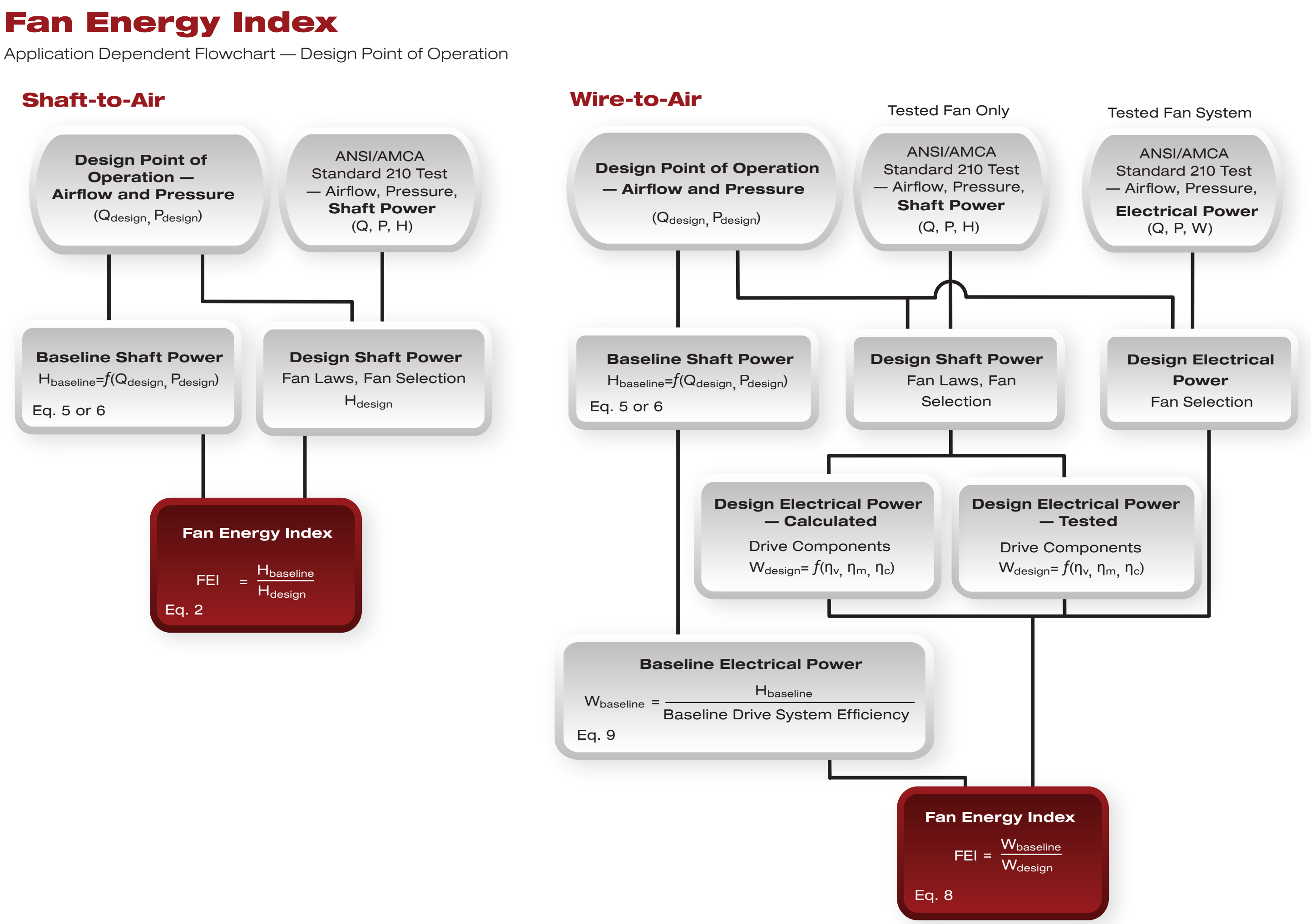
$$W_{baseline} = \frac{H_{baseline}}{\text{Baseline Drive System Efficiency}} \qquad \textbf{Eq. 9}$$

The baseline drive system efficiency covers all drive components, including the motor and belt drives or speed controllers, if used. This factor is not intended to predict the actual efficiency of the specific drive components used; however, it is established based on reasonable efficiencies of typical components. This baseline is a simple equation of drive efficiency as a function of shaft power. Since the same baseline is used for both belt and direct driven fans, and since the actual drive efficiency for a direct driven fan will normally exceed that of a belt drive, a direct drive fan will have a higher FEI than an equivalent belt driven fan.

Fan electrical input power as determined in an ANSI/AMCA Standard 210 test or as calculated in AMCA Publication 207, at any point of operation, can be compared to this baseline power at the same point of operation using Equation 8 to calculate the FEI. The value of FEI will vary for each point on the fan curve. It will also vary with fan speed.

It is important to note that the baseline drive efficiency is the same whether or not the fan has a motor speed controller. The use of a motor speed controller or inlet vanes will always decrease the overall drive efficiency at full speed (and decrease the calculated FEI), yet the use of fan speed control or inlet vanes will always result in significant energy savings at part loads. No attempt is made to arbitrarily increase the FEI for fans with speed controllers or inlet vanes. The potential energy savings with speed control will be evaluated by the DOE and code and rebate authorities. Minimum FEI values for fans with speed control should be set lower by these authorities, based on these potential savings, in order to encourage their use.

Figure 9 was created to assist in the visualization of the FEI calculation process.



CONCLUSION

FEI is a metric that allows many different types of fans to be compared on equal footing, and it does so by concentrating on the energy consumed by a fan as it is applied. It can be used by regulators and purchasers alike to make a price-sensitive market favor true efficiency, helping consumers see how a fan can be affordable and efficient at the same time. Additionally, the FEI can provide manufacturers with concrete assurance they are creating energy-saving products that will appeal to their customers. It is an all-encompassing, high level solution to a complex problem.

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