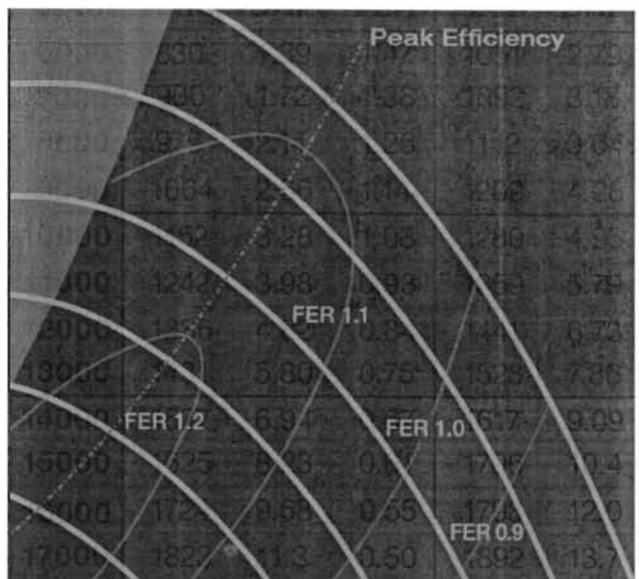

Introducing Fan Efficiency Ratios

An AMCA International Whitepaper

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Introducing Fan Efficiency Ratios

ABSTRACT

This document introduces the fan efficiency ratio (FER), an energy efficiency metric developed by AMCA International. This metric is a ratio of the actual fan efficiency to a baseline fan efficiency, both calculated at a given airflow and pressure point. The FER 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 at design airflow and pressure. The FER can also be used as an application-independent metric when design conditions are not known because it allows the consideration of a single point of rating condition, such as the peak efficiency point.

INTRODUCTION

Fan energy consumption is receiving much attention worldwide. Europe has implemented fan efficiency regulation and is ratcheting up its requirements. China, Malaysia and Taiwan have also implemented fan efficiency requirements. Other countries are considering alternatives. The U.S. Department of Energy (DOE) is working toward the regulation of fan efficiency, while public utilities and code bodies are also looking for ways to drive measurable reductions in fan energy use. AMCA, as an advisor to interested parties worldwide, plays a key role in establishing appropriate fan efficiency metrics. As part of a continuing effort to create metrics that can be used to drive fan energy use down, AMCA has developed the FER, which addresses both fan design and fan application.

Regulators can use the FER to improve the efficiency of fan designs and limit market availability of less efficient fans. Utility companies can use it to establish rebate programs that incentivize the efficient application of fans, and code bodies can use the FER to drive building owners and contractors toward using more energy-efficient fans for ventilation and process applications. Purchasing agents also can use the FER to evaluate fan selections and their suitability for specific applications.

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 toward smaller fans with a lower first cost. This market dynamic works against the effectiveness of regulations that focus on raising fan peak efficiency requirements. If minimum peak efficiency mandates result in higher product cost, then selection and application decisions may shift to compensate. This shift will negate 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 encourage the behaviors desired of 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 is the first thing to be considered. Smaller diameter impellers cannot attain the peak efficiency levels of larger diameter impellers with the same aerodynamic design. This aspect is well-documented and can be addressed in a number of ways. The FEG metric of AMCA Standard 205 relates fan peak efficiency to impeller diameter. The FMEG metric of ISO 12759 takes slightly different approach by relating fan peak efficiency to absorbed input power. The third alternative detailed in this document, FER, relates fan efficiency to both airflow and pressure. An efficiency metric that varies with airflow not only accounts for the size impact but also directly addresses fan selection.

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

Another issue, fan pressure, has an impact on achievable efficiency levels as well. 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. However, these features make fans designed for higher pressure less efficient when applied at low pressures. Other fan efficiency metrics address this issue by varying efficiency requirements based on fan type. The FER metric varies with pressure instead of fan type and can be applied universally, using a single baseline target efficiency, to impact both fan design and fan application. The FER can thus be applied to a broad range of products, encouraging best practices in aerodynamic design.

Proper application of fans also requires the correct use of fan static and total pressure. The industry is currently in a state of confusion on this subject. 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, fans that do not have a duct connected to their discharge should always be selected using fan static pressure, since the velocity pressure cannot be used to overcome system resistance. The FER recognizes the value of velocity pressure in ducted applications and encourages the proper use of fan pressures.

Direct-driven fans offer an obvious improvement in efficiency over belt-driven fans and should be encouraged as a means to save energy. However, belt-driven fans are commonly used because they provide a flexible solution to a number of challenges: matching the fan speed to design conditions; providing a means to modify fan performance in the field; and enabling the use of large, low speed fans when 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. In order to accomplish this, an efficiency metric must be applied to the entire fan, motor and drive from wire to air.

Speed control and inlet vanes also offer energy savings and should be encouraged. Capacity control of fans by changing the speed of the fan wheel saves energy as the cube of the speed reduction. However, when considered in a wire-to-air metric, the use of a speed controller or of inlet vanes will always reduce the efficiency of the fan system at the full load design point. Therefore, some adjustment is warranted — either to the design point efficiency metric or to the required efficiency levels — in order to eliminate this penalty and encourage the use of fan speed control.

The FER takes into account all of these issues. It takes advantage of the large energy savings available from an application-dependent requirement while accommodating the application-independent sales that occur through distributors. It encourages the proper use of fan total pressure for fans applied with outlet ducts while also recognizing that fan static pressure and static efficiency are correct measures to drive energy savings for non-ducted fans. The FER, when used as a wire-to-air metric, also encourages the use of direct-driven fans. But it does so 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, the FER encourages the use of variable speed and inlet vanes, taking advantage of energy savings at reduced fan loads. Finally, the FER discourages the unintended consequences of adverse selection behavior in a market driven by first cost.

HIGH-LEVEL SOLUTION

The FER is an alternative to other metrics available 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 with a different minimum peak efficiency requirement for each product category. Because operating efficiency is 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 each of the various fan types, the FER establishes a baseline efficiency that varies with both airflow and pressure. This baseline efficiency represents a reasonable efficiency level that can be 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 for customers, owners, regulatory bodies and utility rebate programs to use.

With this baseline efficiency established for all fan types and applications, the simple FER carries significant value. For a given application (airflow and pressure), different fan types and sizes can be compared using the same baseline. An FER equal to one means the actual fan efficiency meets the baseline efficiency. An FER greater than one means the fan efficiency exceeds the baseline, while an FER less than one does not meet the baseline. A higher value FER 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 FER requirement. However, there may be exceptions to this. For example, fans used for variable air volume systems should have a lower FER requirement to encourage their use. Fans used infrequently as emergency fans or fans used for material handling could also have lower FER requirements. On the other hand, stretch codes or utility rebate programs could have a higher FER requirement. It is also expected that minimum FER requirements will increase over time as fan technology improves.

The FER can either be used to assess the efficiency of the fan alone, or it can be applied to the driven fan (extended product or fan-motor-drive system). The calculation method of AMCA Standard 207 and the measurement method of AMCA Standard 210 are available to establish the FER as a wire-to-air metric. While code authorities and the DOE will establish minimum FER 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 FER level meets the minimum requirement.

INDUSTRY BENEFITS

The FER is designed to address the wide variability in efficiency of every fan. It does so by concentrating on the energy consumed by a fan as it is applied — at the design point of operation. By focusing on the application, the FER can effectively impact both the fan design and the fan selection. For example, to meet an energy efficiency goal at 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 principally concerned about first cost) will actually force manufacturers to design products that are more efficient and cost effective.

While driving significant energy savings and technological improvements, the FER will also teach proper fan selection. Every source used by a fan consumer to make a fan selection— performance tables, fan curves or electronic selection software — will show the FER value for that selection. Consumers will know immediately how their fan selection compares to the minimum allowable fan efficiency. They will also see how the energy consumption of one product compares to another, regardless of product type, category or drive method.

Even though the FER was developed to focus on fan efficiency as applied, it can also be used as an application-independent metric when the design operating point is not known. In this case, the FER 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 fan efficiency ratio is this:

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

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

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

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 input power, there is a solution for baseline power (and the resulting FER), even at zero pressure.

The FER can either refer to shaft power and traditional fan efficiency, or it can refer to electrical input to a driven fan and overall fan efficiency (wire to air). In this document, the subscripts *H* and *W* shall indicate shaft power and electrical power, respectively. First, the FER_H for the fan alone will be described. Later, the FER_W for the driven fan will be covered.

BASELINE EFFICIENCY CALCULATION

In order to encourage the appropriate use of fan pressures, the baseline efficiency is calculated in terms of total efficiency for fans 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.

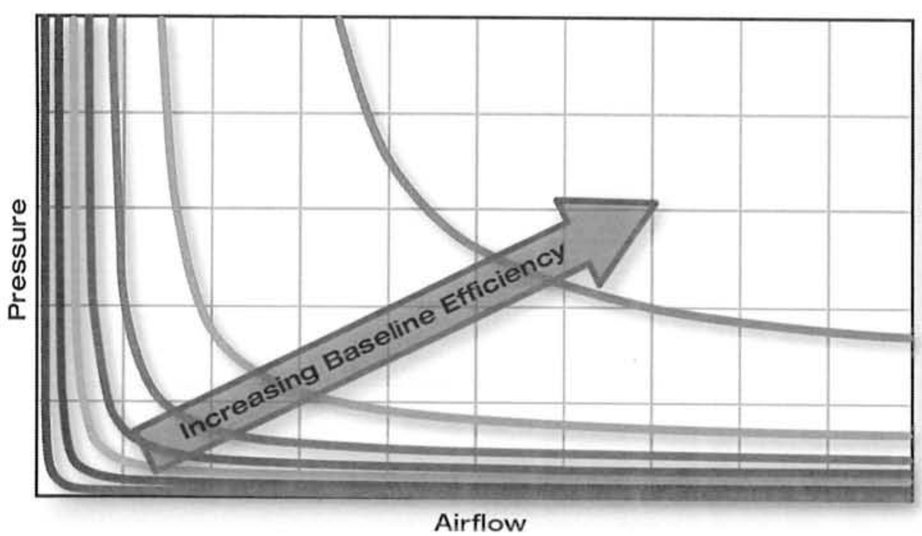


Figure 1. Baseline fan efficiency with lines of constant efficiency varying with airflow and pressure

The baseline efficiency can also be shown as a contour surface that increases at high airflow and pressure while approaching the target efficiency, as in Figure 2.

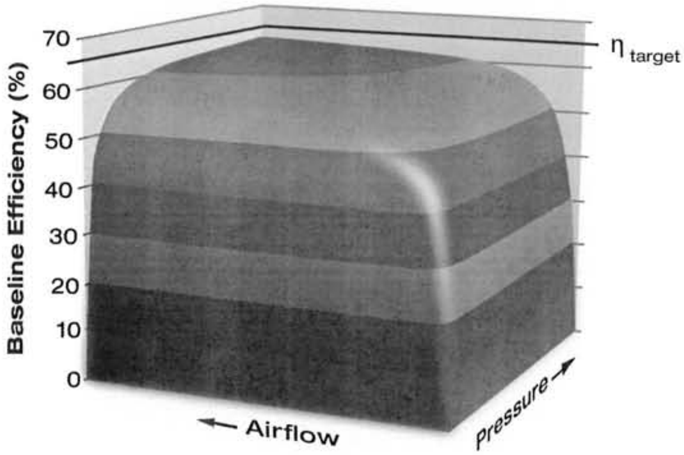


Figure 2. Contour plot of baseline fan efficiency as a function of airflow and pressure. This baseline approaches but never reaches the target efficiency

BASELINE POWER CALCULATION

The baseline power of Equation 2 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.

By combining the baseline efficiency of Equations 3 and 4 into the general equation for fan efficiency, the baseline 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.

Fan mechanical input power (as determined in an AMCA Standard 210 test) at any point of operation can be compared to this baseline power at the same point of operation using Equation 2 to calculate the FER_H. Note that the FER_H will vary for each point on the fan curve. It will also vary with fan speed. Figures 3–7 provide visual examples of this.

	1 in. wg			2 in. wg			3 in. wg			4 in. wg			5 in. wg			6 in. wg		
CFM	**RPM**	**BHP**	**FER**	**RPM**	**BHP**	**FER**	**RPM**	**BHP**	**FER**	**RPM**	**BHP**	**FER**	**RPM**	**BHP**	**FER**	**RPM**	**BHP**	**FER**
6000	830	1.39	1.47	1051	2.79	1.33												
7000	900	1.72	1.38	1092	3.18	1.35	1267	4.83	1.28									
8000	979	2.14	1.26	1142	3.64	1.34	1306	5.41	1.30	1458	7.34	1.25						
9000	1064	2.66	1.14	1209	4.28	1.28	1358	6.13	1.29	1499	8.15	1.27	1633	10.3	1.23			
10000	1152	3.28	1.03	1280	4.95	1.22	1411	6.86	1.28	1550	9.11	1.26	1674	11.3	1.25	1798	13.8	1.22
11000	1242	3.98	0.93	1359	5.79	1.15	1479	7.84	1.22	1597	10.0	1.26	1722	12.5	1.24	1835	14.9	1.24
12000	1336	4.82	0.84	1441	6.73	1.08	1549	8.82	1.19	1660	11.1	1.23	1770	13.6	1.25	1883	16.3	1.23
13000	1431	5.80	0.75	1528	7.86	1.00	1627	10.1	1.13	1728	12.4	1.19	1828	14.9	1.23	1932	17.6	1.23
14000	1527	6.94	0.67	1617	9.09	0.93	1707	11.3	1.07	1799	13.8	1.15	1897	16.6	1.18	1987	19.1	1.22
15000	1625	8.23	0.61	1706	10.4	0.86	1791	12.8	1.01	1878	15.5	1.10	1964	18.1	1.16	2054	21.1	1.19
16000	1724	9.68	0.55	1798	12.0	0.80	1879	14.6	0.95	1957	17.2	1.06	2038	20.0	1.12			
17000	1823	11.3	0.50	1892	13.7	0.75	1967	16.4	0.90	2041	19.1	1.01						
18000	1923	13.1	0.46	1986	15.6	0.69	2056	18.4	0.85									

Selections highlighted in green indicate $FER_H \geq 1.0$ Non-highlighted selections indicate $FER_H < 1.0$

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

Figure 3 is a fan selection table that would be found in a product catalog. FER_H 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.

Fan Size (in.)	Fan Speed (rpm)	Fan Power (bhp)	Total Efficiency	Baseline Power (bhp)	Baseline Total Efficiency	FER_H
18	3238	11.8	40.1%	7.96	59.4%	0.67
20	2561	9.56	49.5%	7.96	59.4%	0.83
22	1983	8.02	59.0%	7.96	59.4%	0.99
24	1579	6.84	69.1%	7.96	59.4%	1.16
27	1289	6.24	75.8%	7.96	59.4%	1.28
30	1033	5.73	82.5%	7.96	59.4%	1.39
33	887	5.67	83.4%	7.96	59.4%	1.40
36	778	6.01	78.7%	7.96	59.4%	1.32

Selections highlighted in green indicate $FER_H \geq 1.0$ 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 FER_H is inversely proportional to fan power

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 FER_H levels occur closer to the peak fan efficiency.

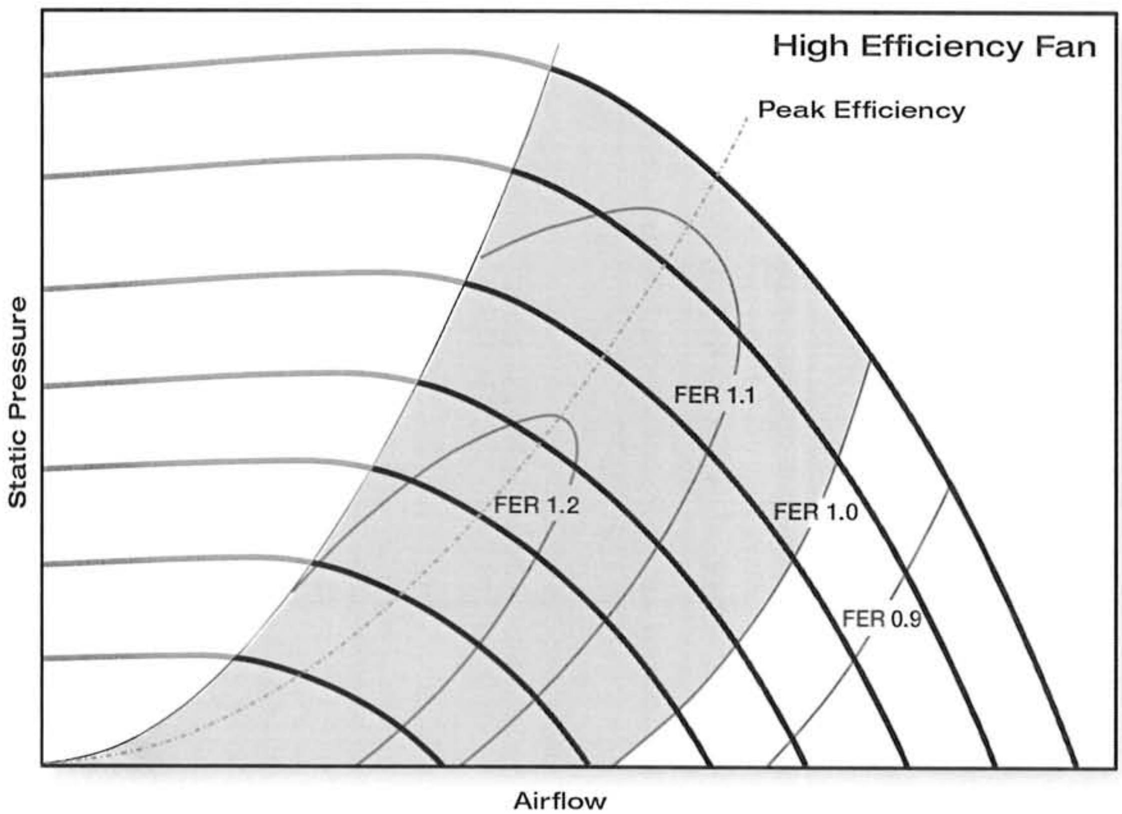


Figure 5. Multiple speed fan curves for a high efficiency fan have a large allowable selection range ($FER_H \geq 1$)

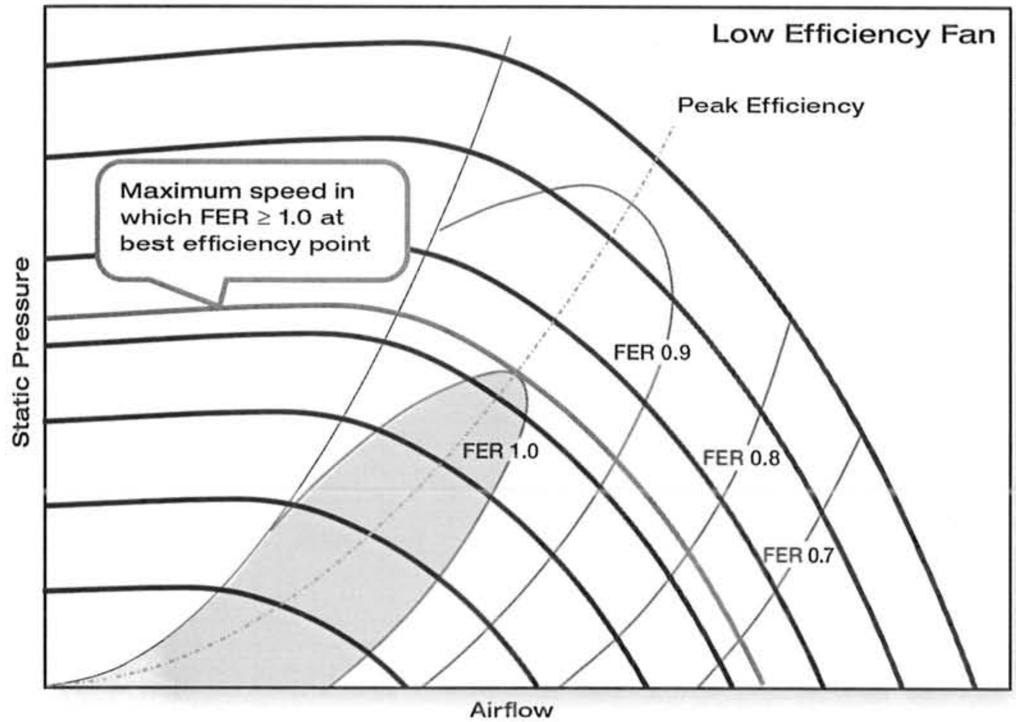


Figure 6. Multiple speed fan curves for a low efficiency fan have a smaller allowable selection range ($FER_H \geq 1$).

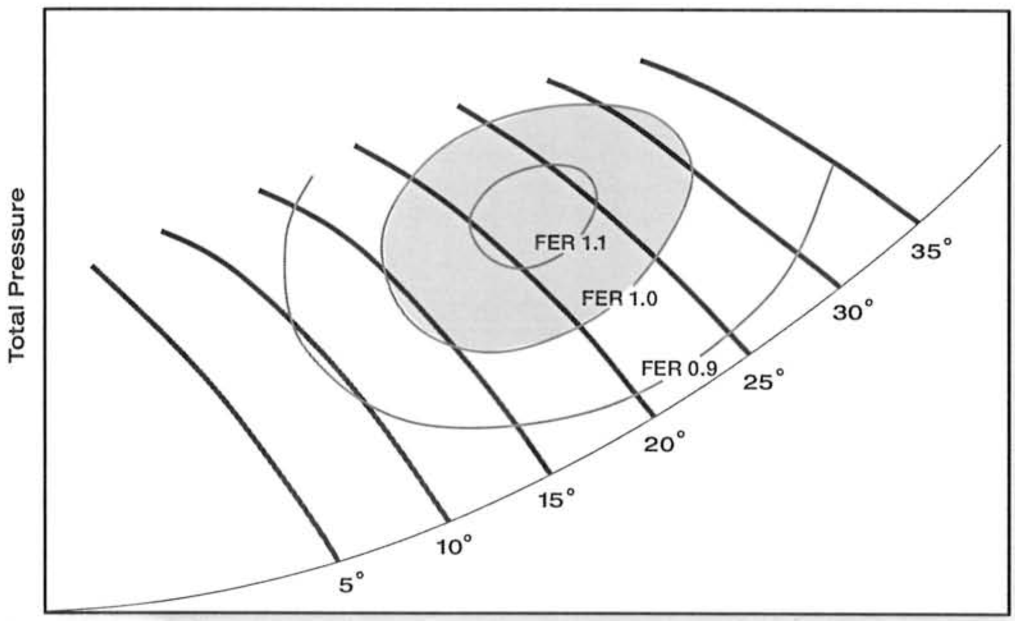
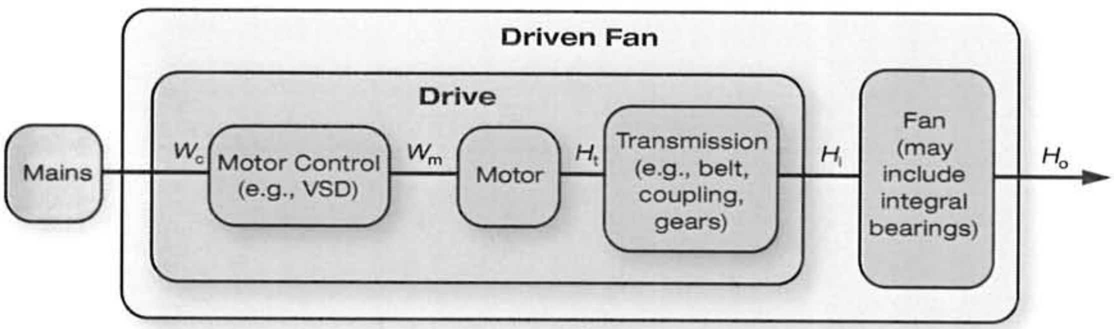


Figure 7. Concentric FER_H curves for adjustable pitch axial fans show highest efficiency areas and allowable selection range ($FER_H \geq 1$)

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

WIRE-TO-AIR CONCEPT

In order to address the electrical energy consumed by the fan and drive, the FER can also be expressed in terms of electrical input power and overall fan efficiency. Figure 8, taken from the current draft of AMCA Standard 210, shows how power flows into a fan.



W shall designate electrical input power, the product of voltage and current, and, in the case of an AC circuit, power factor

H shall designate mechanical power, the product of torque and shaft speed when considering input power

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

The general definition of FER from Equations 1 and 2 becomes a general definition for FER_W when expressed in terms of overall wire-to-air efficiency of the driven fan (Equation 7) and electrical energy input to the driven fan (Equation 8):

$$FER_W = \frac{\text{Driven Fan Efficiency}}{\text{Baseline Driven Fan Efficiency}} \qquad \textbf{Eq. 7}$$

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

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

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

The baseline drive 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 FER_W than an equivalent belt driven fan.

Fan electrical input power (as determined in an AMCA Standard 210 test or as calculated in AMCA Standard 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 FER_W. As with the FER_H, the value of FER_W will vary for each point on the fan curve, and it will 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 FER_W), 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 FER_W for fans with speed controllers or inlet vanes. The potential energy savings with speed control will be evaluated by the DOE, code and rebate authorities. Minimum FER_W 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 FER calculation process.

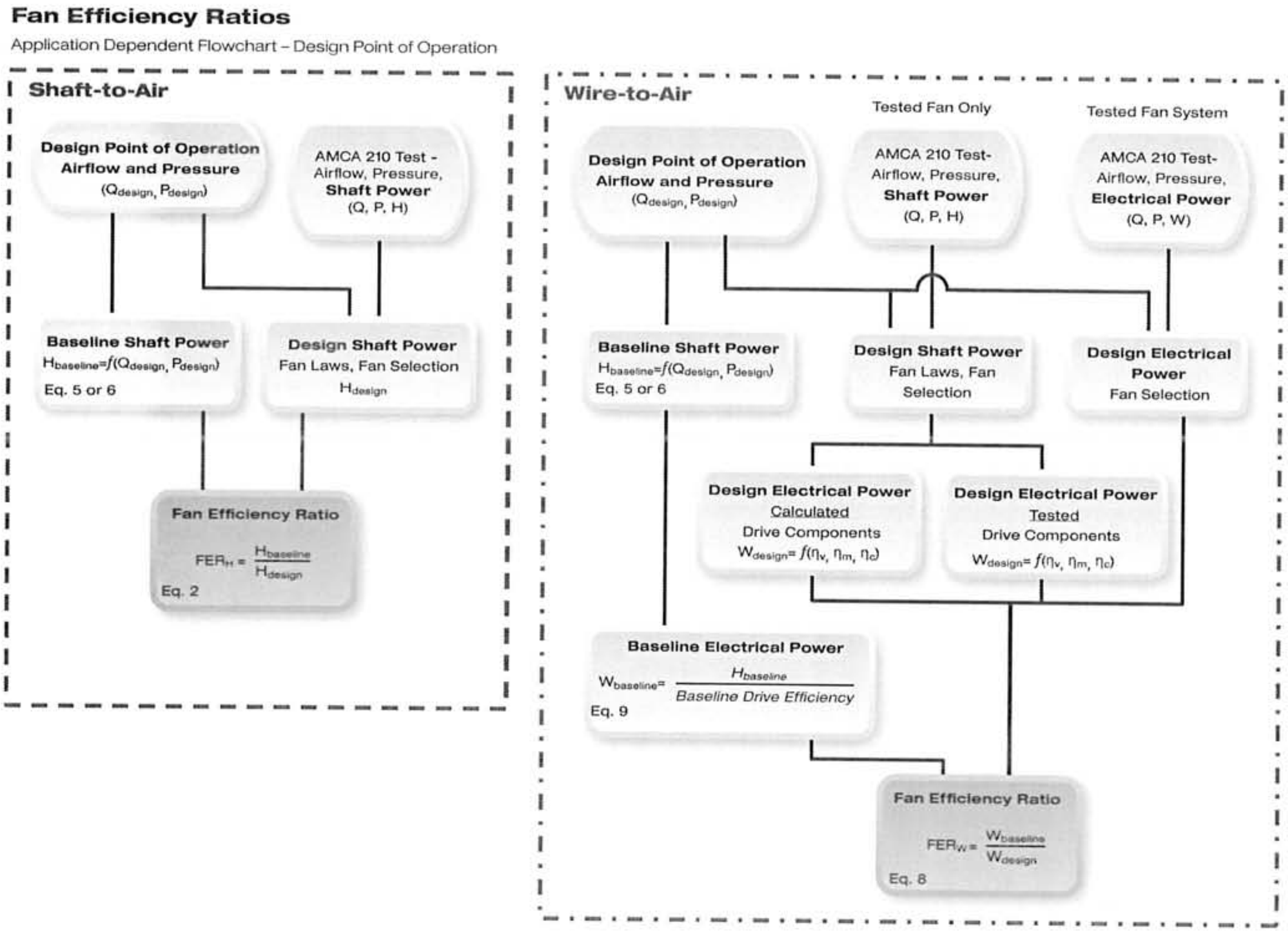


Figure 9. Flowchart of calculation procedures used to determine the fan efficiency ratio at the design point of operation. Both the shaft-to-air FER_H and the wire-to-air FER_W can be calculated from AMCA Standard 210 performance test results

CONCLUSION

The FER 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 FER 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.

REFERENCES

ANSI/AMCA Standard 205. *Energy Efficiency Classification for Fans*. Arlington Hts., IL: AMCA International, 2012.

ISO Standard 12759. *Fans – Energy efficiency classification for fans*. Geneva, Switzerland: International Standards Organization. 2010.

ANSI/AMCA Standard 210–ANSI/ASHRAE 51. *Laboratory Methods of Testing Fans for Aerodynamic Performance Rating*. Arlington Hts., IL: AMCA International, 2007.

BSR/AMCA Standard 207 (Draft). Arlington Hts., IL: AMCA International.