New Efficiency Metric for Fans Enables New Approaches for Efficiency Regulations and Incentives

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Abstract

Since June 2011, the American fan industry has been embarking on the odyssey of being regulated by the U.S. Department of Energy (DOE) for the first time. Nearly six years after the DOE published its intent to regulate fans, DOE has yet to publish a draft test and energy performance labeling procedure or a draft efficiency standard. It is impossible to state at the time of this paper's drafting, what the final rules will look like or when they will be issued.

There have, however, been developments in the rulemaking that provide strong indicators of what many of the key rule components may look like. A public negotiation among stakeholders under a rule-development process known as an ASRAC[1] reached agreement on how fan efficiency will be represented by metrics (FEI and an intermediary metric, Fan Electrical Power – FEP). As planned, an existing fan-test procedure will be the basis for the DOE test procedure [1]. These outcomes were reflected in the third Notice of Data Availability (NODA) published by DOE for the fan rulemaking, which gives Air Movement and Control Association (AMCA) International[2] confidence that the FEI metric has been accepted by DOE [2].

This paper explores and explains some of the innovative regulatory policy and technical recommendations which will maximize the energy savings for this product category, optimize air movement systems in buildings, maintain important customer required product utility, and do so at a reasonable cost and minimal burden to industry and customers.

Introduction

Over the past six years, the DOE fan initiative has initiated the development of relationships between AMCA and its member companies with advocacy organizations, regulators, and other associations. AMCA has worked with these organizations not only on the DOE regulation, but also on rebate programs and energy efficiency education and training.

Most importantly, the exercise has resulted in AMCA and its members developing the Fan Energy Index to replace a metric that will likely be rendered obsolete whether or not the DOE test procedure becomes final. The Fan Efficiency Grade (FEG) metric, which is an efficiency rating calculated in accordance with AMCA Standard 205 Energy Efficiency Classification for Fans [1], is used in model energy codes and standards that collectively have been adopted into at least 11 state energy codes. FEG also is used in fan-efficiency regulations in Taiwan, Thailand, Hong Kong and other Asian countries [3].

FEG has characteristics that may have caused DOE to not adopt an industry standard already so embedded in industry practice. For one thing, FEG is a fan-only metric, which treats only the aerodynamic qualities of the fan without considering the influences of motors and drives. Also, for the FEG to be effective, an application specification based on operating points must be amended to a

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[1] In 2015, DOE initiated Appliance Standards Rulemaking Federal Advisory Committee (ASRAC) to discuss negotiated energy conservation standards and test procedure for fans. For more information about ASRAC, visit http://tinyurl.com/l8cc4h5.

[2] AMCA International a not-for-profit manufacturers association based in Arlington Heights, Illinois. AMCA's member companies manufacture fans, dampers, louvers, air curtains, and other air-system products for residential, commercial, and industrial applications.

FEG charging statement that could not be used by DOE for a product regulation. For example, “Fans must have a minimum FEG 67 rating and be sized and selected to operate within 15 percentage points of the fan’s peak total efficiency. [4]” Finally, because FEG is based on Fan Total Pressure, it is not practical for un-ducted fans, which are sized/selected using Fan Static Pressure. This condition has forced exemptions for these fan types in existing codes and standards provisions [4].
The new metric, Fan Energy Index (FEI), is very different from FEG in many important ways, and by its nature, FEI stands to revolutionize how fans are regulated. Unlike FEG, FEI is a wire-to-air metric consistent with the regulatory approaches being taken for other motor-driven loads, such as pumps and air compressors. FEI also has the “sizing and selection” clause baked into the metric in a manner acceptable by DOE [5].

With these basic conditions in place, FEI stands to revolutionize how fans are sized, selected, and specified by practitioners. In fact, the rationale behind the development of FEI is consistent with “extended product” approach for regulating motor-driven equipment used in Europe Commission regulations for other DOE regulations. FEI takes this further by adding application-based parameters to the energy-savings opportunity, which possibly introduces new regulatory approaches to other equipment, as well.

This innovation has occurred because 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 performance curves. Fan application and selection is therefore far more influential than peak fan efficiency in determining the actual energy consumed by a fan. Unlike, for example, an incandescent light bulb, a fan that is least efficient in some applications may be the most efficient fan in other applications.

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. This establishes a “range of compliant operations” rather than a single-point pass/fail efficiency threshold. Contrary to an aim to eliminate “inefficient models,” the FEI metric seeks to eliminate “inefficient selections. [6]”

In the absence of a DOE test procedure, the FEI metric is currently being formalized in a rating standard by AMCA International, and concurrently being formalized in the ISO standard for fan efficiency. The harmonized AMCA and ISO FEI rating standards will prescribe how a FEI rating is calculated from data taken during performance-rating tests in accordance with AMCA and ISO standards. When finalized by DOE, FEI will eventually replace existing fan efficiency metrics in US model energy codes and standards. FEI already is being considered for utility incentive programs [6].

A Brief History of Fan Efficiency Metrics and Regulations

Although fans have existed for centuries, it wasn’t until the 2007 timeframe that their energy efficiency entered the regulatory spotlight. The early thinking on fan efficiency regulations was to impose a minimum efficiency performance of 65% on fans. However, that would eliminate many fans on the market approximately 20-inches in diameter or smaller (Figure 1) [4]. This is because manufacturing constraints and the influence of bearings have a larger proportional impact on smaller fan sizes. After 20-inches, efficiencies tend to stabilize.

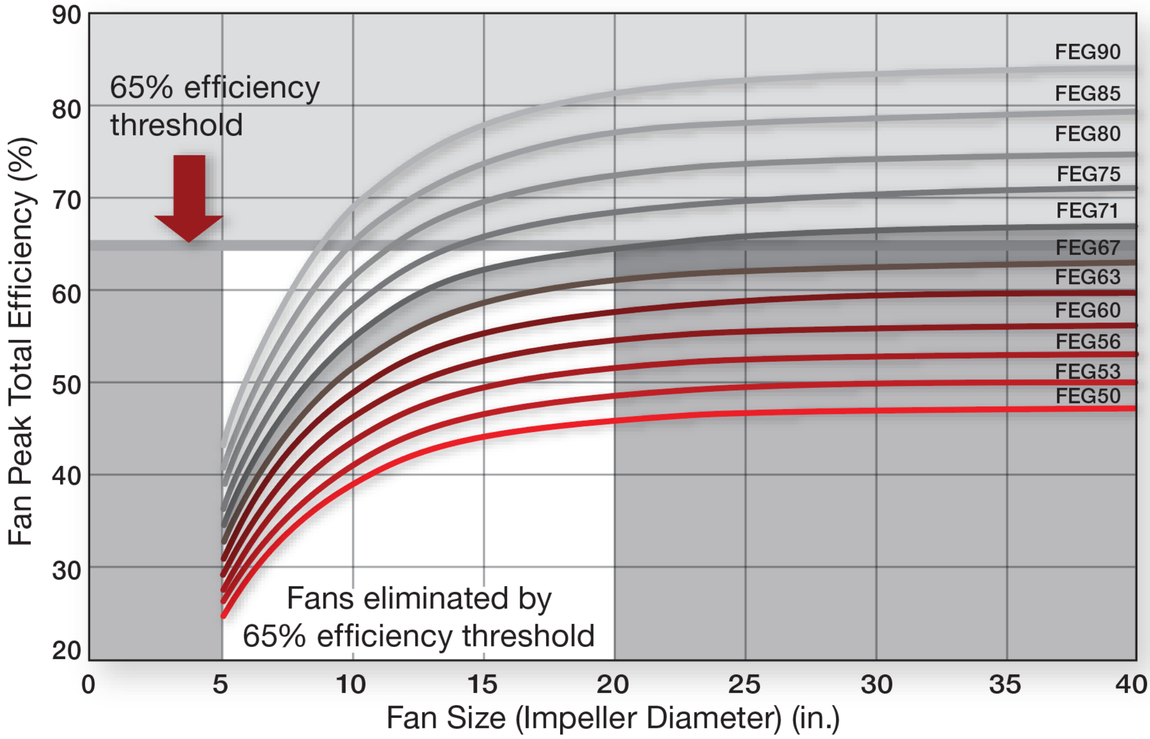

Figure 1: FEG ratings with sizing/selection window used to limit fan selections to larger sizes. FEG curves were developed from numerical analysis of fan data from manufacturers around the world. The 65% efficiency threshold was a starting point for energy standards but was removed because it eliminated fan selections below 20-in. diameter.

The FEG metric was designed around this characteristic of fans. Using numerical analysis on fan test data from a variety of manufacturers around the world and covering different fan types and sizes, FEG curves were developed to provide an index that remains constant over the fan sizes. These curves apply to fan types and sizes where a peak total efficiency can be calculated [7]. FEG curves, and associated mathematical equations embodied in AMCA 205 and ISO 12759 [8] can be used by fan manufacturers to calculate FEG ratings and by regulators to set minimum FEG requirements.

U.S. and European standards bodies worked jointly to develop the Fan Efficiency Grade metric, which was defined in rating standards published in 2010. ISO 12759 defines how to calculate FEG values from data taken during fan-rating tests. ISO 12759 also defines the Fan Motor Efficiency Grade (FMEG) metric. The difference between the two metrics is that FMEG includes the influences of motors and drives in the overall fan efficiency rating while FEG only covers the aerodynamic qualities of a "bare shaft" fan, i.e., without motors and drives. [9].

The differences in rating metrics presaged differences in regulatory approaches. ISO 12759 became the basis for the European Commission's federal fan-efficiency regulation, EC 327, which took effect in January 2012 [10]. Beginning in 2012, AMCA 205 became the basis for fan-efficiency provisions appearing in all U.S.-based model energy codes and standards: International Green Construction Code (2012) [11], ASHRAE 90.1 (2013) [12], ASHRAE 189.1 (2014) [13], and the International Energy Conservation Code (IECC) (2015) [14].

The FEG provision remains in the subsequent editions of each of these publications, and is slowly making its way into state energy codes. To date, AMCA is aware of 11 states that have FEG-based fan-efficiency provisions by adopting model codes and standards[3]. FMEG remains in effect in Europe, with a revision underway that will not fundamentally change the metric being used [15].

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[3] FEG uptake into state energy codes is coming through gradual adoption of the 2015 edition of International Energy Conservation Code and ASHRAE 90.1-2013. AMCA looked at the state-by-state adoption record of these editions at Building Codes Assistance Project (BCAP at

DOE initiated the rulemaking for commercial and industrial blowers (CIFB) in June 2011 [16], well after the path had been set for FEG in model codes and standards. The fate of FEG being a short-term metric was effectively sealed in February 2013, when DOE published its Framework Document for the fan rulemaking [17]. The Framework Document signaled DOE's preference for a wire-to-air metric like FMEG, which was consistent with how DOE concurrently was working on a regulation for electric pumps, i.e., with a water-to-air metric.

A significant problem with FEG is that the metric alone is not sufficient to establish energy-saving regulations or code provisions. This is due to a characteristic about FEG – as mentioned earlier, by design, FEG ratings remain constant across different sizes of the same model even though fan efficiency varies with fan diameter for a given operating point (Figure 1). Hence, a manufacturer's hypothetical fan Model #123 with an FEG rating of 67 would have an FEG 67 across all its sizes. Thus, when an engineer is selecting a fan for a given application, the sizing/selection software would provide an array of sizes to select from - from, say, 18-inch (460 mm) diameter to 36-inch (920 mm) diameter (Table 1) [18].

As shown in Table 1, the fans of smaller diameter operate much less efficiently than fans of larger diameters to meet the airflow requirements at a given pressure. The airflow at a specific air pressure defines the fan's "duty point" for fan selection on a fan curve (Figure 2).

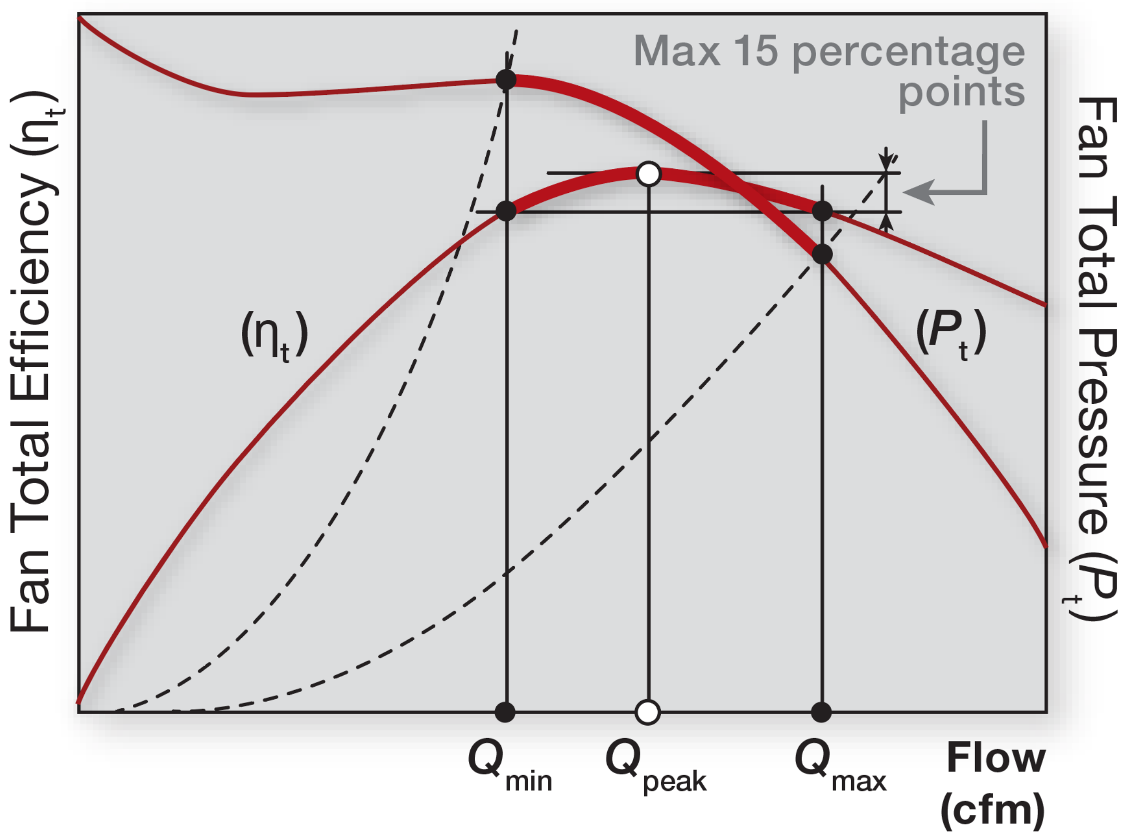

Figure 2. Typical fan curve showing total efficiency vs airflow vs total pressure. The sizing/selection window of 15 percentage points also is showing, which is applied during the design phase to lead toward higher-efficiency fan selections.

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http://bcapcodes.org/code-status/state/ and examined the published state codes to ensure the FEG provision carried through the adoption process.

Thus, to nudge engineers toward selecting a larger fan, FEG-based code provisions must include a clause to limit fan operating points to be "within 15 percentage points of the fans peak total efficiency" (Figure 2) [19]. This clause makes FEG-based provisions more difficult to enforce because labels alone cannot be used for compliance. Code officials must go back to engineering submittals to verify the sizing/selection window is met. FEI, however, as will be shown later, has the operating point characteristics built into the calculation, so compliance officials for any program, code, or regulation need only check the FEI rating on the label [6].

Table 1: Example Impact of Fan Size on Annual Power Consumption and Operating Cost*

Diameter (in.) [mm]	FEG Rating	Total Efficiency (%)	Operating Power (hp) [kW]	Price ($)	Operating Cost Per Year ($)	Weight (lbs) [kg]
36 [920]	85	56	114 [85]	21,200	37,797	2,330 [1,056]
40 [1016]	85	62	90 [67]	16,100	29,939	2,850 [1,293]
44 [1118]	85	68	74 [55]	16,900	24,402	3,570 [1,619]
49 [1245]	85	77	60 [45]	17,600	19,926	4,170 [1,891]
54 [1372]	85	78	56 [42]	20,300	18,401	5,200 [2,359]
60 [1524]	85	81	51 [38]	23,800	16,976	6,310 [2,862]

*Data courtesy of Greenheck

Table 1 shows the output of a manufacturer's sizing/selection program for a double-width, double-inlet fan sized/selected for 80,000 cfm (37,755 l/s) at 3-in. (747 pa) static pressure. The operating costs are based on a run time of 16 hours per day, 250 days per year, and electricity cost of $0.10 per kWh. The $7,700 price differential for the larger fan is paid for in less than one year from reduced electrical costs of approximately $12,960 per year.

Table 2: Example Data Comparing FEG with FEI for Multiple Sizes of the Same Fan Model

Fan Size [in.] (mm)	Fan Speed (rpm)	Fan Power (bhp) [kW]	Actual Total Efficiency (%)	Baseline Power	FEG	FEI
18 (460)	3,238	11.8 [8.8]	40.1	7.96	85	0.67
20 (510)	2,561	9.6 [7.2]	49.5	7.96	85	0.83
22 (560)	1,983	8.0 [6.0]	59.0	7.96	85	0.99
24 (610)	1,579	6.8 [5.0]	69.1	7.96	85	1.16
27 (685)	1,289	6.2 [4.6]	75.8	7.96	85	1.28
30 (770)	1,033	5.7 [4.3]	82.5	7.96	85	1.39
36 (920)	778	6.0 [4.5]	78.7	7.96	85	1.32

Fan sizing/selection data for a FEI increases with fan size for a given baseline power requirement while FEG remains the same. Design point is 10,000 cfm (4,719 l/s) at 3.0-in. (747 pascal) total pressure.

Introducing FEI

From the ASRAC Term Sheet, FEI is calculated as the ratio of the actual fan efficiency to a baseline fan efficiency (Equation 1), 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 (Equation 2).

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

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

Equation 2 is equivalent to Equation 1, but because the goal of mandatory and voluntary programs is to reduce wasted energy, Equation 2 is preferred because reducing electrical power consumption has more relevancy than simply increasing energy efficiency. Equation 2 also is easier to apply and has the added benefit of working along the entire fan curve.

Equation 2 suggests that there is an intermediary calculation leading to FEI which is the measurement or calculation of Fan Electrical Power (FEP). FEP is obtained either by directly measuring fan electrical input power during rating tests, or FEP is calculated by measuring fan shaft power and incorporating default values for motors and drives [1]. The default values are defined in AMCA Standard 207 Fan System Efficiency and Fan System Input Power Calculation [20], which currently is in press. Fan rating tests can be conducted using ANSI AMCA Standard 210 Laboratory Methods of Testing Fans for Aerodynamic Performance Rating [21], which the ASRAC fan working group agreed to being the basis of the DOE test standard per the ASRAC Term Sheet [1].

Once the FEP rating of a fan is known, it is compared against the baseline FEP, called FEP_{std} as shown in Equation 3. Note that FEP has engineering units of kW, which cancel out when FEI is calculated.

$$FEI = \frac{FEP_{std}}{FEP\ rating} \qquad \text{Eq. 3}$$

Table 3 shows how FEI can used for regulations and voluntary incentive programs [5].

Table 3: How FEI can be applied in regulatory and voluntary programs.

Fan Regulatory or Voluntary Program Body	Possible FEI Requirement
U.S. Department of Energy	FEI ≥ 1.0 at Design Point
ASHRAE 90.1 or International Energy Conservation Code	FEI ≥ 1.0 at Design Point
ASHRAE 189.1	FEI ≥ 1.1 at Design Point
Utility Incentive Programs	FEI ≥ 1.1 at Design Point

A useful characteristic of FEI is that for FEI ratings greater than one, the amount of energy savings over the baseline is FEI-1 on a percentage basis. So, a fan rated FEI = 1.1 uses 10% less energy than the baseline requirement. This makes FEI useful for comparing relative energy savings between any two fans, or between a fan and the FEI threshold in a fan code/standard/regulation provision.

Applying the FEI Metric

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 [5]. FEI defines a “compliant range of operation,” not a single compliant efficiency threshold. For a single speed fan curve, the compliant range is a subsection of the total fan curve (Figure 3) [22].

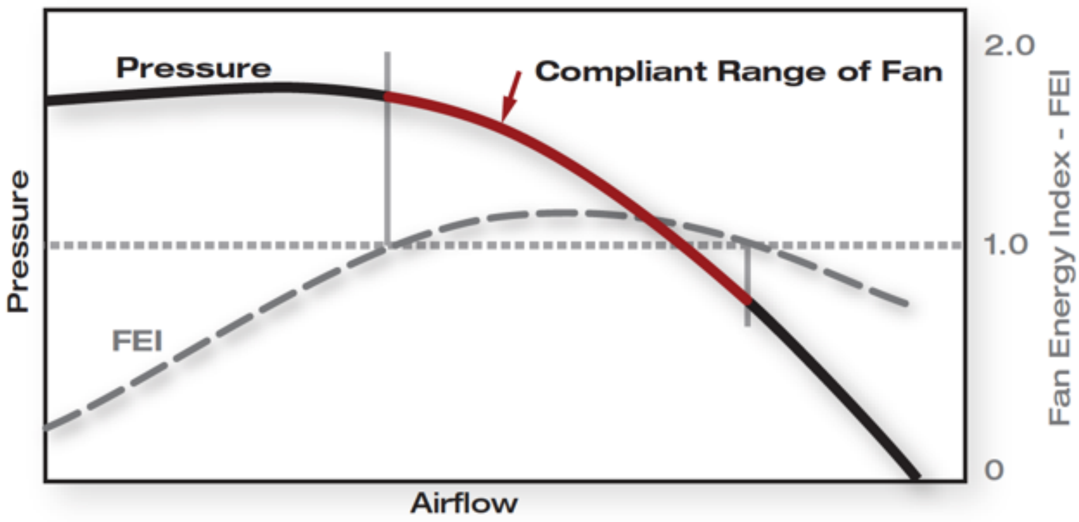

Figure 3. Compliant range of operation for a single-speed fan on a fan curve based on air pressure and airflow. The FEI curve's compliant range is FEI 1.0 and above.

On multiple speed fan curves, as would be used if a variable frequency drive (VFD) were being used, these compliant zones look like bubbles that are proportional to fan efficiency. Generally, the more efficient the fan, the larger the compliance bubble (Figure 4, Figure 5) [6]. In some cases, however, fans can be very efficient over a small operating range. The shaded regions in the figures indicate compliance FEI 1.0. Bubbles are defined within the compliance zone to indicate higher FEI levels, where applicable, and outside the compliance zone where FEI is less than zero. In Figure 5, a label for fan speed indicates the maximum speed the fan can be operated to achieve compliance. This gives operators and engineers an opportunity to set up variable speed drives and belts to restrict fan speed where needed.

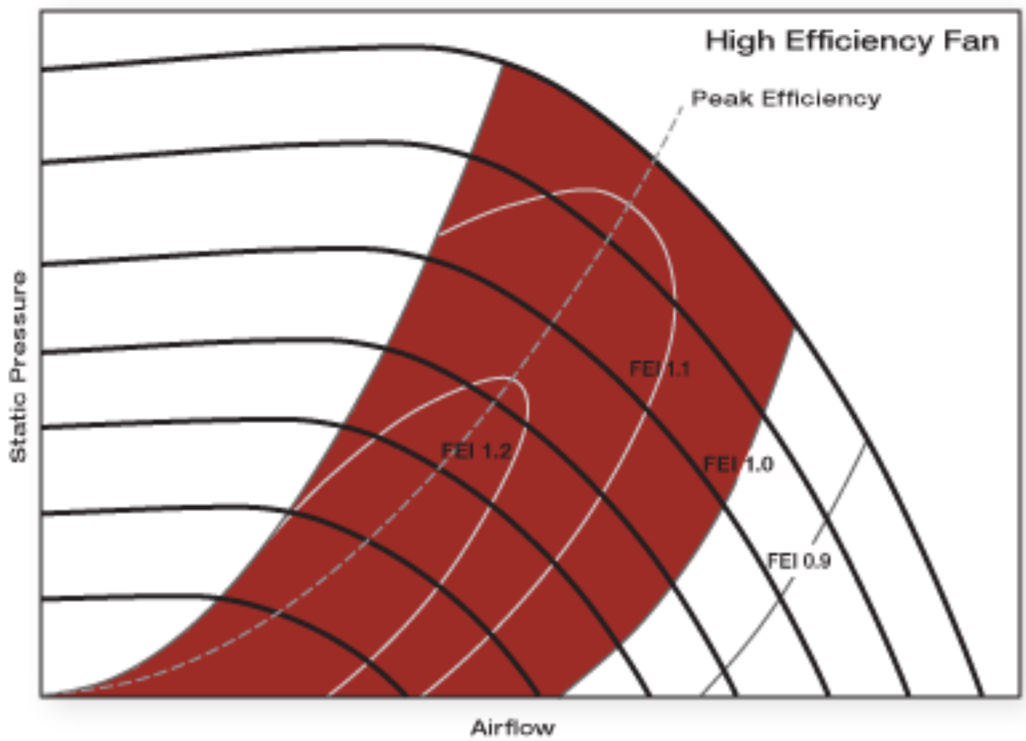

Figure 4. Compliance bubble for a high-efficiency fan operating at multiple speeds, such as those using a variable-speed drive. The colored region shows FEI 1.0 and higher with the larger FEI levels having smaller bubble regions. The high-efficiency fan has a larger FEI compliance bubble than lower-efficiency fans.

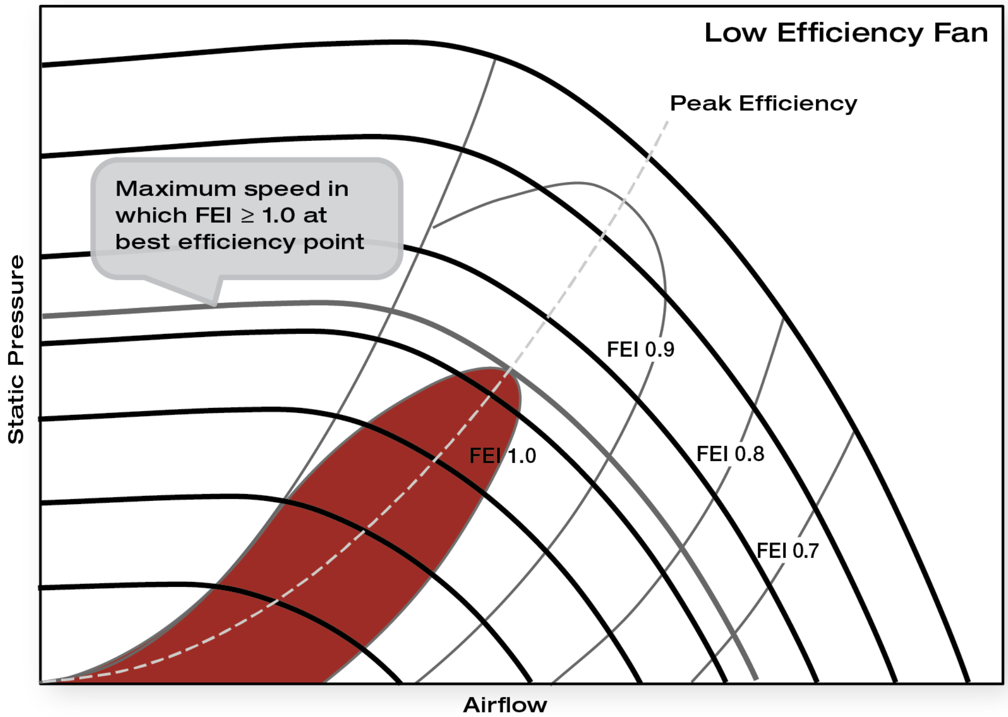

Figure 5. Compliance bubble for a low-efficiency fan operating at multiple speeds, such as with a variable speed drive. Note the smaller compliance region FEI = 1.0 compared to the higher efficiency fan in Figure 4.

Manufacturers' would include such diagrams or their tabular equivalents in product literature and sizing/selection software.

The ratio of fan power to this baseline power at design conditions is used to package the metric and make it easier to use for customers, owners, regulatory bodies and utility rebate programs to use relevant data. The baseline represents a reasonable efficiency level that is common to all fan types as they are normally applied.

The baseline value is an important component of a regulation, and needs to be selected to represent a reasonable benchmark efficiency. Regulations can be written around FEP_{std}, as documented in the ASRAC Term Sheet [1]. However, a regulation or program or written FEI of "1.0" could serve as an optimal FEI requirement, for example, for most types of fans. Exceptions where FEI is less than 1.0 could be allowable to include fans used for variable air volume (VAV) systems to encourage more use of VAV systems [6]. Fans used infrequently, such as emergency fans or fans used for material handling, could also have "less than 1.0" FEI requirements.

As shown in Table 3, high-performance-building standards (such as ASHRAE 189.1) or utility rebate programs would set FEI requirements to be greater than the baseline requirement. In the current fan efficiency provision in ASHRAE 189.1, additional stringency is added to the corresponding ASHRAE 90.1 provision by making the sizing/selection window smaller – from 15 percentage points to 10. This is because more energy is saved by further restricting fan selections to larger sizes rather than increasing the FEG rating from 67 to the next level up – FEG 71 [9, 13]. The approach taken by ASHRAE 189.1 further validates the utility of having sizing/selection criteria baked into FEI.

The FEI metric also supports the expected increased stringency in codes and regulations over time as fan technology improves. The baseline FEI can be moved, for example, from 1.0 to 1.1. This would nudge requirements higher while also preserving the integrity of fans labeled with FEI ratings set previously. A fan's label showing FEI 1.0 today showing compliance with a requirement of FEI 1.0 would be valid in the future if the requirement was raised to FEI 1.2. A building owner replacing the fan under the future regulation would replace the FEI 1.0 fan with a FEI 1.2 fan.

Absent a draft or final DOE labeling requirement, Figure 6 shows a label mocked up by Twin City Fans, for consideration in a rebate program being developed for motor-driven loads [5]. The Extended Motor Product Label Initiative (EMPLI) is a "collaborative effort involving over two dozen representatives from the motor-drive equipment manufacturing sector, trade organizations, utilities, energy efficiency program administrators, and energy efficiency nongovernmental organizations" [23]. Note in Figure 6 that both FEP and FEI are represented.

Under EMPLI, AMCA, Hydraulics Institute, and Compressed Air and Gas Institute (CAGI) represent fans, pumps, and air compressors, respectively by providing knowledge and experience in their given markets. Utilities program managers and their consultants bring program knowledge, including development, implementation, and measurement and verification [23].

For fans, EMPLI progress has been stalled due to the slow pace of DOE's fan rulemaking. However, when the AMCA FEI rating standard is complete, it should enable rebate program development and implementation.

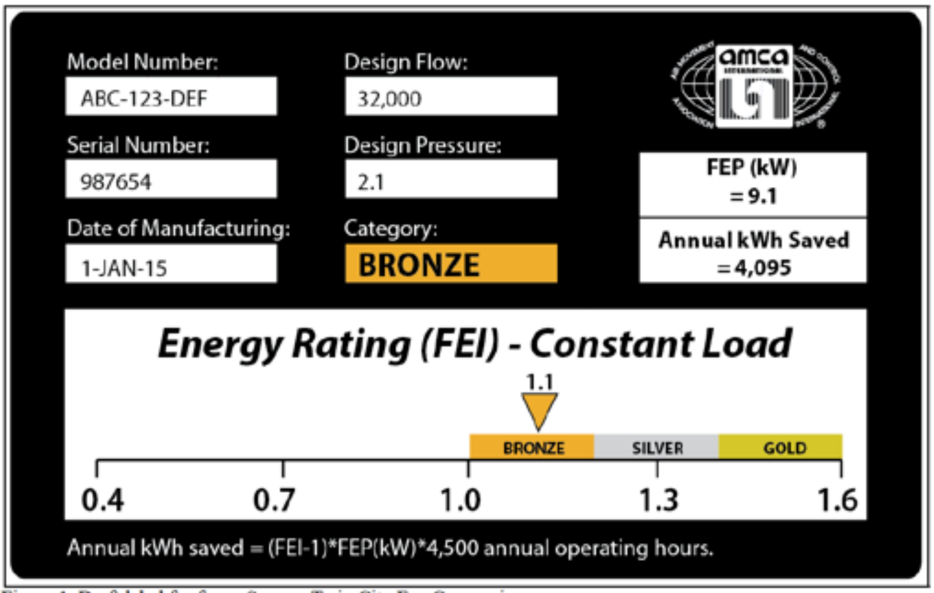

Figure 6. Draft of a possible label supporting fan rebate programs. Design flow and pressure are needed to provide context for the FEI rating. The designation of bronze/silver/gold are optional.

Fine Points about FEI

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 [20] and the measurement method of ANSI/AMCA Standard 210 [21] 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, if the combined FEI level meets the minimum requirement [1].

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 [5]. This would be true for fans sold off-the-shelf without a motor. In this case, the FEI is evaluated at the best efficiency point at the maximum published fan speed. If the fan on the shelf has a motor and drive, the distributor will provide the FEI bubble. By considering this single point, the metric establishes a restricted speed range while remaining consistent with its use at the design point of operation. As shown in Figure 5, the "restricted speed size" is the maximum speed the fan can be operated at to remain at FEI = 1.0 or greater.

While driving significant energy savings and technological improvements, the FEI will also help 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 baseline fan electrical input power. They will also learn how the energy consumption of one product compares to another, regardless of product type, category, size or drive method [6].

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 energy efficiency. This can help 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 market. It is an all-encompassing, high level solution to a complex problem.

FEI was selected by DOE, AMCA and other industry stakeholders to be the metric around which a federal efficiency standard would be developed. FEI will replace FEG where used in existing energy codes and standards, and it can be applied in rebate programs for commercial and industrial fans. The long work that has gone into the development of this sophisticated and effective metric and supporting regulatory framework deserves to be brought to conclusion.

In the absence of DOE action, there are some nascent efforts to restart this process at the state level, but there are great risks to such a balkanized approach. It could result in confusion among regulators, manufacturers, distributors and customers; create a competitively un-level playing field across the country; and fail to strike the appropriate national balance of competing objectives. We hope that the commercial and industrial fan industry can finally complete its odyssey toward achieving unprecedented levels of cost-effective fan energy efficiency by application of the widely helpful metrics that have been developed.

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