Applying Fan Energy Index (FEI) in Regulations and Applications

Michael Ivanovich*, Ronald Wroblewski, PE**, Jeff Boldt, PE, FASHRAE***

****Air Movement and Control Association (AMCA) International, **Productive Energy Solutions LLC, ***IMEG Corp.***

Abstract

Fan energy index (FEI) is replacing fan efficiency grade as a metric for efficiency provisions in ASHRAE standards and the International Energy Conservation Code. Additionally, U.S. appliance-efficiency regulations for commercial and industrial fans and blowers are being developed around FEI. FEI is more than a rating metric, however. It also is a design tool, one that can be used by application and design engineers to reduce energy consumption through right-sizing of fans for variable-air-volume (VAV) and constant-speed (CS) systems. This article summarizes FEI as a regulatory metric and provides guidance for using FEI in VAV and CS applications.

Background on FEI

Fans are unique from other appliances in that their operating efficiency varies significantly based on how they are applied and where within their operating envelope they are selected. Application and selection, therefore, are far more influential than peak efficiency in determining the actual energy consumption of a fan. Unlike, for example, an incandescent light bulb, a fan that is the least efficient for one application may be the most efficient for another.

In June 2011, the U.S. Department of Energy (DOE) initiated a rulemaking for commercial and industrial fans and blowers. At the time, fan efficiency grade (FEG) was the established metric for fan-efficiency provisions in model energy codes and standards. In February 2013, however, the DOE released a rulemaking framework indicating a preference for a metric based on electrical power consumption, a departure from FEG. AMCA International and its members then went about developing a new fan-efficiency metric, fan energy index (FEI), for use in the expected federal regulation.[1] Although finalization of that regulation has been postponed, FEI is making its way into model energy codes and standards. Most recently, in June 2019, ASHRAE's board of directors approved the publication of Addendum *ao* to ANSI/ASHRAE/IES 90.1-2016, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, which replaces FEG language with FEI language.

A wire-to-air metric formalized in ANSI/AMCA Standard 208-18, *Calculation of the Fan Energy Index*[1], FEI is calculated using data collected during manufacturers' rating tests and considers efficiency losses associated with the fan impeller, motor, and drive. It establishes a baseline efficiency and resulting baseline power that varies with both airflow and pressure and can be applied to all fan categories. For energy-efficiency regulations, codes, and standards, this establishes a "range of compliant operations," rather than a single-point pass/fail efficiency threshold.

An EEMODS) 2017 paper[2], "Two New Metrics for Fan System Efficiency: Fan Energy Index and Fan Electrical Power," has more background information on FEI. Following publication of that paper, ANSI/AMCA Standard 208-18 was completed and International Organization for Standardization (ISO) Technical Committee 117, Fans, began the work of harmonizing ISO 12759:2010, *Fans—Efficiency Classification for Fans*[3], with ANSI/AMCA Standard 208-18 by incorporating FEI into ISO 12759:2010 as Section 6[4].

Table 1 summarizes FEI's status in regard to U.S. model energy codes and standards and state and federal regulations[5]. The baseline FEI level for all current code/standard/regulation activity is FEI ≥ 1 at the duty point (design point of operation) for standalone fans (including powered roof ventilators) ≥ 1.0 HP or ≥ 0.89 kW and fan arrays with combined power > 5 HP or > 4.1 kW. In variable-air-volume (VAV) systems, covered fans rated at FEI ≥ 0.95 are allowed to account for the slight efficiency loss of variable-speed drives. For stretch codes/standards, such as ANSI/ASHRAE/USGBC/IES 189.1, FEI ratings must be slightly more stringent at FEI ≥ 1.10. Exemptions include:

- Fans embedded in equipment that is regulated or third-party-certified for air performance or energy performance.
- Reversible tunnel ventilation fans.
- Fans for high temperatures, explosive atmospheres, or emergency conditions.
- Ceiling fans.

Table 1: FEI in Model Energy Codes, Standards, and U.S. State/Federal Regulations

Publication	**Publication Type**	**Version Date**	**Status**	**Estimated Completion**	**Effective Date**
ANSI/ASHRAE/IES 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*	Model energy standard	2019	Awaiting ANSI approval of Addendum *ao*	August 2019	Upon publication, but needs to be adopted to have effect
ANSI/ASHRAE/USGBC/IES 189.1, *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings*	Model energy standard	2020	Awaiting publication of addendum for public review	January 2020	Upon publication, but needs to be adopted to have effect
International Energy Conservation Code	Model energy code	2021	Awaiting final action balloting by International Code Council	November 2019	Upon publication, but needs to be adopted to have effect
U.S. Department of Energy Rulemaking on Commercial and Industrial Fans and Blowers	Federal test procedure and energy standard as separate regulations	Unknown	Work stopped	Unknown	Unknown
California Title 20 Appliance Efficiency Regulations	State test procedure and efficiency requirement as one regulation	Estimated 2020	Awaiting second edition of staff report (draft regulation)	Estimated 2020	Estimated 2021 or 2022

Applying FEI in System Designs

For designers of VAV systems and constant-speed (CS) systems, FEI is a useful metric for fan sizing and selection, indicating whether a fan will operate at or below required power levels. With CS systems, fan selection is easier than it is with VAV systems, as an engineer specifies a duty point and selects a fan that has an FEI rating at or above the minimum.

For VAV systems, the question is on what operating point FEI ratings should be based. In short, for a VAV system, a fan with an FEI rating that is acceptable at the peak-flow operating condition always should be selected. Normally, this will ensure the fan also will be in compliance when it serves a load below peak flow, as slowing a fan's rotational speed generally increases its FEI rating.

FEI for CS Systems

In short, for a CS system, fans can be selected to meet a desired duty point (airflow and pressure) at which FEI is greater than or equal to the desired FEI rating. A "desired FEI rating" could be:

1. A minimum FEI level per a code, standard, or regulation.

2. A minimum established by a voluntary incentive program, such as a utility rebate program. Such minimum thresholds usually are more stringent (more efficient) than those required by energy codes and regulations.

3. A minimum established by a building owner or other entity that establishes functional and performance requirements of systems for new construction or renovation.

Figure 1 shows the "compliant range" of pressure and airflow duty points for a CS system and a minimum FEI rating of 1.00. The engineer's desired duty point would have to fall within the compliant range.

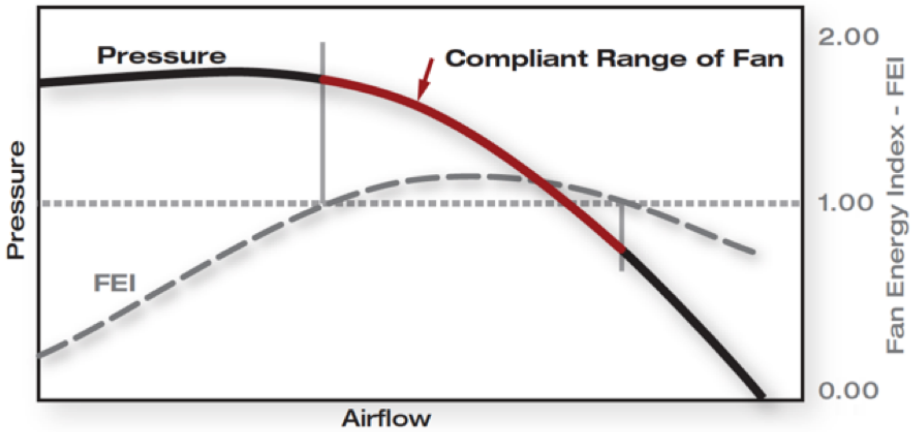

Figure 1: Compliant Range of Duty Points for a Constant-Speed Fan for a Minimum FEI of 1.00

Table 1 shows an example for a duty point defined by:

- Airflow rate: 18,000 cfm (8.50 m^3/s)
- Air pressure: 5.4 in. wg (1,345 Pa)
- Air density: standard (sea level)

A manufacturer's sizing/selection software could output one or more types of fans at a variety of sizes for the engineer to consider. Table 2 shows an output of two fan types, a double-width airfoil fan and a double-width backward-inclined fan. The table shows selections having FEI ratings from below 1.00 to well over 1.00. Compliant selections for FEI $\geq$ 1.00 are shown with shaded cells. Other project considerations, such as acoustics, form factor, weight, budget, and incentives for higher energy performance, would lead the engineer toward a final selection.

Table 2: Fan Selections to Consider for a Constant-Speed Air System and a Minimum FEI Rating at the Duty Point of 1.00

Impeller diameter, in. (mm)	Fan-Impeller Type (all double-width)	FEI @ 100% Flow
18 (464)	Airfoil	0.90
20 (508)	Airfoil	1.05
22 (565)	Airfoil	1.13
24 (622)	Airfoil	1.23
27 (686)	Airfoil	1.21
18 (464)	Backward-inclined	0.82
20 (508)	Backward-inclined	0.93
22 (565)	Backward-inclined	1.05
24 (622)	Backward-inclined	1.16
27 (686)	Backward-inclined	1.17

Selecting the Correct FEI for a VAV System

FEI is a solid indicator of the ability of a fan to serve a duty point efficiently. However, it is based on a single point of operation; in a VAV system, there are many points of operation. Figure 2 shows the system curve of a VAV air handler that might serve one floor of a multistory high-rise. The curve is offset upward from the origin because the controls are set to provide a minimum static pressure in older systems and a minimum pressure reset downward from an initial set point based on VAV-box position in systems complying with recent versions of ANSI/ASHRAE/IES 90.1 and the International Energy Conservation Code (IECC). Where the system curve reaches zero flow rate is the nominal static-pressure set point. Often, this is about 0.75 in. wg. Both ANSI/ASHRAE/IES 90.1 and the IECC require it to reset based on VAV-box position, so it effectively is much lower in properly operating systems.

In a VAV air-conditioning system, the peak flow rate is needed on only the hottest days (“100%” in Figure . On average days, with the building requiring less cooling and less flow, we can slow the rotational speed of the fan using a variable-frequency drive, allowing the fan speed to track the changing cooling needs of the building. For our discussion, let’s say the average flow rate is 70 percent and the minimum flow rate is 40 percent, as illustrated in Figure .

In this case, the FEI rating should be determined at the peak flow rate. Determining it at the average flow rate would be problematic for two reasons: the first related to compliance, the second to structural integrity.

Compliance Considerations

Let’s consider potential problems related to compliance. In this case, for a fan to be compliant, it must be sized and selected for an FEI rating of 1.00 or higher. This is the threshold that code and standard bodies and regulators appear to be converging on, although a rebate program might require an FEI rating of 1.20 or higher.

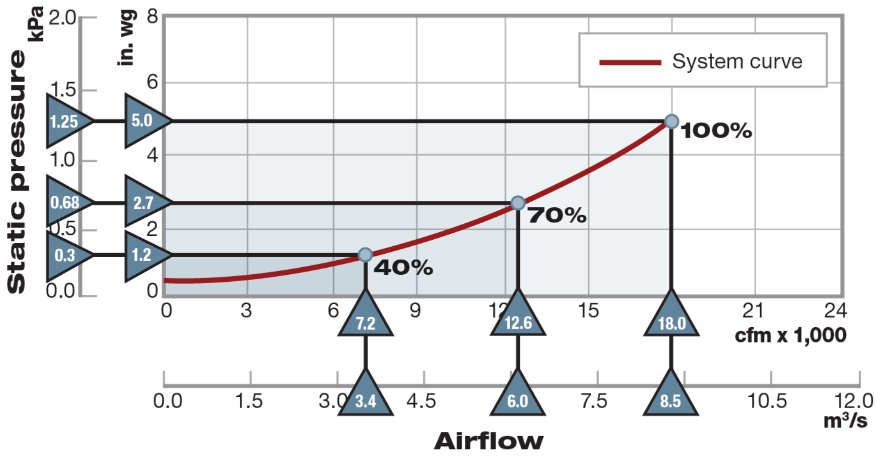

Figure 2: Operating Points in a Typical VAV System

Table 3 summarizes the performance of airfoil and backward-inclined fans of different sizes that could be deployed to serve a VAV system. At 40-percent flow, the 18-in. (464-mm) fans meet the FEI threshold of 1.00, while at full flow, the FEI rating drops to 0.89 for the airfoil fan and 0.82 for the backward-inclined fan.

Table 3: FEI Ratings at Various Duty Points for a Range of Fan Sizes

Impeller diameter, in. (mm)	Fan-impeller type (all double-width)	FEI at 40% flow[1]	FEI at 70% flow[2]	FEI at 100% flow[3]
18 (464)	Airfoil	1.07	0.97	0.89
20 (508)	Airfoil	1.21	1.14	1.01
22 (565)	Airfoil	1.23	1.20	1.13
24 (622)	Airfoil	1.27	1.29	1.25
16 (406)	Backward-inclined	1.01	0.89	OVERSPEED
18 (464)	Backward-inclined	1.02	0.90	0.82
20 (508)	Backward-inclined	1.10	1.01	0.93
22 (565)	Backward-inclined	1.21	1.12	1.04
24 (622)	Backward-inclined	1.24	1.23	1.16
27 (686)	Backward-inclined	1.22	1.23	1.18

1. 7,200 cfm, 1.2 in. wg (3.40 m^3/s, 304 Pa)
2. 12,600 cfm, 2.7 in. wg (5.95 m^3/s, 674 Pa)
3. 18,000 cfm, 5.0 in. wg (8.49 m^3/s, 1,245 Pa)

Figure 3 shows what is called an FEI-rating "bubble curve" for the 18-in. (464-mm) backward-inclined fan. FEI ratings shown apply for all duty points defined by the bubble. Here, we see that while the fan is in compliance at 40-percent flow (blue bubble with FEI = 1.00), it is not at duty points associated with 70-percent flow and 100-percent flow, as the FEI ratings are less than 1.00.

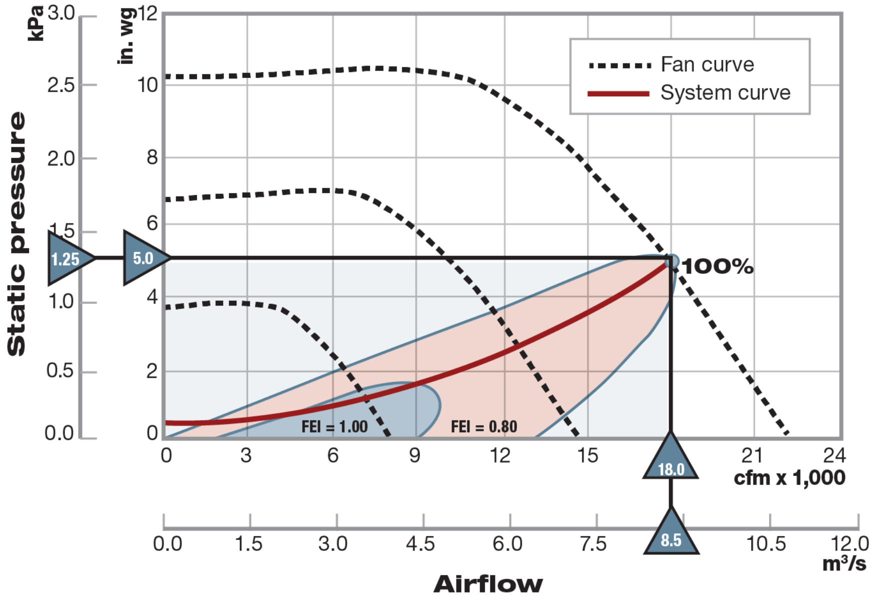

Figure 3: FEI Bubble Curve for 18-in. (464-mm) Backward-Inclined Fan Showing Compliance at Low Flow Rates, but not at the Peak Design Condition

A fan may have an FEI rating above 1.00 at average flow and an FEI rating below 1.00 when speeded up to full flow, which would be unacceptable from a regulatory perspective. Selecting a fan to have an acceptable FEI rating at peak flow will nearly always ensure the fan is in compliance when it serves a lesser load, as slowing a fan's rotational speed generally increases its FEI rating.

In the case of the 24-in. (622-mm) and 27-in. (686-mm) fans, the FEI ratings for all of the duty points of interest (40 percent, 70 percent, 100 percent) are greater than 1.00. Considerable energy could be saved by using these larger fans.

Figure 4 is the FEI bubble chart for the 22-in. (565-mm) backward-inclined fan. At the 40-percent and 70-percent duty points, the FEI rating is 1.21 and 1.20, respectively. At the 100-percent duty point, it is just within compliance at 1.04.

Structural Limitations and Surge

A fan needs to be operated within a range of speeds per the manufacturer's rating. If a fan is operated at a speed too high, it will be vulnerable to its structural limitations.

First, we will consider problems related to structural integrity. Let's say a fan is selected properly for peak flow rate. If the manufacturer rated the fan for that duty point, the impeller should have sufficient structural strength to withstand the associated rotational speed and centrifugal forces.

In their quest to maximize FEI ratings, system designers may be tempted to oversize fans, which can lead to surge. Operation in the surge region can result in violent pulsations that can damage a fan or cause injury to personnel. Responsible, experienced HVAC-system designers know to ensure a sufficient safety margin in a fan's available peak pressure (sometimes called pressure reserve)—that is, ensure the duty point falls sufficiently to the right of peak fan pressure so that the fan does not operate in the surge region (Figure 5). Typically, for both fans and centrifugal chillers, maximum efficiency is achieved with the largest impeller not in surge, while the "best" selection may be one size smaller to prevent problems if the system has higher-than-predicted pressure drop.

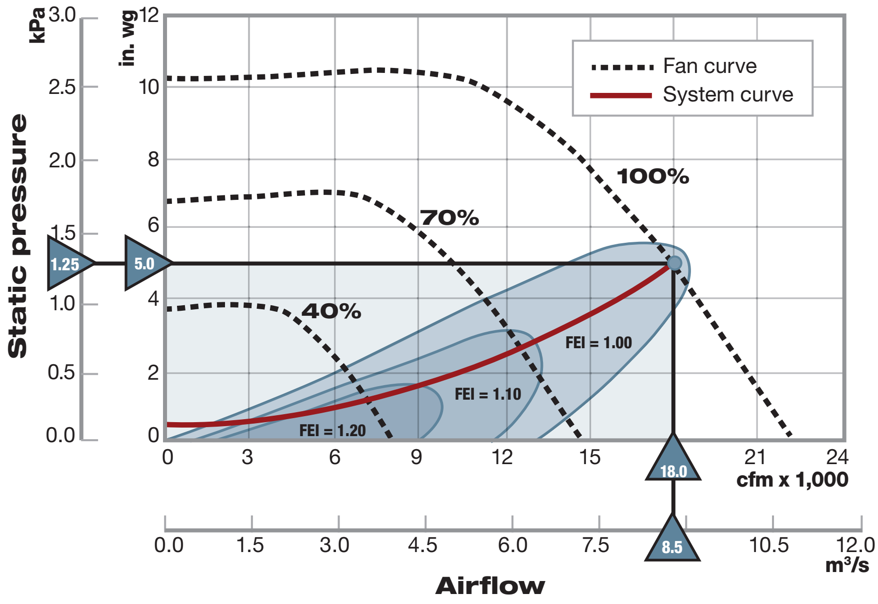

Figure 4: FEI Bubble Curve for 22-in. (565-mm) Backward-Inclined Fan Showing Compliance at all Three Duty Points of Interest

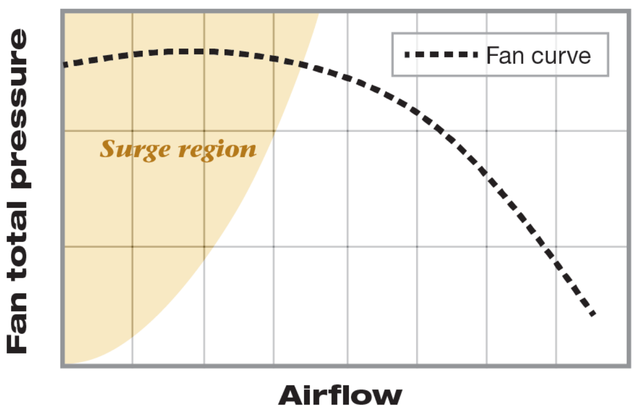

Figure 5: Typical Fan Curve Showing Surge Region

Benefits of FEI

Although the fan with the higher FEI rating at the design duty point may cost a little more to purchase and be slightly larger than the fan with the lower FEI rating, it generally will result in much lower energy use and life-cycle costs and significantly quieter operation. Normally, the purchase of a fan with higher FEI rating is an investment with a very high rate of return.

Summary

FEI will replace FEG in model energy codes and standards and, eventually, wherever all or part of a particular model energy code or standard with an FEG provision has been adopted. FEI also seems destined to be used in energy-efficiency regulations at the state level. And should the U.S. Department of Energy restart its commercial-and-industrial-fans rulemaking, FEI will be the regulatory metric at the federal level as well.

As FEI is incorporated into more energy codes and standards in the coming years, manufacturers may adapt their product offerings. HVAC-system designers are advised to ensure that:

- The FEI ratings of the fans they select are in compliance with the FEI criteria at the design flow and pressure duty point.
- Fan rotational speed is less than the manufacturer's maximum rated speed.
- Fans meet anticipated system pressure losses, but include a safety margin to avoid surge in the event of unanticipated duct-system design changes.

For designers, FEI can be used today to help reduce wasted fan energy through selection of fan types and sizes with higher FEI ratings.

Where design and regulation meet is in addressing FEI levels for VAV systems in model or state energy codes and standards. To avoid ambiguity, regulators and code-setting bodies should require fans in VAV systems to meet FEI criteria at peak operating conditions. A fan that meets FEI criteria at peak operating conditions is likely also to meet the criteria at reduced-flow conditions, as FEI ratings typically are the same or better at lower fan speeds.

References

[1] AMCA. ANSI/AMCA Standard 208-18, *Calculation of the fan energy index*. Arlington Heights, IL: AMCA, 2018. Can be downloaded at no cost throughout 2019 at http://bit.ly/AMCA_208

[2] Ivanovich M., Stevens M. and Wolf M. *Two new metrics for fan system efficiency: Fan energy index and fan electrical power*. Paper presented at EEMODS'17 (Rome, 6-8 September 2017).

[3] ISO. ISO 12759:2010, *Fans—Efficiency classification for fans*. Geneva, Switzerland: ISO, 2010.

[4] Joseph Brooks: *private communication*. Mr. Brooks is chair of the U.S. technical advisory group to ISO/TC 117, Fans.

[5] AMCA. FEI resource page, www.amca.org/fei