FAN ENERGY EFFICIENCY METRICS AND FAN SELECTION IN COMMERCIAL AND INDUSTRIAL FAN SYSTEMS

Mark BUBLITZ[1], Tom CATANIA[2],
Michael IVANOVICH[3], Tim MATHSON[4], Nazme MOHSINA[3],
Trinity PERSFUL[5], Mark STEVENS[3]

[1] *The New York Blower Company, La Porte, IN, USA*

[2] *University of Michigan, Ann Arbor, MI, USA*

[3] *AMCA, Inc., Arlington Heights, IL, USA*

[4] *Greenheck Fan Corporation, Schofield, WI, USA*

[5] *Twin City Fan and Blower, Minneapolis, MN, USA*

SUMMARY

This paper reviews regulatory development in Europe and the United States, evaluates first-generation fan efficiency metrics, defines and develops the new metrics of Fan Efficiency Index (FEI) and Fan Electrical Power (FEP), and describes how these new metrics can be applied in regulations and rebate programs. The paper also investigates how these new metrics provide improved fan selections and as a result save more energy than traditional energy efficiency metrics.

INTRODUCTION

Fan Efficiency Grade (FEG) is a first-generation fan-efficiency metric published in 2010 [1] that has received wide adoption in a variety of codes, standards, and regulation around the world. Since the publication of FEG, the fan engineering community has advanced its understanding and treatment of fan efficiency particularly related to regulatory environment, which has resulted in the development of second-generation fan-efficiency metrics.

FEG is an efficiency representation closely tied to what could be described the base fan unit, commonly referred to in the fan industry as a bare fan. The bare fan typically consists of the fan impeller, a drive shaft, and a fan housing, if present, but does not include motors and drives [2]. This metric is incomplete with respect to extended product approaches taken for other motor-driven loads such as clean water pumps in the U.S. and Europe [3]. FEG on its own is not capable of estimating electrical input power to the fan system. The concept of FEG was extended to a wire-to-air metric with the introduction of the fan motor efficiency grade (FMEG) described in ISO Standard 12759 in 2010 [4]. ISO Standard 12759 is employed in European fan-efficiency regulations effective January 2012 [3]. Although FMEG is a wire-to-air metric, it remains a first-generation metric based on a fan system's capability to operate efficiently. Differences between the FEG and FMEG metrics and how these metrics are applied in U.S. and European fan-efficiency regulations were described in a paper presented at CIBSE/ASHRAE Technical Symposium in Dublin, Ireland, in 2014 [1]. At this time, the limitations of first-generation metrics were noted, but second-generation metrics were still being developed.

The United States Department of Energy (DOE) initiated action to regulate commercial and industrial fans and blowers in June 2011. This provided the initiative to develop a new, more sophisticated metric [5]. DOE subsequently released a rulemaking framework document in February 2013 [6]. In the framework document, DOE indicated a preference for a metric based on electrical power consumption. This was a departure from the first-generation metric, FEG, that was making its way into model codes and standards for energy efficiency and green construction building codes [1].

In addition to supporting a wire-to-air framework for regulation, participants in the metric development process understood significant energy savings can be obtained if the energy efficiency metric influences product selection and operation closer to the best efficiency point (BEP) of the fan. FEG is a rating system strictly based on the characteristic of the fan. An effort was made to influence product selection and operation by adding an appendix to AMCA Standard 205 [7] that required the operating selection to be within 15 percentage points of the peak efficiency of the fan (see Figure 1 below). Consequently, the requirement did not affect the FEG rating of the product, but to be compliant with ACMA Standard 205, the operating condition needed to meet the 15 percentage point requirement. This proved to be a cumbersome requirement that would be complicated to implement in a regulatory environment.

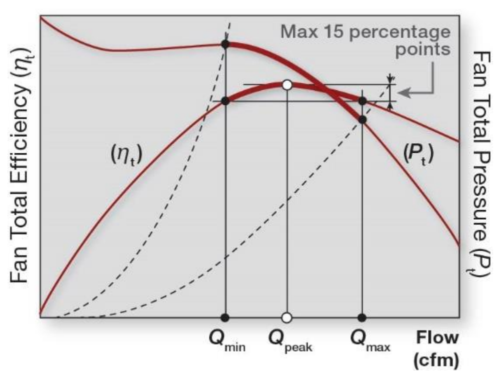

Figure 1: typical fan curve showing total efficiency vs flow vs total pressure

The second-generation metrics, Fan Electrical Power (FEP) and Fan Energy Index (FEI) are developments that stand on the work of previous fan energy efficiency metrics and advance the technology to include wire-to-air operation and the fan duty point in the metric. To provide a basis for energy efficiency initiatives, The Air Movement and Control Association, International, Inc. (AMCA) Standard 208 [8] defines FEP and FEI so that these new metrics can be used in conjunction with the AMCA Standard 210 [9] test standard. AMCA has also published a standard that enables calculation of FEP and FEI using measured and default values for motors, variable speed drives, and belt drives.

AMCA Standard 207 [10], Fan System Efficiency and Fan System Input Power Calculation, is a rating standard that provides a method to estimate the input power and overall efficiency of an extended fan system.

FAN EFFICIENCY METRICS

Although fans have existed for centuries, it was not until the 2007 timeframe that fan energy efficiency entered the regulatory spotlight. An early proposal was to impose a minimum total efficiency performance of 65 percent on fans [2]. The impact of such an approach is graphically portrayed in Figure 2. As was quickly discovered, such an approach would eliminate many fans on the market in the range of approximately 20 inches (~50 cm) in diameter or smaller. Figure 2 was developed by culling the peak efficiency capabilities of fans with respect to their impeller diameter. In general, it can be seen it is more difficult for fans of smaller diameter to achieve efficiency levels compared to fans of larger diameter – or at least one can argue that is what is present in the market.

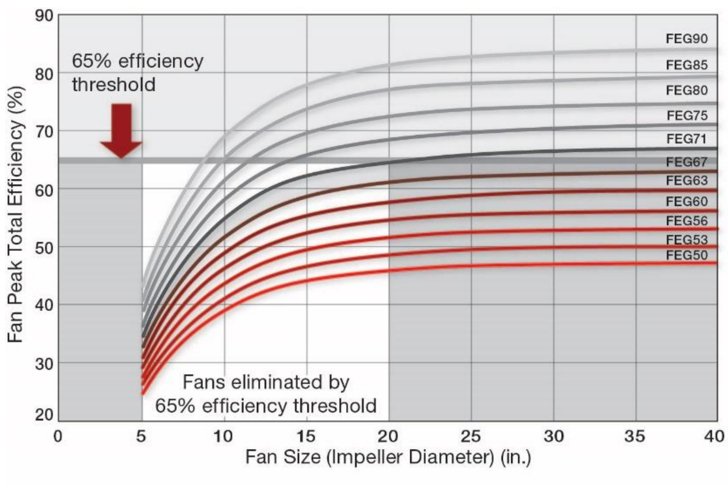

Figure 2: the impact of a minimum total efficiency threshold on product sizes in the market

The performance of many fans can be estimated across sizes using affinity laws, or fan laws, as they are commonly referred to in the fan industry. The fan laws require geometric similarity, however. As fan diameter is reduced, smaller fans suffer from what is often described as a size-effect. Manufacturing constraints such as material thicknesses do not scale perfectly with size. As a fan is scaled down, the blade thickness for the scaled product may become paper thin. Also, a reasonable gap between rotating and fixed components for a fan of impeller diameter of 1 m scaled to 25 cm may result in a design that is impractical to manufacture or be too expensive for the market. Above 20 inches (~50 cm), the size effect diminishes and efficiencies stabilize and, in general, the size effect becomes insignificant above 40 inches (~1 m) in diameter. Applying a minimum total efficiency threshold as a regulatory approach would, as a consequence, have a disproportionate impact on smaller diameter fans.

A unique characteristic of fans is that those of similar geometric design but different sizes (based on impeller diameter) can operate at a similar duty point, with a duty point defined as a fan delivering a specified flow and pressure. Figure 3 below demonstrates this phenomenon. Although only one fan size consumes the minimum power, other sizes of fan can deliver an identical flow-pressure operating condition. These fans, in theory, would have identical BEP/FEG ratings yet when applied consume vastly different amounts of energy.

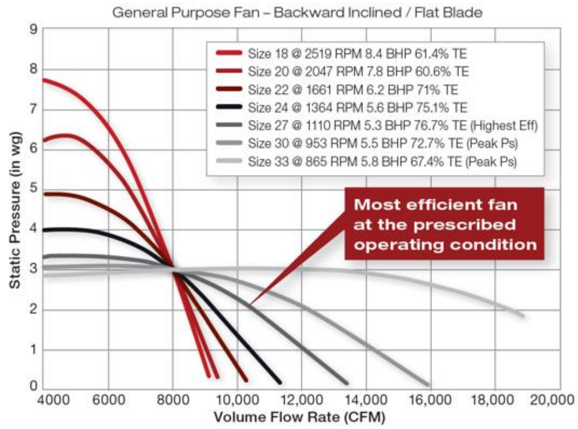

Figure 3: fans of similar geometric design operating at an Identical Duty Point. Source: the New York Blower co.

Another characteristic of fans that create challenges for regulatory approaches is the efficiency of a fan can vary significantly over the operating range of the product (see Figure 1). This provides a unique challenge for compared to electric motors, for example, or other regulated appliances that have a characteristic of a relatively stable efficiency value over the usual or expected operating range of the product. This is an important point to note pertaining to a regulatory approach. Because fans have a wide range of operating efficiency, identifying a fan as *good* or *bad* based on the fan's efficiency capability does not specifically result in obtaining efficiency gains or energy consumption reduction in fans in operation. Second generation metrics employ duty point, or incorporation of the expected operating conditions in the metric. The result will be the influence of product selection to be made closer to peak efficiency values of the product, resulting in real energy savings.

A review of measures of fan efficiency metrics is valuable both for historical context and to guide discussion of the impact of efficiency metrics on fan selection and application. Various fan efficiency metrics are reviewed below.

Total Efficiency

Total efficiency is the purest measure of fan efficiency. Total efficiency is the ratio of air power or energy as delivered by the fan (flow x total pressure) compared to the input power at the fan shaft or impeller required to deliver the specified air power.

$$\text{Total Efficiency} = \text{Volume flow rate x total pressure / shaft power} \quad (1)$$

It would be possible to extend total efficiency through the drive system of the fan to obtain a form of fan system efficiency that compares fan air power to electrical input power.

Static Efficiency

Static efficiency is similar to total efficiency with the exception that instead of using total pressure in the computation, static pressure is used. Static efficiency is the ratio of flow x static pressure (static air power) compared to the fan shaft or impeller power required to deliver the specified static air power. In essence, static efficiency ignores the energy delivered through velocity pressure component of the air ejected from the fan.

$$\text{Static Efficiency} = \text{Volume flow rate x static pressure / shaft power} \quad (2)$$

In a similar manner to total efficiency, it would be possible to extend static efficiency through the drive system of the fan to obtain a form of fan system efficiency that compares static air power to electrical input power.

Fan Efficiency Grade (FEG) and Fan-Motor Efficiency Grade (FMEG)

FEG is a grade based system consisting of specific ratings, or grades determined for fans that display efficiency qualities within a certain range (see Figure 2). No fractional FEG values or ratings exist. FEG ratings are shown below.

- FEG90
- FEG85
- FEG80
- FEG75
- FEG71
- FEG67
- FEG63
- FEG60
- FEG56
- FEG53
- FEG50

FEG uses total efficiency as its base efficiency metric, but then relaxes the efficiency requirement as the impeller diameter of the fan decreases. The result is the total efficiency requirement for smaller fans is relaxed to claim a similar FEG rating as a larger impeller diameter fan. As explained above, the argument for the allowance is related to the challenge of making a smaller diameter fan as efficient as a larger diameter fan particularly related to material thicknesses and gap sizes. For more information related to FEG, see AMCA Standard 205, *Energy Efficiency Classification for Fans*.

FEG is also a peak efficiency based metric. The total efficiency value used to determine the FEG rating is taken at the BEP of the fan operating at a one speed. Being a BEP metric, computing savings from any regulatory approach relies on the FEG rating reflecting the fan's efficiency rating in operation. Significant differences in fan efficiency exist across the operating range of a fan at a single speed. While FEG remains a viable and an accurate measure of a fan's capability to operate efficiently, a significant gap can exist between a fan's capability to operate efficiently and how the fan actually operates when installed.

By multiplying the FEG value by a motor efficiency value, one can obtain a value for the fan system efficiency consisting of a fan and a motor. This value can be computed at the fan BEP and a nominal motor efficiency. The result is considered a wire-to-air metric that provides a measure of fan efficiency comparing fan air power output to electrical input. This is the approach used in the FMEG metric. The assumptions implied in the calculation are the fan is operating at BEP and the motor is operating at its nominal motor efficiency. For more information related to FMEG, see ISO Standard 12759 *Fans—efficiency classification for fans.*

CFM-per-watt

Cubic feet per minute per watt (CFM/watt or CFM-per-watt) is an efficiency metric promoted by BESS Laboratories, has references in AMCA Standard 230, and is promoted in the agriculture market. The metric is argued to have the best interests of the customer in mind by measuring what the customer is interested in (flow) and the required energy to deliver that flow (electrical power) on a per unit flow.

Different implementations of the standard vary slightly but in general, to conduct a test the flow is measured while the fan experiences a static resistance of 0.125 in wg of pressure. The specified pressure requirement limits the application of CFM/watt outside of applications that are free exhaust or circulatory in nature.

Fan Electrical Power (FEP) and Fan Energy Index (FEI)

FEP and FEI are wire-to-air metrics consistent with the regulatory approaches being taken for other motor-driven loads, such as pumps and air compressors. FEP and FEI are considered second-generation metrics because they employ duty-point (sizing and selection) specifications in the metric in a manner acceptable to regulatory agencies. FEP and FEI can also influence how fans are sized, selected, and specified by practitioners.

FEI was developed as the ratio of the actual fan system efficiency to a baseline fan system efficiency, both calculated at a given airflow and pressure point. The phrase *fan system* is used to imply the incorporation of motors, transmission systems, and controls in the efficiency calculation. Because the actual and baseline efficiencies are 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.

$$\text{FEI} = \text{Fan System Efficiency} / \text{Baseline Fan System Efficiency} \quad (3)$$

$$\text{FEI} = \text{FEP}_{\text{baseline}} / \text{FEP} \quad (4)$$

Equation 4 indicates an intermediary calculation leading to FEI—the measurement or calculation of FEP. FEP is obtained either by directly measuring fan electrical input power during rating tests, or it is calculated by measuring fan shaft power and incorporating default values for motors, drives, and control. Default values are defined in AMCA Standard 207, *Fan System Efficiency and Fan System Input Power Calculation*. Fan rating tests are incorporated in AMCA Standard 210.

FEI uses a measure of air power deemed appropriate for the application (based on either total or static pressure), compares this value to the shaft or impeller power and includes drive components to arrive at electrical input power. The FEI can be compared between two products operating under identical requirements and an energy savings directly determined. A fan operating at the duty point with an FEI of 1.1 will consume 10% less electrical power than a fan operating at the same duty point with an FEI value of 1.0.

A complete definition of FEP and FEI can be found in AMCA Standard 208 *Calculation of the Fan Energy Index*. Of the metrics reviewed, only FEI has broad applicability to provide a metric and a feasible approach toward regulation of a fan's power consumption efficiency at a specified operating condition.

FAN METRICS AND PRODUCT SELECTION

Because a fan's energy efficiency at a specified operating condition can vary significantly from the fan's peak efficiency, or best efficiency point (BEP), a valuable contribution a metric could make to actually conserving energy would be to influence markets to make more efficient fan selections.

Countless hours have been spent arguing whether static efficiency compared to total efficiency are viable measures of fan efficiency for certain applications. Rather than raise the specter of the debate again, this paper investigates the application of static and total efficiency measures in fan efficiency metrics and the impact of using those metrics in product selection.

Total Efficiency and Static Efficiency

As explained earlier, both total and static efficiency, on their own, do not take into effect manufacturing challenges inherent in fans. And while total and static efficiency are incorporated in various metrics examined, total and static efficiency, on their own, are considered insufficient to be used energy as fan efficiency metrics.

CFM/watt

As a sample of CFM/watt analysis, the fan requirements for an application are specified as 40,000 CFM and 0.125 in wg static pressure. Panel fans of geometric similar design but different sizes were selected with the summary of results shown below in Table 1.

Table 1: summary of fan selections based on static pressure requirements

Impeller Dia (inch)	Fan Speed (rpm)	Fan Power (BHP)	Static Efficiency	Total Efficiency	CFM/watt
48	625	7.81	10.1 %	61.1 %	6.0
54	455	5.43	14.6 %	60.5 %	8.6
60	346	4.04	19.4 %	59.6 %	11.2
72	225	2.76	28.0 %	55.1 %	15.9

Because static pressure is used in the test specification, it can be seen that total efficiency values do not correlate to decreasing power consumption. It can be seen that static efficiency values do correlate with power consumption, meaning that increasing values of static efficiency are directly correlated to decreasing power consumption of product selections. It can also be determined from Table 1 that CFM/watt values are increasing with decreasing power consumption. In other words, the CFM/watt metric can influence product selection.

What is missing from the CFM/watt metric are acceptable minimum threshold values that would specify acceptable levels of minimum fan performance from a regulatory perspective. In addition, the pressure requirement of 0.125 in wg limits the application of the metric outside the market that accepts CFM/watt as a measure of product performance. If the pressure requirement were released from the metric, comparison between applications would be not possible. Consequently, CFM/watt will remain limited to the market currently served.

Fan Efficiency Grade – FEG

As explained earlier, FEG is a peak efficiency based metric. A significant shortcoming of FEG is that the metric alone is not sufficient to establish energy-saving regulations or code provisions. This is due to a characteristic of FEG, as well as characteristics of fans in general. As mentioned earlier, by design, FEG ratings remain constant across different sizes of the same geometrically similar model, even though fan efficiency varies, sometimes radically, for a given operating point.

Fan sizing selection data are displayed below for a design point of 10,000 cfm (4,719 l/s) at 3.0 inches (747 Pa) total pressure. The data clearly indicates that while total efficiency values are increasing with increasing size and power consumption is decreasing, the FEG values provide no guidance for product selection.

Table 2: summary of fan selections based on total pressure requirements (data courtesy Greenheck corp).

Impeller Dia (inch)	Fan Speed (rpm)	Fan Power (BHP)	Total Efficiency	FEI
18	3238	11.8	40.1 %	0.72
20	2561	9.6	49.3 %	0.87
22	1983	8.0	59.1 %	1.04
24	1579	6.8	69.5 %	1.22
27	1289	6.2	76.3 %	1.35
30	1033	5.7	83.0 %	1.46
36	778	6.0	78.8 %	1.39

Consequently, FEG does not have the capacity to influence product selection, at least within a model.

Fan Energy Index – FEI

For discussion purposes, the similar selection as used above for FEG has be included here and the FEI values have been included. Table 3 demonstrated the advantage of FEI over FEG for compliance purposes. In Table 3, a baseline FEP rating has been assumed to compute an FEI value. Fan sizing/selection data are displayed for a design point of 10,000 cfm (4,719 l/s) at 3.0 inches (747 Pa) total pressure

Table 3: summary of fan selections based on total pressure requirements (data courtesy Greenheck corp).

Impeller Dia (inch)	Fan Speed (rpm)	Fan Power (BHP)	Total Efficiency	FEPref (kW)	FEPact (kW)	FEG	FEI
18	3238	11.8	40.1 %	7.14	9.97	85	0.72
20	2561	9.6	49.3 %	7.14	8.22	85	0.87
22	1983	8.0	59.1 %	7.14	6.84	85	1.04
24	1579	6.8	69.5 %	7.14	5.83	85	1.22
27	1289	6.2	76.3 %	7.14	5.31	85	1.35
30	1033	5.7	83.0 %	7.14	4.88	85	1.46
36	778	6.0	78.8 %	7.14	5.13	85	1.39

Table 3 shows the value of the FEI metric. First, if a minimum threshold of FEI 1.0 was used for regulatory purposes, it can be seen the first three selections in the table would be unacceptable. Thus, a minimum threshold of efficiency or similarly a maximum allowable power consumption for an application has been established. Second, the FEI value clearly indicates improved efficiency for each fan selection and the FEI values trend in a direction of increasing efficiency.

A peculiar challenge exists for low-pressure, non-ducted outlet applications where static pressure is specified for product selection. As can be seen from Table 4, total efficiency values are decreasing while power consumption is also decreasing. On the surface, this would imply total efficiency is not a valid component for a metric. One can also glean from Table 4 that static efficiency does correlate with energy consumption. Namely, increasing values of static efficiency indicate decreasing power consumption. This is a result of the requirement of static pressure at product selection, but in the application no duct is available to convert velocity pressure to static pressure to overcome system resistance.

Table 4: fan selections based on static pressure requirements including FEI

Impeller Dia (inch)	Fan Speed (rpm)	Fan Power (BHP)	Static Efficiency	Total Efficiency	FEPref (kW)	FEPact (kW)	FEG	FEI
48	625	7.811	10.10 %	61.10 %	4.84	6.68	67	0.72
54	455	5.434	14.60 %	60.50 %	4.85	4.65	67	1.04
60	346	4.04	19.40 %	59.60 %	4.82	3.57	67	1.35
72	225	2.762	28.00 %	55.10 %	4.76	2.47	67	1.93

FEI accommodates this challenge by using static pressure in applications that are typically considered non-ducted outlet and using total pressure in applications that are typically considered ducted outlet. The purists will continue to argue about the best metric to describe a fan's energy efficiency, but FEI incorporates the appropriate pressure value to influence product selection to make more efficient selections in applications, resulting in increased energy savings.

CONCLUSIONS

As has been shown, FEI provides a robust basis for fan efficiency measure and application in regulatory frameworks. Of the metrics examined, all but FEI have shortcomings that disqualify them from achieving realizable energy savings from regulatory endeavors.

CFM/watt is limited to a specified pressure and does not contain the capacity for a reference or baseline for regulation.

Static and total efficiency provide guidance for selection, but are not wire-to-air metrics and do not provide electrical consumption estimates. They also do not provide guidance on a baseline that could be employed across sizes within a model or across products in an industry.

FMEG does not influence fan selection on a size basis within a model and is not application based.

Only FEI provides both an acceptable fan selection limit (FEI $\geq$ 1.0) and a measure of relative power consumption between fan selections directly through the FEI values, which can be compared between models or even different products.

Regulatory implementation challenges remain. As noted, European regulatory product requirements as well as current fan efficiency metrics are product based. In addition, many distribution channels result in a fan's application being unknown. An opportunity for continued discussion and development resides in using FEI applied in a product-based regulatory environment.

BIBLIOGRAPHY

[1] M. Ivanovich, N. Jones – *A Comparison of U.S. and European Approaches to Regulating Fan Efficiency*. ACMA, Arlington Heights, **2014**.

[2] J. Cermak, Ivanovich – *Fan Efficiency Requirements For Standard 90.1-2013*. ASHRAE Journal, April 2013: 24–30, **2013**.

[3] European Commission – *Commission Regulation (EU) No 327/2011 of 30 March 2011*. Official Journal of the European Union, L90/8, **2011**.

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

[5] U.S. Department of Energy – *Energy Conservation Program for Consumer Products and Certain Commercial and Industrial Equipment: Preliminary Determination of Commercial and Industrial Fans, Blowers, and Fume Hoods as Covered Equipment*. Federal Register 76 FR 37678. Washington, DC, **2011**.

[6] U.S. Department of Energy – *Energy Efficiency Program for Commercial and Industrial Equipment: Public Meeting and Availability of the Framework Document for Commercial and Industrial Fans and Blowers.* Federal Register 78-FR-7306. Washington, DC, **2013**.

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

[8] AMCA – AMCA Standard 208 *Calculation of the Fan Energy Index*. Arlington Hts., IL: AMCA, **2018**.

[9] AMCA – ANSI/AMCA Standard 210–ANSI/ASHRAE 51 *Laboratory Methods of Testing Fans for Aerodynamic Performance Rating*. Arlington Hts., IL: AMCA, **2016**

[10] AMCA – AMCA Standard 207. *Fan System Efficiency and Fan System Input Power*. Arlington Hts., IL: AMCA, **2017**.