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Calculating In Situ Fan Energy Index

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Abstract

Fan energy index (FEI) is the established performance metric currently recognized as the preferred method for efficient and compliant fan selection, and has been used as the metric for unit energy savings measures. Though FEI is primarily focused on proper fan selection during the design phase, this document summarizes the methodology for calculating in situ (installed) FEI. Calculating and assessing in situ FEI may be useful for gauging the efficiency of an operational fan system, comparing the in situ FEI with the design FEI, and reducing uncertainty in energy savings measures that utilize this metric.

Background

FEI is a dimensionless metric calculated by fan manufacturers under controlled laboratory conditions. It serves as an important tool for contractors and engineers in selecting appropriate fans for their design and application. FEI breaks away from past metrics that focused on best efficiency points of fans and minimum efficiency thresholds, and it also addresses the challenge of separating a fan's inherent energy efficiency capability from the energy efficiency of the fan as applied in a system (Ivanovich et al. 2017). FEI is a wire-to-air metric that accounts for losses associated with the fan, motor, transmission systems, and controls. It considers part load performance and peak efficiency, and it is applicable for fan ratings using fan static or total pressure. This means that FEI sets an efficiency and power baseline that changes as airflow or pressure varies.

FEI is calculated as:

$$FEI = \frac{Actual\ Fan\ System\ Efficiency}{Baseline\ Fan\ System\ Efficiency}$$

The "Fan System" referenced in this equation includes not only the fan but also the motor, transmission systems, and controls (if applicable) (Ivanovich et al. 2017). The baseline fan system efficiency is calculated at the same duty point (defined as the operating airflow and pressure) as the actual fan system efficiency. However, the baseline fan system uses standardized equations and default values for the motors, transmission systems, and controls (AMCA 2018).

Since the actual and baseline efficiencies are both calculated at the same duty point, FEI can also be expressed as:

$$FEI = \frac{Baseline\ Fan\ Electrical\ Input\ Power}{Actual\ Fan\ Electrical\ Input\ Power}$$

These two equations are equivalent, but the second equation is preferred and more valued by regulatory bodies as it directly relates to a reduction in energy consumption (Ivanovich et al. 2017). The second equation implies an intermediary calculation leading to FEI—the measurement of the fan electrical power (FEP). The actual fan system's FEP can be obtained by directly measuring the fan's electrical input power during laboratory rating tests or by calculating the fan shaft power and applying default efficiency values for motors, transmission systems, and controls (Ivanovich et al. 2017). All FEI calculations are done in a laboratory setting to provide customers with the information needed to help them correctly size and select an efficient fan appropriate for their operational needs.

Steps to Calculate In Situ FEI

In the field, very few fans are installed in conditions similar to the controlled lab settings in which the original fan performance data was developed. Additionally, fans often perform at operating points other than the intended design point during operation in the field. However, in situ FEI can be evaluated at any operating point of the fan system, providing a valuable means of assessing actual performance.

This research paper aims to address a critical question: **Is it possible to accurately measure and calculate in situ FEI?** In situ FEI has historically not been calculated for a number of reasons, including time, effort, cost, and perceived importance; however, calculating in situ FEI may be feasible. Doing so would provide value in reducing the uncertainty in energy savings measures and calculations that utility and energy efficiency groups require for resource planning and development of incentive and rebate programs. The complexity of this process depends on the specific fan system configuration, and in some cases, it may not be feasible.

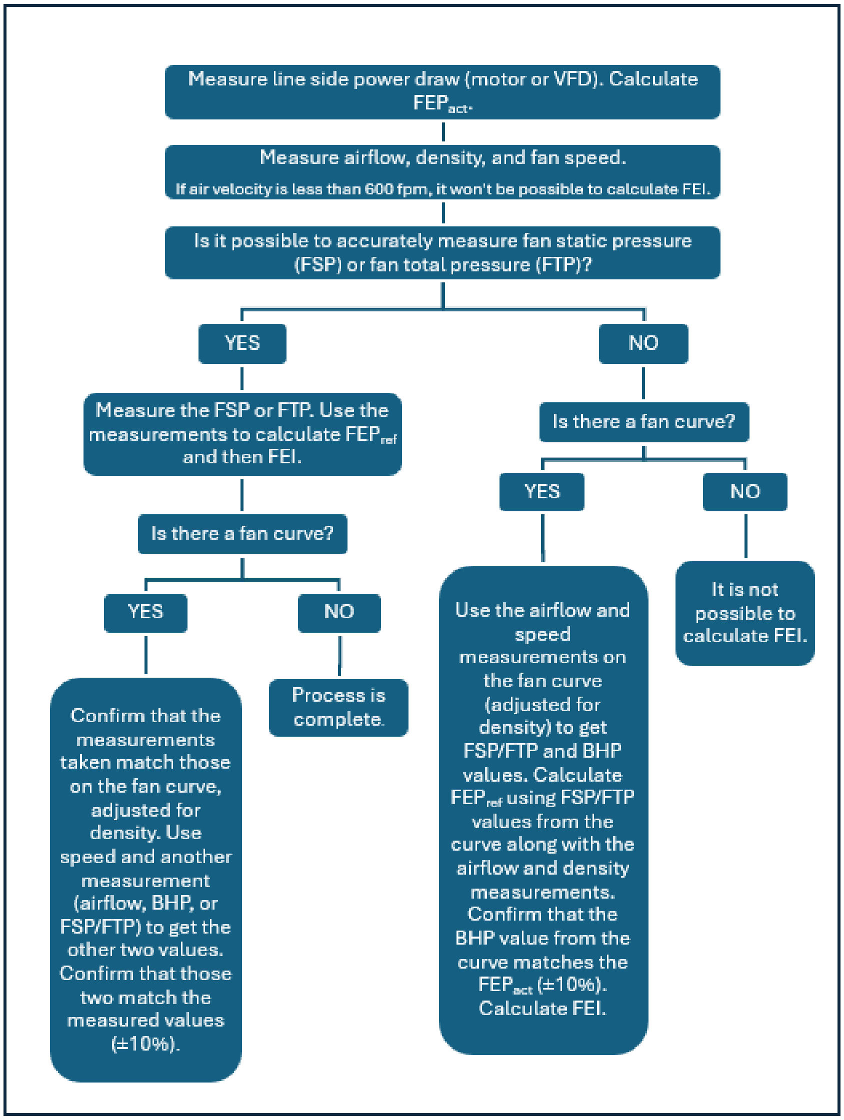
The steps shown in the rest of this document (and summarized in the flowchart on the following page) outline a direct approach for calculating in situ FEI. Subsequent sections in this report provide more information and guidance related to each of the below steps.

Once these steps have been evaluated on fan systems in the field, one can begin to compare in situ FEI to design FEI, which can provide insights into performance differences.

Prior to taking measurements and calculating in situ FEI, first determine the desired operating conditions to calculate in situ FEI. This could include one or more of the following:

- As-found when taking the measurements
- Conditions that represent average annual performance
- Conditions that represent design performance

Figure 1. Flowchart to determine whether accurate calculation of in situ FEI is possible



If any of the above measurements cannot be made accurately and in compliance with the relevant AMCA standards and guidelines (e.g., small rooftop unit), accurate calculation of the in situ FEI won't be possible. Testing of the process outlined in this document can help determine the actual feasibility of calculating in situ FEI.

Measuring FEPact

The line side power draw can be measured using a power meter. For non-VFD driven fans, measure the line side motor power draw. For VFD-driven fans, measure the line side VFD power draw. When using the power reading off a VFD, confirm whether the power reading is line or load side power. If load side, estimate the VFD efficiency and divide the load side power by that efficiency to obtain the line side power.

Power meters require the installation of voltage clips and current transducers on all three phases of incoming power. This work should be performed by qualified personnel using appropriate personal protective equipment (PPE). The power measurement reading taken is the FEP_{act} value, which will be used to help calculate in situ FEI.

Measuring Airflow

Pitot tubes are considered the most common way to measure airflow. Two of the biggest benefits of a pitot tube are:

- It does not require calibration if applied properly
- It can be inserted into existing and pressurized ductwork (hot tapping) without requiring a shutdown (AMCA 2011)

Multiple sizes of pitot tubes are available depending on the configuration of the system. The caveat for measuring flow rate accurately is that a high enough velocity in the system is required. 1,000 feet per minute (fpm) is considered the minimum airflow velocity required to accurately measure flow rate (Garner, J. 2025). While specialized equipment exists that can measure airflow velocities below 1,000 fpm with a lower level of accuracy, AMCA does not provide alternate measuring procedures for any airflow velocities below 600 fpm (AMCA 2011). Calculating in situ FEI accurately at low airflow velocities may prove to be infeasible.

A fan installed with a VFD, may experience times where the VFD is controlling the fan to a reduced speed where the airflow velocity may be too low (<600 fpm) for an accurate airflow measurement. In these situations, the fan with the VFD may be temporarily sped up to obtain a high enough airflow velocity that is accurately measurable for the purpose of calculating in situ FEI. Note that this calculated in situ FEI would not be at as-found conditions.

Using a pitot tube in a system to measure flow rate requires many conditions; the main one is finding a suitable traverse plane. The necessary qualifications for a traverse plane suitable for determining flow rate are laid out in AMCA 203 (AMCA 2011). Utilize these qualifications to properly locate an acceptable traverse plane. In general, a location well downstream of the fan in a long, straight run of uniform cross-section duct will provide acceptable conditions for the pitot traverse tube. If an acceptable area away from the fan cannot be found, or if a location closer to the fan to minimize the effects of leakage is desired, then the traverse plane needs to be close to the fan. In such situations, the conditions are usually more suitable on the inlet of the fan due to the flow profile not being fully developed on the outlet of the fan close to the discharge (AMCA 2011).

Sometimes, no good traverse planes exist. The only way to address this without modifying the system is to evaluate the undesirable effects of the location on the accuracy of the measurements (AMCA 2011). Evaluating the effects of a bad traverse plane is difficult, and the estimated accuracy may indicate the results of the measurements would be meaningless, thus making the calculation of in situ FEI impossible.

Fan arrays (fan walls), which are systems with multiple smaller-sized fans, are becoming more common. To measure the airflow of these systems, measure the total airflow of the fan array system and divide by the number of operational fans to get the airflow per fan.

Measuring Fan Wheel Speed

The fan wheel speed can be measured with a tachometer. In the case of fans, a non-contact tachometer would be optimal, and is the most common tachometer used by testing, adjusting, and balancing (TAB) contractors is a strobe light tachometer or stroboscope (Garner, J. 2025). The tachometer flashes a light at an adjustable frequency, and the fan wheel speed is determined by adjusting the flash rate until the fan wheel appears stationary, indicating that the strobe frequency matches the rotational speed of the fan blades. Several factors need to be considered in order to use a strobe tachometer correctly:

- A small mark or distinctive feature on one of the blades is needed as a reference point.
- The fan blade being measured should be visible for all 360° of rotation.
- Due to harmonic frequencies at certain flash rates, the fan blade may appear to be stationary at multiples of the actual speed. Before using the tachometer, knowing the approximate expected speed of the fan is important, to determine which stationary measurement is accurate (Monarch Instrument 2000).

A similar piece of equipment that can be utilized is a portable laser tachometer. A laser tachometer works by placing a piece of reflective tape on one of the fan blades. The laser tachometer sends out a beam of laser light towards the reflective tape. As the beam hits the tape, the light is reflected back to the tachometer. The tachometer will count the number of reflections to calculate the RPM. This piece of equipment can be easier to use than a strobe light tachometer, but the fan must be turned off to place the piece of reflective tape on the fan blade before the measurement can be captured.

In the case of direct drive fans installed with VFDs, most VFDs have a screen that will display the output frequency (Hz). This output frequency can be used along with the rated RPM and frequency of the motor that is driving the fan to calculate the fan wheel speed. The rated RPM and frequency can be found on the motor nameplate. The fan wheel speed can be calculated from the following equation:

$$\text{Fan Wheel Speed} = Motor\ Rated\ RPM * (\frac{\text{VFD Output Frequency}}{\text{Motor Rated Frequency}})$$

Measuring Air Density

The air density at the fan installation location must be measured to calculate in situ FEI, as it is a key variable in calculations for determining actual fan total or static pressure, as well as the baseline fan system shaft power. Additionally, air density factors into the fan curve provided by the manufacturer and if any adjustments need to be made, since most fan curves are generic fan curves tested at standard conditions. While some manufacturers may provide the fan curve tailored to the specified fan installation location, this should not be assumed to be the norm.

Air density should be measured for any location situated at elevations greater than 1,000 feet above sea level (Garner, J. 2025). For elevations below 1,000 feet, adjustments are usually not required. Calculating the air density requires measuring the dry bulb temperature, absolute barometric pressure, and the relative humidity of the air. Air density can also be calculated using software from trusted sources such as the MEASUR tool from the US Department of Energy. The equations for air density are as follows (Hoyos, L. 2022):

$$\rho = \frac{P_d}{R_d * T} + \frac{P_v}{R_v * T}\ \textbf{(SI)}$$

$$\rho = \frac{5.2024 * P_d}{R_d * T} + \frac{5.2024 * P_v}{R_v * T}\ \textbf{(I-P)}$$

Where:
ρ = Air density in kg/m^3 (SI) or lbm/ft^3 (I-P)
P_d = Partial pressure of dry air in Pa (SI) or in. w.c. (I-P)
P_v = Partial pressure of water vapor in Pa (SI) or in. w.c. (I-P)
R_d = Specific gas constant for dry air = 287.05 J/(kg*K) (SI) or 53.35 ft*lbm/(lb*°R) (I-P)
R_v = Specific gas constant for water vapor = 461.5 J/(kg*K) (SI) or 85.78 ft*lbm/(lb*°R) (I-P)
T = Absolute dry bulb temperature in K (SI) or °R (I-P)

The intermediate steps needed to calculate air density are as follows:

Calculate the saturation vapor pressure using the equation:

$$e_s = 610.78 * \mathrm{e}\hat{}(\frac{17.269 * T}{237.3 + T})\ \textbf{(SI)}$$

$$e_s = 2.45 * e\hat{}\left(\frac{17.269 * (\frac{5}{9} * (T - 32))}{237.3 + (\frac{5}{9} * (T - 32))}\right) \textbf{(I-P)}$$

Where:
e_s = Saturation vapor pressure in Pa (SI) or in. w.c. (I-P)
T = Dry bulb temperature in ºC (SI) or ºF (I-P)

1) Calculate the actual partial pressure of water vapor using the equation:

$$P_v = RH * e_s$$

Where:
P_v = Partial pressure of water vapor in Pa (SI) or in. w.c. (I-P)
RH = Relative humidity (%)
e_s = Saturation vapor pressure in Pa (SI) or in. w.c. (I-P)

2) Calculate the actual partial pressure of dry air using the equation:

$$P_d = P - P_v$$

Where:
Pd = Partial pressure of dry air in Pa (SI) or in. w.c. (I-P)
P_v = Partial pressure of water vapor in Pa (SI) or in. w.c. (I-P)
P = Standard condition pressure = 101,325 (Pa) or 407 in. w.c. (I-P)

The air density at standard conditions is 1.199 kg/m^3 (SI) or 0.075 lbm/ft^3 (I-P). Standard air qualities are defined as being at sea level with a pressure of 101,325 Pa (SI) or 407 in. w.c. (14.696 psi) (I-P), a temperature of 20ºC (SI) or 68ºF (I-P), and a relative humidity of 50% (AMCA 2016). In order to determine the magnitude of the shift of the fan curve, the calculated actual density must be divided by the standard density since pressure and power vary in accordance with the ratio of actual density to standard density (ASHRAE 2024). The ratio calculated must be multiplied by the pressure and power points on the fan curve, thus shifting the fan curve straight up or down depending on the actual density calculated.

Measuring Fan System Pressures

The fan system pressure measurements and calculations are determined by whether there is an outlet duct in the system. If an outlet duct is present, the system pressure is calculated in terms of fan total pressure. This is because both the static and velocity pressures at the outlet of the fan contribute to overcome system losses. If no outlet duct is present, the velocity pressure at the fan discharge is immediately dissipated and only the fan static pressure can be used to overcome system losses, so this setup requires calculating only the fan static pressure (AMCA 2018).

Measuring the static pressure at the fan inlet and outlet is necessary for both types of configurations, and this measurement can be taken using a pitot tube. The measurements should be made near the inlet and outlet of the fan, and where the airway between the measurement plane and the plane of interest is straight and without change in cross sectional area. Sometimes, finding a measurement plane farther upstream and downstream of the fan is necessary to avoid irregularities in the system to obtain accurate measurements. If there is a system component (duct fitting, filter, etc.) between the measurement plane and the plane of interest, the pressure loss must be calculated and attributed to the fan. The pressure loss of the system component can usually be found by the performance rating of the component, which can be provided by the manufacturer. Refer to AMCA 203 for the required adjustments to the measurements if the cross sectional area between the planes is different (AMCA 2018).

Determining the measurement plane is key to obtaining an accurate measurement. The qualifications for a well suited measurement plane are laid out in AMCA 203 (AMCA 2018). If the fan installation lacks one or more qualifications needed for a good measurement plane and the system cannot be modified, one can either:

- Accept the best location possible and evaluate the effects of the plane on the accuracy of the measurements.
- Use the alternate method to calculate FEI using the fan curve and measured airflow and fan speed.

As with the flow rate measurements, modifying the system temporarily for the sake of creating a good measurement plane is not recommended, since the modified system will not represent true operation of the fan system once the modification is removed.

For systems with an outlet duct, the velocity pressure at both the inlet and outlet must be measured in order to calculate fan total pressure. For systems with no outlet duct, only the velocity pressure at the inlet must be measured to calculate fan static pressure. The velocity pressure can be calculated using the measured airflow, density, and cross sectional area of the inlet or outlet area. The cross sectional area of the fan inlet or outlet can be determined from the fan catalog or by measuring it directly with a tape measure. Measurements should be made at the inlet or outlet flange, which is before any reductions (Wroblewski 2025). The velocity pressure can be determined by the following equations:

$$P_v = \frac{Q^2 * \rho}{2 * A^2} \textbf{ (SI)}$$

$$P_v = \frac{Q^2 * \rho}{1{,}203{,}409 * A^2} \textbf{ (I-P)}$$

Where:
P_v = Velocity pressure in Pa (SI) or in. w.c. (I-P)
Q = Flow rate in m^3/s (SI) or cfm (I-P)
A = Cross-sectional area of the inlet/outlet area in m^2 (SI) or ft^2 (I-P)
ρ = Density of the air in kg/m^3 (SI) or lbm/ft^3 (I-P)

Note that $\frac{Q^2}{A^2}$ is normally represented as V^2, where V = velocity in m/s (SI) or ft/s (I-P).

The fan total pressure is then calculated by the following equation, in units of Pa (SI) or in. w.c. (I-P):

$$P_t = P_{s,outlet} - P_{s,inlet} + P_{v,outlet} - P_{v,inlet}$$

Where:
P_t = Fan total pressure
$P_{s,\ outlet}$ = Fan outlet static pressure
$P_{s,\ inlet}$ = Fan inlet static pressure
$P_{v,\ outlet}$ = Fan outlet velocity pressure
$P_{v,\ inlet}$ = Fan inlet velocity pressure

For systems with no outlet duct, the outlet velocity pressure is removed from the above equation to calculate fan static pressure, as shown in the equation below, in units of Pa (SI) or in. w.c. (I-P):

$$P_s = P_{s,outlet} - P_{s,inlet} - P_{v,inlet}$$

Where:
P_s = Fan static pressure
$P_{s,\ outlet}$ = Fan outlet static pressure
$P_{s,\ inlet}$ = Fan inlet static pressure
$P_{v,\ inlet}$ = Fan inlet velocity pressure

Fan Curves

While locating the fan curve is not essential if the pressure readings can be measured accurately, it can help confirm the validity of the measurements taken. Additionally, the fan curve along with the measurements taken can help assess the presence of system effect factors (SEFs), which may negatively affect the system performance. SEFs refer to pressure losses caused by fan system inlet and outlet restrictions or other conditions that can influence fan system performance (AMCA 2011). Further investigations into the fan system and corresponding SEFs may lead to fan system design and efficiency improvements.

The fan curve is required if accurate pressure measurements cannot be taken. In this case, the fan curve is used to determine the operating pressure on the curve using other measurements taken (speed and airflow). Without accurate pressure measurements and the fan curve, calculating in situ FEI is not feasible.

Facilities in which the fan is installed may have on-site records of the fan curve, or it may be available through the fan manufacturer or project designer. If these sources cannot provide the fan curve, the serial/model number should be printed on the fan assembly, and this information can be used to locate a fan curve online or through the manufacturer. While this method may not always yield the most precise fan curve, it should be sufficient for the intended analysis.

Locating Fan Duty Point on Fan Curve

If accurate pressure measurements are obtained and the fan curve is available, it can be used to verify the measurements. While this step is not mandatory, it can help identify potential with measurements taken on the fan system itself. By utilizing the speed and another measurement (airflow, brake horsepower (BHP), or File Service Protocol (FSP)/File Transfer Protocol (FTP), the remaining two variables can be read from the fan curve. Compare the values derived from the curve with the measured values. If the difference is within ±10% of each other, no further investigation is warranted. However, larger discrepancies may arise for two reasons:

- The measured variables may not have been measured accurately. Double check the validity of these measurements by confirming functioning, accurate equipment, and suitable measurement locations.
- Large differences may suggest large SEFs in the configuration of the fan system. Further investigation is required to determine the presence of any SEFs that may be causing large discrepancies in the variables and whether calculating in situ FEI is feasible.

If accurate pressure measurements cannot be obtained, the fan curve becomes essential for calculating FEI. The measured fan speed and airflow must be used alongside the fan curve to estimate the operating FSP/FTP and BHP of the fan system. Use the FSP/FTP value taken from the fan curve to calculate FEP_{ref}.

The power meter reading (kW) that was taken to calculate FEP_{act} can be back-calculated to estimate BHP using estimates of motor, transmission systems, and, if applicable, control efficiencies. Compare this measured value to the BHP value taken from the fan curve and verify that the values are within ±10% of each other. If larger differences exist, the measured airflow and density values should be revalidated. If those measurements are revalidated and still show large discrepancies, significant SEFs may be present in the system, causing the fan to operate outside the expected fan curve. In such cases, calculating in situ FEI is not feasible.

FEP_{ref}

FEP_{ref} is calculated at the same duty point (flow and pressure) at which the actual fan system is operating when the power (FEP_{act}), flow, pressure, and density measurements are obtained. Those measurements taken on the actual fan system are used in the equations below to calculate FEP_{ref}. The entirety of this section references the equations and calculations laid out in ANSI/AMCA Standard 208-18, which defines a standardized and consistent calculation method for the FEI (AMCA 2018).

Reference Fan Electrical Input Power

The reference fan electrical input power is calculated at the actual fan system’s operating flow and pressure, which were measured in previous steps. The reference fan is defined as one that requires a certain reference fan shaft power, uses a V-belt drive, has a motor efficiency based on the IE3 level for a four-pole 60 Hz motor, and does not have speed control. The equation for calculating FEP_{ref} at a specific duty point (i) is shown below:

$$FEP_{ref,i} = H_{i,ref} * \left(\frac{1}{\eta_{trans,ref}}\right) * \left(\frac{1}{\eta_{mtr,ref}}\right) * \left(\frac{1}{\eta_{ctrl,ref}}\right) \textbf{ (SI)}$$

$$FEP_{ref,i} = H_{i,ref} * \left(\frac{1}{\eta_{trans,ref}}\right) * \left(\frac{1}{\eta_{mtr,ref}}\right) * \left(\frac{1}{\eta_{ctrl,ref}}\right) * 0.7457 \textbf{ (I-P)}$$

Where:

$H_{i,ref}$ = Reference fan shaft power in kW (SI) or hp (I-P)

$\eta_{trans,ref}$ = Reference transmission efficiency

$\eta_{mtr,ref}$ = Reference motor efficiency

$\eta_{ctrl,ref}$ = Reference motor controller efficiency

Reference Fan Shaft Power

The reference fan shaft power is calculated on a fan total pressure basis or a fan static pressure basis. For fans installed with an outlet duct, system pressures are typically calculated in terms of total pressure. For fans installed with no outlet duct, system pressures are calculated in terms of static pressure (AMCA 2018). Exceptions to this requirement include:

- Circulating fans and jet fans are non-ducted, but their sole purpose is to increase the momentum of the air.
- Laboratory exhaust fans typically require a minimum discharge velocity of 3,000–5,000 fpm in addition to their fan static pressure requirements.

Each of these non-ducted fan types uses the fan total pressure as a basis for FEI calculations to account for the velocity pressure at the fan outlet (AMCA 2018). The reference fan shaft power on a fan total pressure basis is calculated according to the following equations:

$$H_{i,ref} = \frac{(Q_i + 0.118) * \left(P_{t,i} + 100 * \left(\frac{\rho}{\rho_{std}}\right)\right)}{660} \quad \textbf{(SI)}$$

$$H_{i,ref} = \frac{(Q_i + 250) * \left(P_{t,i} + 0.4 * \left(\frac{\rho}{\rho_{std}}\right)\right)}{4186.38} \quad \textbf{(I-P)}$$

Where:

Q_i = Fan airflow in m^3/s (SI) or cfm (I-P)

$P_{t,i}$ = Fan total pressure in Pa (SI) or in. w.c. (I-P)

ρ = Air density in kg/m^3 (SI) or lbm/ft^3 (I-P)

ρ_{std} = Standard air density = 1.199 kg/m^3 (SI) or 0.075 lbm/ft^3

The reference fan shaft power on a fan static pressure basis is calculated according to the following equations:

$$H_{i,ref} = \frac{(Q_i + 0.118) * \left(P_{s,i} + 100 * \left(\frac{\rho}{\rho_{std}}\right)\right)}{600} \quad \textbf{(SI)}$$

$$H_{i,ref} = \frac{(Q_i + 250) * \left(P_{s,i} + 0.4 * \left(\frac{\rho}{\rho_{std}}\right)\right)}{3805.8} \quad \textbf{(I-P)}$$

Where:
Q_i = Fan airflow in m^3/s (SI) or cfm (I-P)
$P_{s,i}$ = Fan static pressure in Pa (SI) or in. w.c. (I-P)
ρ = Air density in kg/m^3 (SI) or lbm/ft^3 (I-P)
ρ_{std} = Standard air density = 1.199 kg/m^3 (SI) or 0.075 lbm/ft^3 (I-P)

Reference Fan Transmission Efficiency

Once the reference fan shaft power has been determined, the reference fan transmission efficiency can then be calculated. For consistency, the reference fan is defined as one having a V-belt transmission, regardless of the drive arrangement of the actual fan for which the FEI is calculated. The equation for calculating reference fan transmission efficiency is:

$$\eta_{trans,ref} = 0.96 * \left(\frac{H_{i,ref}}{H_{i,ref} + 1.64}\right)^{.05} \quad \textbf{(SI)}$$

$$\eta_{trans,ref} = 0.96 * \left(\frac{H_{i,ref}}{H_{i,ref} + 2.2}\right)^{.05} \quad \textbf{(I-P)}$$

Reference Fan Motor Efficiency

The reference fan motor efficiency can be calculated next. The reference fan is defined as having a motor efficiency based on the IE3 level for a four-pole 60 Hz motor. In order to simplify the calculation of part load efficiency for this reference fan motor and to avoid sizing and otherwise identifying a specific motor for this reference fan, a curve fit is used through the IE3 motor efficiency requirements. The result is a reference motor efficiency that varies continuously based on the required motor output power. The reference fan motor output power can be calculated from the following equation:

$$H_{t,ref} = \frac{H_{i,ref}}{\eta_{trans,ref}}$$

The reference fan motor efficiency is calculated according to the following equations using the coefficients found in the table below.

$$\eta_{mtr,ref} = A * \left(\log_{10}(H_{t,ref})\right)^4 + B * \left(\log_{10}(H_{t,ref})\right)^3 + C * \left(\log_{10}(H_{t,ref})\right)^2 + D * \left(\log_{10}(H_{t,ref})\right) + E \textbf{ (SI)}$$

$$\eta_{mtr,ref} = A * \left(\log_{10}(H_{t,ref} * 0.7457)\right)^4 + B * \left(\log_{10}(H_{t,ref} * 0.7457)\right)^3 + C * \left(\log_{10}(H_{t,ref} * 0.7457)\right)^2 + D * \left(\log_{10}(H_{t,ref} * 0.7457)\right) + E \textbf{ (I-P)}$$

Where:

Table 1. Coefficients for calculating reference fan motor Efficiency

	$H_{t,ref}$ < 185 kW (< 250 BHP)	$H_{t,ref}$ ≥ 185 kW (≥ 250 BHP)
A	-0.003812	0
B	0.025834	0
C	-0.072577	0
D	0.125559	0
E	0.850274	0.962

Reference Fan Motor Controller Efficiency

The reference fan is defined as a constant speed fan regardless of the control arrangement of the actual fan for which the FEI is calculated. Therefore, the motor controller efficiency is 100%.

$$\eta_{ctrl,ref} = 1$$

In Situ FEI Calculation

Use the equation below to calculate in situ FEI for the duty point:

$$In\ Situ\ FEI = \frac{FEP_{ref}}{FEP_{act}}$$

Costs

TAB contractors provided rough estimated costs for the equipment necessary to perform the required measurements. These are outlined below (Cunningham, D. 2025; Garner, J. 2025).

Table 2.Rough cost estimates for equipment to perform required measurements

Equipment	Measured Variable	Rough Estimated Cost
Digital manometer with pitot tube set	Airflow, pressure, barometric pressure	$2,000
Strobe tachometer	Fan wheel speed	$1,000
Thermometer	Temperature	$800
Power meter	Power	$15,000-$20,000
Hygrometer	Relative humidity	$400

Due to equipment pricing and the expertise needed to correctly operate and gather precise readings, hiring a licensed TAB contractor is highly recommended to gather measurements and calculate FEI. TAB contractors provided an estimated cost to hire a TAB contractor to perform this work for one fan system. Note that these prices may vary based on regional differences or the complexity of the fan system. The estimated costs are shown below (Cunningham, D. 2025; Garner, J. 2025).

Table 3. Estimated cost to hire a TAB contractor to perform work for one fan system

TAB contractor labor	$150/hr * 8hrs = $1,200
Specialized equipment	$500
Total	**$1,700**

Additional hours may be needed depending on the complexity of the system. The specialized equipment in the table above pertains to the power meter needed to measure the actual fan system input power. Although power meters are not commonly used by TAB contractors, they are recommended for the purpose of calculating FEI. TAB contractors should have the other equipment noted in the first table (manometer, tachometer, thermometer, hygrometer).

Many fan systems, especially newer systems, have sensors that continuously report measured values to a central building automation system (BAS). Power draw and airflow are values that are sometimes measured and available on the BAS, but the report authors have never seen fan static (or total) pressure and density on a BAS. It's likely not feasible to install instrumentation and controls to continuously and accurately calculate in situ FEI. Even if a system is accurately measuring airflow, fan wheel speed (direct drive fan) and VFD power draw, the FEI calculation may be impractical since the fan curve would need to be input into the BAS.

Accuracy

The measurements will have some level of inaccuracy, and that is to be expected. It is important to use the correct equipment with the highest level of accuracy possible as well as to find the most ideal locations to take measurements. In some instances, such as poor measurement conditions (e.g., unsteady flow, excess turbulence) or inaccurate measuring equipment, the level of inaccuracy may become so great that the measurements and calculations may become useless to accurately calculate in situ FEI.

AMCA 203 states the level of uncertainties for most measurements based on conditions encountered in typical field test situations.

Flow measurements typically have uncertainties that range from 2%–10% (AMCA 2011). To obtain the most accurate flow measurements, it is imperative to avoid areas of low velocity, which are hard to determine accurately, as well as areas of nonuniform velocity distribution, swirl, and other mass turbulence.

Pressure measurements typically have uncertainties that range from 2%–8% (AMCA 2011). To obtain the most accurate pressure measurements, one must avoid locations with turbulence or other unsteady flow conditions. The uncertainty range presented does not account for uncertainties that occur due to velocity pressure conversions, pressure losses between measurement plane and plane of interest, and determinations of the values of SEFs. It is best to avoid situations where determination of these uncertainties is required, since these variables are often difficult to accurately determine.

Power measurements taken by an industrial power meter to measure FEP_{act} typically have an accuracy of 1% for volts, amps, and power factor and 2% accuracy for watts (W) or kilowatts (kW) (AMCA 2011). It is recommended to measure watts or kilowatts directly.

Measuring fan wheel speed is typically measured by TAB contractors using a strobe light tachometer. High quality strobe tachometers have a demonstrated accuracy within 0.05%. As mentioned before, a rough idea of the fan wheel speed is needed to make sure the reading gathered is correct and that a multiple of the speed is not captured during data gathering.

Density calculations include measuring the dry bulb temperature via a thermometer, the relative humidity via a hygrometer, and the barometric pressure via a barometer.

- Thermometer: For temperatures up to 220°F, the thermometer used should be accurate to within 2°F of the measured value and readable to 1°F or finer. For temperatures above 220°F, the thermometer should be accurate to within 5°F and readable to 5°F or finer (AMCA 2011).
- Relative humidity: The hygrometer used to measure the relative humidity should have an accuracy of ±3% (Evergreen Telemetry 2025).
- Barometric pressure: The barometer used to measure the barometric pressure should be accurate to within 0.05 in-Hg of the measured value (AMCA 2011). TAB contractors can also use airport data to gather accurate barometric pressure readings depending on the proximity and elevation difference between the airport and the test site (Garner, J. 2025).

Uncertainties in density measurements and calculations are expected to be less than 3% (AMCA 2011). Since temperatures and pressures may vary, care must be taken to take multiple measurements over the course of the testing period to create the greatest accuracy.

Future Research

The authors recommend testing the process outlined in this document at a select number of facilities to evaluate its effectiveness and make any necessary adjustments to the process. Specific steps could include:

- Create a spreadsheet tool that will calculate FEP_{ref} & FEI based on user-input values.
- Use the process outlined in this document and, if developed, the spreadsheet tool to calculate FEI.
- Analyze the results, including both the process itself and the measurements taken. Specific aspects include, but are not limited to:
    - Identify fan system configurations that may require additional considerations and/or steps.
    - Identify additional instances where this process may not be possible.

The methodology outlined in this document can be used to calculate in situ FEI under as-found operations conditions or at design conditions. A key benefit of FEI is that it can be calculated at any duty point of the system. If the process outlined in this document proves to be feasible, another step could be to expand this testing to a larger population of fan systems and compare in situ FEI at design conditions (i.e., design airflow) to design FEI. This comparison should provide insight into fan system performance in the field, potential installation issues, and opportunities to refine FEI considerations at the design stage.

- This document only outlines the process of calculating in situ FEI and taking the measurements needed for that calculation. If the process proves to be feasible after further testing, follow-up research and applications could include:
- Determining the overall accuracy of in situ FEI
- Calculating fan energy savings based on in situ FEI
- Updating code requirements for minimum FEI

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