Laboratory Method of Testing Energy Performance of Fan-Filter Units, Version 1.2

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Foreword

This test standard is developed by the Lawrence Berkeley National Laboratory (LBNL), in collaboration with the Industrial Technology Research Institute (ITRI) of Taiwan and members of the Project Advisory Committee (PAC) for the high-performance building project supported by the California Energy Commission. This standard intends to provide a laboratory method for testing fan-filter units. This focuses solely on their energy and aerodynamic performance. The use of this method can provide comparable information on energy performance of fan-filter units (FFUs).

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Contents

1. Purpose

The purpose of this document is to provide a uniform test procedure for laboratory characterization of fan-filter units by determining energy performance in terms of unit airflow rate, static pressure, electrical power usage, and total pressure efficiency. The objective is to provide a method for performance testing and reporting based upon consistent procedures. This can then be referenced by and integrated into a relevant industry recommended practice or standard.

1.1 Intent

This document is intended for industry use, including fan-filter-unit manufacturers, end users, utility companies, and designers. It provides a means of obtaining energy performance of an FFU at selected conditions. It is not the purpose of this document to guide field-testing, although some of the techniques can be applied to field-testing.

1.2 Review and Amendment

This document is subject to review and amendment as experience in its use and technologies advance.

2. Scope

2.1 The scope of this document

This document includes terminology used in the filter and cleanroom industry. This document is intended to apply specifically to fan-filter energy and air movement performance. It may be used as the basis for gathering baseline information and for comparison of fan-filter units' energy performance equipped with typical filters (e.g., ULPA or HEPA). This procedure may be used in development of a more comprehensive procedure such as the Recommended Practice to be developed by the Institute of Environmental Sciences and Technology (IEST).

The procedure is limited to test FFUs with filter media for removing particulates under normal cleanroom environmental conditions. This document is not intended to cover filters used for controlling airborne molecular contamination (AMC). Users of FFUs dealing with AMC should refer to relevant publications for more information, such as IEST RP 035 "Design Considerations for Airborne Molecular Contamination Filtration Systems in Cleanrooms."

2.2 The non-coverage of this document

The scope of this document does not cover testing procedures for

- Acoustic performance
- Vibration performance
- Particulate filtration efficiency
- Individual fan motor efficiency
- Airborne molecular contamination filter media
- Outlet airflow uniformity
- Field performance

3. Definitions

3.1 Terms used in this document - <To be added>

4. Nomenclature

4.1 Notation

4.1.1 Q (Unit Airflow Rate): Actual airflow rate through the FFU tested under a specific static pressure, in m^3s^{-1} or cubic foot per minute (cfm).

4.1.2 V (Airflow Speed): Unit airflow rate divided by the net FFU face area under a specific static pressure, in m/s or foot per minute (fpm).

4.1.3 V_n (Nominal Airflow Speed): Unit airflow rate divided by the gross FFU face area under a specific static pressure, in m/s or fpm.

4.1.4 p_{stat} (Static Pressure), in Pa or inch water.

4.1.5 p_{total} (Total Pressure): Sum of the static pressure and the velocity pressure, in Pa or inch water.

4.1.6 Fan Wheel Rotational Speed: Number of rotation per minute (RPM).

4.1.7 P_t (Total Power Usage): Total electric power input to operate the FFU at certain airflow conditions, including fan motor, controller, etc., in kW or HP. In the cases that lighting is incorporated into an FFU, the gross total power usage should include lighting.

4.1.8 P_v (Airflow Dynamic Power): The dynamic power of the airflow through an FFU, in kW or HP.

4.1.9 EPI (Energy Performance Index): Unit's total power usage normalized by the airflow rate of an FFU, in $W/(m^3s^{-1})$ or W/cfm.

4.1.10 E_t (Total Pressure Efficiency): Ratio of airflow dynamic power to the total power input to an FFU, in % (dimensionless).

5. Instrumentation, Testing Setup, Control and Methods

5.1 Key testing parameters

The purpose of conducting laboratory testing is to obtain characterization data of energy performance for FFUs under various operating conditions, and to provide performance reporting for specific FFUs with HEPA/ULPA filters. In addition to reporting relevant characteristics of an FFU, such as filtration efficiency and filter size, this document specifies the required tests applicable to this standard and suggests additional (or optional) tests relevant to the energy performance.

The required tests include the unit airflow rates (or actual airflow speeds), total power usage, and the static (and total) pressures across the FFU. The total power usage shall be measured at a range of airflow rates with the actual static (total) pressure gain, and should include the power consumption of other components associated with the FFU, such as embedded lighting and motor controller.

The additional (optional) tests can include airflow uniformity[i], leaks, etc.

5.2 Key instrumentation and accuracy recommendation

5.2.1 Key instrumentation

5.2.1.1 Unit airflow rate

5.2.1.2 Static and total pressure

5.2.1.3 Total power usage

5.2.2 Recommendations for good accuracy

Good engineering practice conforming to relevant industry standards should be performed to achieve acceptable accuracy in measurement data. For the measurement device, users of this procedure should pursue good measurement accuracies (e.g., an error within 5%). For valid comparisons, accuracies of the measurement device shall be verified and reported.

5.3 Testing setup

5.3.1 Principles

The amount of airflows through the FFU being tested shall be controllable within a reasonable range for the FFU. The test setup should be consistent with other standard test methods. The measurements and evaluation of FFU performance shall include multi-points for various operation conditions in order to generate performance curves (e.g., similar to fan's aerodynamic performance). The setup shall ensure no air leaks between the enclosed testing

[i] In addition to energy performance of an FFU, airflow uniformity is also an important aspect of FFU performance. The issue of testing of airflow uniformity would be worthy of addressing in a future project.

system and the ambient. The measurement of airflow through the FFU can be conducted upstream or downstream of the FFU, with an error within 5% or 5 cfm.

5.3.2 Testing device layout

For laboratory testing, ideally the FFU tested will be mounted horizontally on the exit of the air chamber. As an alternative, the FFU can be mounted vertically on the exit of the air chamber[i].

5.4 Control and Methods

To control the airflow rate across the FFU tested, an ancillary fan and a damper are needed to modulate static (and total) pressures and airflows across the FFU. The ancillary fan and the damper shall be installed in upstream of airflows directed through the FFU.

[i] FFUs are most commonly installed horizontally in cleanrooms to provide vertically downward airflows. Further investigations and confirmation about difference between vertical and horizontal FFU setup would be needed for existing data (from ITRI) to be comparable.

5.4.1 FFU with a single-speed-drive motor

The FFU shall be tested at the fixed fan-wheel rotational speed, while adjusting damper positions modulates static pressures and airflows across the FFU. The corresponding static pressure, unit airflow rate (and airflow speed), and total power usage shall be recorded.

5.4.2 FFU with a multi-speed-drive motor

The FFU shall be tested for each fixed level of fan-wheel speeds offered by the motor. Adjusting damper positions modulates the static pressure across the FFU. The corresponding static pressure, unit airflow rate (and airflow speed), and total power usage shall be recorded for each level of rotational speed.

5.4.3 FFU with a variable-speed-drive (VSD) motor

For an FFU equipped with speed modulation device using a VSD, the fan motor in FFU shall be set at various speeds for testing. Similar to the FFU with multi-speed-drive motor, the corresponding static pressure, unit airflow rate (and airflow speed), and total power usage shall be recorded for each level of the fan-wheel's rotational speeds, e.g., 20%, 40%, 60%, 80%, and 100% of the maximal speed.

5.5 Measurements

5.5.1 Unit airflow rate measurement

This procedure provide two options to obtain unit airflow rates. The unit airflow rate, airflow speed, total power usage shall be recorded at a range of operating points adjusted by varying the static pressures across the FFU.

5.5.1.1 Airflow measurement upstream of FFU

The setup contains a multiple-nozzle bank for recording airflow rates through the tested unit. The air from the immediate downstream of the FFUs can be discharged to the atmosphere or a space with a specific static pressure. The following diagram illustrates the experimental setup for measuring airflows, static (and total) pressure, and total power usage. Measuring the airflow using this setup, which is consistent with ASHRAE/AMCA standard, can provide most accurate airflow measurement (e.g., 1%) and may best emulate common setting in real cleanrooms.

Figure 1 illustrates an exemplar setup using nozzles to measure airflow upstream of airflow path directed through an FFU. For simplicity, the FFU is shown to be vertical, although a horizontal FFU is desired to best emulate common FFU applications in cleanrooms.

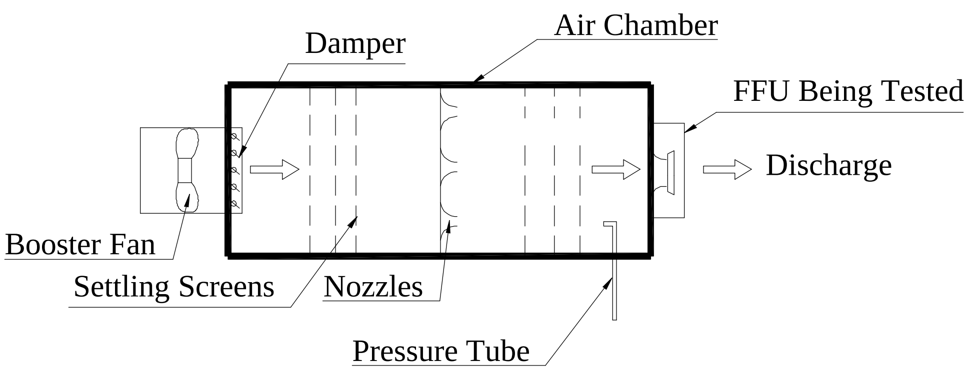

Figure 1 An illustrative test setup – preferably FFU would be horizontal

5.5.1.2 Airflow measurement downstream of FFU

The setup requires an accurate flow hood to be deployed in the downstream of airflows through the FFU. This test procedure requires that measurement errors be within 5% of the measured airflow rate. Cautions however shall be taken to identify the accurate flow hood for this application[i].

It is imperative that measures be taken to verify the accuracy claims of flow hood manufacturers. The challenge of using this method is to ensure and prove that flowrate measurement results from using flow hoods that are commercially available are accurate, which requires a comparison of between flow hood measurements and standard measurements using nozzles as described in 5.5.1.1.

Measures should be taken to ensure no leakage between the connection of the FFU and the flow hood. For FFUs of various sizes, it is necessary to use appropriate tapered connectors for accurate flow measurement.

<to insert a figure showing the setup of airflow measurement downstream of FFU>

Figure 2 An illustrative test setup – *airflow measurement downstream of FFU*

5.5.2 Static (total) pressure across the FFU

Concurrent measurements of static (total) pressure across the FFU shall be recorded.

[i] Currently, there is no specific standard for evaluating measurement accuracies of flow hoods that are commercially available.

5.5.3 Total power usage

Concurrent measurements of total power usage supplied to the FFU shall be recorded. Appropriate power meters shall be used to measure true power usage of the unit. In the case that lighting device is integral to the FFU, the total power usage shall include its power consumption.

5.5.4 Ambient conditions

The test can be conducted at various ambient conditions. Cautions must be taken to ensure that the airflow through the testing device is isothermal; otherwise, necessary corrections shall be undertaken to account for the impact on the measured data. The ambient conditions (elevation, temperature, and humidity) and the airflow conditions shall be recorded.

6. Reporting Test Results

6.1 Descriptive Parameters

6.1.1 Physical size

The physical size, weight, noise, vibration, efficiencies, maintenance, capacity, and reliability of an FFU are among the major considerations of product design and selection. Physical dimensions (height, length, and width) of the fan filter unit and weight shall be reported.

6.1.2 Filter characteristics

6.1.2.1 Filter type, material, and dimensions shall be reported. The net face area of the FFU shall be reported.

6.1.2.2 Particulate filtration efficiency shall be specified. This will be based upon the data information from filter supplier, e.g., 99.99% for 0.3 micron-meter particles. Details of specifying acceptable filter testing standards can be found in relevant literatures, such as IEST RP-CC-006 or ISO 14644-3.

6.1.2.3 Pressure resistance can be derived from its performance curve with airflow.

6.1.3 Fan and motor

It is common that an FFU is equipped with backward inclined centrifugal impellers. The report shall, nevertheless, include the type and size of the fan wheel and motor used in the FFU. For example, the parameters should include the following: impeller diameter, number of blades, and blade pitch.

An FFU can be equipped with an AC external rotor motor (single-phase or three-phase) or a DC external rotor motor. Constant-speed-drive motors are commonly employed; however, some motors are equipped with variable-speed-drive to allow on-field adjustment of fan wheel speeds. The option of adding a VFD is to provide an easy means to adjust airflow in the field if values are above or below prescribed criteria for some applications.

6.2 Test Conditions

6.2.1 Unit airflow rate and fan-wheel rotational speed

Actual unit airflow rates (and/or airflow speeds) shall be recorded corresponding to various static pressures.

The fan wheel rotational speeds (RPM) should be recorded and reported.

6.2.2 Static pressure across the FFU

To generate various testing points, the static pressure shall be controlled at various levels (e.g., 0.2 inch water through 1.5 inches water). The performance metrics can then be obtained for a specific static pressure (e.g., 0.5 inch water) or a specific actual unit airflow rate (e.g., 70 fpm, up to 550 cfm for a 2ftx4ft FFU).

6.2.3 Total power usage

Total electric power usage shall include the fan, frequency drive motor, speed control device, etc. In the cases that lighting is incorporated into an FFU, the gross total power usage should include lighting. Power factors shall be reported.

6.2.4 Ambient air condition

Recorded air conditions shall be converted to standard air condition for calculating air density. The recorded data (elevation, temperature, and humidity) shall be used for the air density conversion to the equivalent standard condition (i.e., 1 atm, 20°C).

6.3 Key Performance Metrics

6.3.1 Unit airflow rates (and/or actual airflow speeds) corresponding to various static pressures Maximum unit air flowrate shall be reported.

6.3.2 Total power usage corresponding to various static pressures across the FFU. The total power usage should also be reported for a certain unit airflow rate with the actual static pressure gain.

6.3.3 Total pressure efficiency at various static pressures or unit airflow rates. The total pressure efficiency changes with operating pressures.

6.3.4 Energy performance index (EPI) at various static pressures or unit airflow rates. EPI can be reported directly based upon a selective static pressure of concerns, e.g., 125 Pa (or 0.5 inch water). As an alternative, EPI can be reported for a specific unit airflow speed (e.g., 70 fpm) along with the actual static pressure gain.

6.4 Reporting Format

6.4.1 Descriptive parameters specified in Section 6.1 shall be reported.

6.4.2 Experimental data obtained through the testing shall be reported and should be presented in graphical format. Graphical format is to provide performance curves with a range of testing point tested.

6.4.2.1 The report shall contain performance data of the static (and total) pressure gains, total power usage, total pressure efficiency, and EPI as a function of unit airflow rate for specific fan-wheel speeds.

6.4.2.2 As an addition to 6.4.2.1, the performance curves can also be presented as a function of actual airflow speeds.

6.4.2.3 The report shall include specification of sizes of the fan and fan-filter unit, and the motor speed control for the performance curves produced.

6.4.3 A simplified table format can be derived for other purposes, such as performance rating[i].

7. References

1) ISO. 2002. ISO 14644-3 Cleanrooms and associated controlled environments — Part 3: Metrology and test methods. The Institute of Environmental Sciences and Technology (IEST). Rolling Meadows, IL.

2) ISO. 2001. ISO 14644-4 Cleanrooms and associated controlled environments — Part 4: Design, Construction and Start-up. The Institute of Environmental Sciences and Technology (IEST). Rolling Meadows, IL.

3) NEBB. 1996. Procedural Standards for Certified Testing of Cleanrooms, 2nd Edition 1996 - Chapter 5: Airflow Test Procedures.

4) ISO 14644-7 - Cleanrooms and associated controlled environments — Part 7: Separative enclosures (clean air hoods, gloveboxes, isolators, minienvironments). The Institute of Environmental Sciences and Technology (IEST). Rolling Meadows, IL.

5) ASHRAE. 2003. ASHRASE Handbook - HVAC Applications: Chapter 16 - Clean Spaces.

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8) The Institute of Environmental Sciences and Technology (IEST). 1993. IEST RP CC 001.3 - HEPA AND ULPA Filters. Rolling Meadows, IL.

9) The Institute of Environmental Sciences and Technology (IEST). 1999. IEST-RP-CC002.2: Unidirectional Flow Clean Air Devices. Rolling Meadows, IL.

10) The Institute of Environmental Sciences and Technology (IEST). 1997. IEST RP-CC-006.2: Testing Cleanrooms. Rolling Meadows, IL.

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12) The Institute of Environmental Sciences and Technology (IEST). 1995. IEST-RP-CC021.1: Testing HEPA and ULPA Filter Media. Rolling Meadows, IL.

13) The Institute of Environmental Sciences and Technology (IEST). 1999. IEST RP CC 034.1 - HEPA and ULPA Filter Leak Tests. Rolling Meadows, IL.

[i] See the “Usage of results” section in the Addendum

14) The Institute of Environmental Sciences and Technology (IEST). IEST RP CC 035 - Design Considerations for Airborne Molecular Contamination Filtration Systems in Cleanrooms. Rolling Meadows, IL.

8. Addendum

Informative (not part of this test standard)

8.1 Non-energy performance

Methods of testing acoustics, particulate filtration efficiency, and filter leak have been addressed in specific industry standards and/or recommended practices. Although the measurements of these parameters are not covered in this procedure, FFU manufacturers should make this information available as part of the product specifications. Vibration issue is important and needs further development outside the scope of this document. ,

8.2 Flow uniformity

In addition to filtration performance, FFU's airflow uniformity is an important element to characterize the overall performance of HEPA or ULPA filters; therefore, airflow uniformity is an important element required for cleanroom certification, and should be part of the product specification. Because cleanroom certification would involve operational testing in facilities, relevant industry standards or guidelines for recommended practices address certain aspects of uniformity testing. For example, users can refer to IEST RP-CC-002.2 "Unidirectional Flow Clean Air Devices" for relevant information.

8.3 FFU position

It is believed that the effect of the positioning the FFU tested (i.e., vertically vs. horizontally) on measurement data (unit airflow rate, power usage) is minimal[i].

8.4 Filter leak

This protocol assumes that the energy impact due to filter leak is minimal (negligible). The possible filter leak may become an additional issue for the IEST RP. Currently another IEST RP covers the filter leak issue.

8.5 Interpretation of results

8.5.1 Interpretation: Result from using this standard test should not automatically be considered as being "certified." Although an AMCA certified facility is not necessarily required for performance testing using this procedure, results from using this procedure in a certified facility can be certifiable by a recognized entity such as AMCA.

8.6 Usage of results

Suppliers and designers can use the performance data to specify performance metrics. The actual operating conditions of different cleanroom systems (e.g., static pressure ranging from 50 to 400 Pa) can vary dramatically; therefore, FFU product specification report shall include the pressure and efficiency (power consumption) within the achievable airflow speed and unit airflow rates for the laboratory testing.

[i] To confirm this without actual test data or reference is a challenge. There is not any published study to address this; therefore, additional comparison tests will be needed to address the issue. This can become a topic for future investigations.

8.7 Method of developing energy performance rating

While it is almost impossible to specify a single point that is representative for every actual application (similar to the performance rating for a chiller), a baseline rating can be developed to provide a criterion to encourage the adoption of energy-efficient FFUs. The key to the baseline information is to define and establish the energy metric and referenced base for rating purpose that is suitable for FFUs of various types.

Energy Performance Index (EPI, W/cfm) is recommended for the use of performance comparison, such as kW/ton for chillers). This metric can be used to formulate baseline information on FFUs' energy performance under a certain operating condition. Based upon a pool of FFUs tested, users such as utility can draw a line of ranking line EPI (W/cfm) for each typical operating point to generate baseline information.

This addendum provides two options for the methods of calculating EPI, one at the static pressure of 125 Pa (about 0.5 inch water), and the other at actual airflow speed at 0.35 m/s (or 70 fpm), which corresponds to an actual unit airflow rate up to 550 cfm for a 2x4 FFU, and up to 1100 cfm for a 4x4 FFU.

8.7.1 FFUs with single-speed-drive motors. The following offers the possible solutions to direct performance comparing.

8.7.1.1 The performance data obtained through this procedure can be presented by the energy metric (i.e., EPI) under a certain unit airflow rate (in the form of airflow speed, e.g., 70 fpm), with an achievable static pressure that surpasses a minimal value (e.g., using 0.5 inch water as the threshold).

Table 1 Exemplar Reporting on EPI (W/cfm)

Minimal Static Pressure – Column Airflow speed – Row	P_{stat} = 0.5 inch water = 125 Pa	P_{stat} = 1 inch water = 250 Pa
70 fpm (= 0.35 m/s), up to 560 cfm for 2x4 FFU	0.42	N/A

8.7.1.2 An alternative to 8.7.1.1 is to provide the energy metric (i.e., EPI) under a specific static pressure (e.g., 0.5 inch water), with the understanding that the actual unit airflow rate would normally be different from unit to unit.

Figures 3 and 4 provide exemplar results from the small sample data provided by ITRI[i].

[i] Relevant information can be found in the draft paper "Laboratory Evaluation of Fan-filter Units' Aerodynamic and Energy Performance," which will appear in *Journal of the IEST*: 2004 Edition, Institute of Environmental Sciences and Technology (IEST), Rolling Meadows, IL.

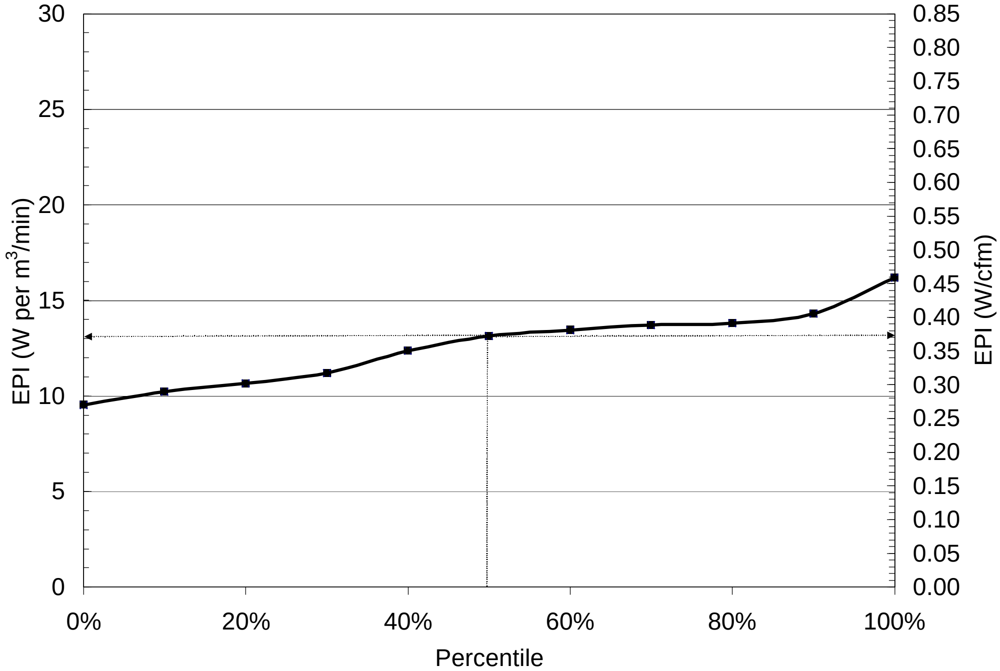

Figure 3 Performance-rating based upon EPI at 70 fpm

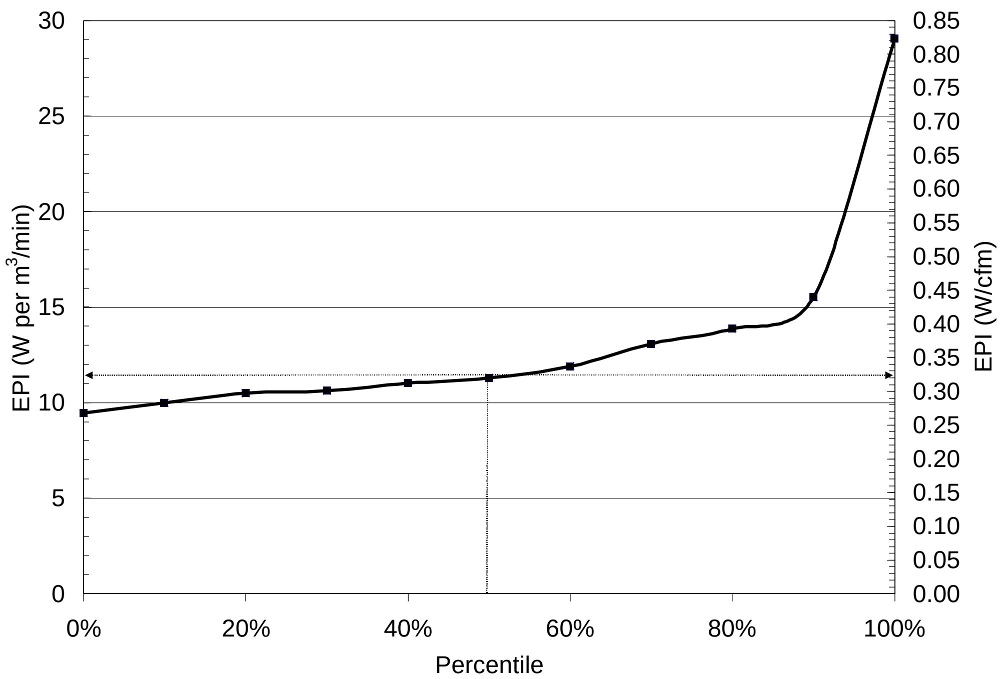

Figure 4 Performance-rating based upon EPI at 0.5 inch water

8.7.2 FFUs with multi-speed-drive motors. Parallel rating curve can be developed using the method in 8.7.1 (single-speed-drive) for each level of motor speed. The eventual rating score may be given based upon the performance at the highest speed.

8.7.3 FFUs with variable-speed-drive motors. With a VSD drive, using the standard test will allow the user to produce performance metrics at a combined condition with a specific unit airflow rate and a specific static pressure. There are various alternatives that we can establish for the rating purpose.

8.7.3.1 The performance data obtained through the procedure can be presented as the energy metric (i.e., EPI) under a certain unit airflow rate (in the form of airflow speed, e.g., 70 fpm), with a specific static pressure (e.g., 0.5 inch water).

8.7.3.2 Similar to the single-speed-drive motor FFUs, the EPI may be calculated for selective airflow (e.g., 70 fpm, 90 fpm) and selective static pressures (e.g., 0.5 inch water and 1.0 inch water) in the following table.

Table 2 Exemplar Reporting on EPI (W/cfm) - for rating purpose

Static Pressure – Column Airflow speed - Row	P_{stat} = 0.5 inch water (= 125 Pa)	P_{stat} = 1 inch water (= 250 Pa)
70 fpm (= 0.35 m/s), up to 560 cfm for 2x4 FFU	0.3	0.35
90 fpm (= 0.46 m/s), up to 720 cfm for 2x4 FFU	0.25	0.27

Note: The EPI numbers in the table are randomly plugged in for illustration purpose.

8.7.3.3 The EPI can be obtained for the maximum speed under a fixed static pressure.