Proposal Information Template – Commercial and Industrial Fans and Blowers

2017 Appliance Efficiency Standards

Air Movement and Control Association International (AMCA), Appliance Standards Awareness Project (ASAP), Northwest Energy Efficiency Alliance (NEEA), Natural Resources Defense Council (NRDC), American Council for an Energy-Efficient Economy (ACEEE), Pacific Gas and Electric Company (PG&E), San Diego Gas and Electric (SDG&E), Southern California Edison (SCE), and SoCalGas®

Contents

Purpose

This document is a report template to be used by researchers who are evaluating proposed changes to the California Energy Commission’s (Commission) appliance efficiency regulations (Title 20, California Code Regulations, §§ 1601 – 1608). This report specifically covers Commercial and Industrial Fans and Blowers.

We are proposing test procedures and efficiency standards for commercial and industrial fans. We are also recommending requirements regarding reporting, labeling, and marketing materials/selection software to assist CEC in implementing the proposed efficiency standards.

Our proposal contains the following sections:

- Product/Technology Description
- Overview
- Methodology
- Proposed Standards and Recommendations
- Analysis of Proposal
- Conclusions
- References

Product/Technology Description

Commercial and industrial fans and blowers (or “fans”) are used in a wide variety of applications such as commercial building HVAC systems, commercial kitchen exhaust systems, industrial processes, and agricultural ventilation.

There are three basic types of fan impellers: axial, centrifugal, and mixed flow. In an axial fan, the air enters and exits the impeller parallel to the shaft axis. In a centrifugal fan, the air enters the impeller parallel to the shaft axis and exits perpendicular to the shaft in a radial direction. Finally, in a mixed flow fan, the direction of airflow through the impeller takes on characteristics that are intermediate between axial and centrifugal fans: the air exits the fan in a direction that is neither parallel nor perpendicular to the shaft.

Fans can be either direct-drive or belt-drive. In a direct-drive fan, the fan impeller is directly connected to the motor, and there are no power transmission losses. In a belt-drive fan, the fan impeller is connected to the motor through a set of belts and sheaves mounted on the motor shaft and fan shaft, and there are associated power transmission losses. The speed of a direct-drive fan can be adjusted by changing the speed of the motor, for example by using a variable frequency drive (VFD). The speed of a belt-drive fan can be adjusted by adjusting the belts and sheaves.

Fans can be driven by various types of motors including single-phase motors, three-phase induction motors, and advanced motor technologies such as electronically commutated motors (ECMs).

As we describe in the section on scope, we are recommending seven fan types to be subject to efficiency standards: axial inline; axial panel; centrifugal housed (excluding inline and radial); centrifugal unhoused; centrifugal inline and inline mixed flow; radial housed; and power roof/wall ventilators. Below are descriptions of each of these fan types.

<u>Axial inline fans</u>
Axial inline fans include tube axial and vane axial fans. Tube axial and vane axial fans both include a cylindrical housing. Vane axial fans also incorporate straightening vanes in front of or behind the blades, which allow for generating higher pressures and which can also increase efficiency. The inlet and/or outlet of an axial centrifugal housed fan can be ducted. Axial inline fans are used in applications such as general ventilation and industrial processes.

Source: http://www.greenheck.com/products/detail/21

<u>Axial panel fans</u>
Axial panel fans, which are often referred to as “propeller fans,” are a type of axial fan. The inlet and outlet of a panel fan are not ducted. Panel fans transport air from one space to another such as for ventilation through a wall in factories and warehouses.

Source: http://www.lorencook.com/pw.asp

Centrifugal housed fans

Centrifugal housed fans include forward-curved, backward-curved, backward-inclined, and airfoil fans. Forward-curved, backward-curved, and backward-inclined fans have fan blades of a single thickness, while airfoil fans have backward-inclined airfoil blades. In a centrifugal housed fan, the airflow exits into a housing that directs the air through a single outlet. The inlet and/or outlet of a centrifugal housed fan can be ducted. Centrifugal housed fans are commonly used to supply ventilation air and are also used in industrial process applications.

Source: http://www.nyb.com/backward-inclined-single-width-class-4-fans/

Centrifugal unhoused fans

Centrifugal unhoused fans, which are often referred to as "plenum fans," typically use the same impellers as those in centrifugal housed fans. In a centrifugal unhoused fan, the airflow enters through a panel and is discharged to free space. Centrifugal unhoused fans are commonly used in air handling applications.

Source:
https://www.peerlessblowers.com/products/unhoused_centrifugal_blowers/

Centrifugal inline and inline mixed flow fans

Centrifugal inline and inline mixed flow fans often have cylindrical housing similar to axial inline fans, but they have either centrifugal or mixed flow impeller designs. Centrifugal inline fans can also have square or rectangular housing, and they have forward-curved, backward-curved, backward-inclined, or airfoil blades. Inline mixed flow fans have impellers with characteristics in between those of axial and centrifugal impellers. Centrifugal inline and inline mixed flow fans are typically used for general ventilation applications.

Source: http://www.aerovent.com/products/inline-centrifugal-mixed-flow-fans/amx-mixed-flow-fans

Radial housed fans

Radial housed fans are a type of centrifugal fan that has blades that extend radially from a central hub. Radial housed fans are typically used for material handling.

Source: http://www.tcf.com/products/radial-bladed-fans/rbo---industrial-radial-blade-fan-paddle-wheel

Power roof/wall ventilators

Power roof/wall ventilators exhaust air from a building and include housing designed to prevent precipitation from entering the building. They are typically mounted on a roof, but can also be mounted on a wall. Power roof/wall ventilators can include various impeller designs.

Source: https://www.captiveaire.com/catalog/showCatalogList.asp?cattypeid=4

Overview

In this proposal we are recommending test procedures and efficiency standards for commercial and industrial fans. We are also recommending requirements regarding reporting, labeling, and marketing materials/selection software.

Table 1: Summary of Proposal

Topic	Description
Description of Standards Proposal/Framework of Roadmap	Commercial and industrial fans are used in a wide variety of applications such as commercial building HVAC systems, commercial kitchen exhaust systems, industrial processes, and agricultural ventilation. We are proposing efficiency standards for fans based on a metric called fan energy index (FEI), which compares the power consumption of a fan at a given duty point to the power consumption of a reference fan at the same duty point. We have developed an innovative approach where the standards would apply to the entire certified operating range of each fan model. This approach would drive better fan selection to reduce power consumption in addition to encouraging improved fan design.
Technical Feasibility	The most important product efficiency opportunity associated with commercial and industrial fans is better fan selection. Additional opportunities include improved fan design and more-efficient transmission, motors, and motor controllers. The proposed efficiency levels are technically feasible based on their current availability in the market. Most fan models will not need to be redesigned in order to comply with our proposed standards. Instead, the manufacturer would certify the compliant operating range of current models, which in most cases would be smaller than the currently-advertised operating range.
Energy Savings and Demand Reduction	Our proposed standards would provide 39 GWh of estimated first-year electricity savings for California and 1,118 GWh per year after stock turnover. Estimated peak demand reductions after stock turnover are 128 MW.
Environmental Impacts and Benefits	Our proposed standards would provide environmental benefits by reducing energy consumption. Reduced energy consumption results in reduced pollutant emissions from power plants and reduced pressure on energy resources.
Economic Analysis	Our proposed standards would provide estimated electricity bill savings of $164 million for California consumers after stock turnover.
Consumer Acceptance	Our proposed approach for standards would provide consumers with an easy way to evaluate the efficiency of different fans for a particular application and would drive consumers to make better fan selections. It would also allow consumers to specify an FEI level above the minimum standard, which would drive additional savings. Furthermore, the proposed standard level will not impact the utility or performance of fans in consumer applications, but will rather reduce the energy consumption associated with providing the same service.
Other Regulatory Considerations	Our proposed standards would not interfere with any local, federal, or other regulations/legislation.

Methodology

AMCA and efficiency advocates have been working together for many years to develop an approach for fan efficiency standards. In addition, all of our organizations were represented on the U.S. Department of Energy's (DOE's) Appliance Standards and Rulemaking Federal Advisory Committee (ASRAC) working group for commercial and industrial fans and blowers.[1] The ASRAC working group was comprised of representatives of fan, motor, and HVAC manufacturers, consulting engineering firms, utilities, efficiency advocates, and DOE. The ASRAC working group reached consensus in 2015 on a number of items related to the scope of coverage, test procedures, and an efficiency metric. Our proposal to CEC, summarized in this document, is largely based on the term sheet developed by the ASRAC working group. In addition, DOE has published three notices of data availability (NODAs) with analysis for commercial and industrial fans, and our proposal is supported by DOE's analysis.

Since the conclusion of the ASRAC working group, AMCA has published one standard (AMCA 207) and is in the process of finalizing another (AMCA 208) that form the basis of our proposed test procedure (along with AMCA 210). AMCA 207 is based on concepts developed by the ASRAC working group for calculating fan electrical input power based on measured fan shaft power and default values for transmission, motor, and motor controller efficiency. AMCA 208 defines our proposed efficiency metric (Fan Energy Index; FEI) and its calculation, and efficiency advocates have participated in the development of this standard.

Proposed Standards and Recommendations

We are proposing efficiency standards for fans. Our proposed standards would establish a minimum fan energy index (FEI) for all fans included in our proposed scope. The minimum FEI level would apply to the entire manufacturer-declared operating range of each fan model. Below is our recommended regulatory language for scope, definitions, test methods, and standards.

Section 1601 Scope.

(x) <u>Fans which are: stand-alone and one of the following categories: axial inline fan, axial panel fan, centrifugal housed fan, centrifugal unhoused fan, centrifugal inline fan, inline mixed flow fan, or power roof/wall ventilator;</u>

<u>(1) with rated shaft input power greater than or equal to 1 horsepower, or, for fans without a rated shaft input power, electrical input power greater than or equal to 1 kW, and fan airpower less than or equal to 150 horsepower; and</u>

<u>(2) excluding the following:</u>

1. <u>Radial housed unshrouded fans with diameter less than 30 inches or a blade width of less than 3 inches;</u>
2. <u>Safety fans;</u>
3. <u>Circulating fans;</u>
4. <u>Induced flow fans;</u>

[1] With the exception of ACEEE.

5. Jet fans;

6. Cross flow fans; and

7. Embedded fans.

Section 1602 Definitions.

(x) Fans.

"Fan" means a rotary bladed machine used to convert power to air power, with an energy output limited to 25 kJ/kg of air, consisting of an impeller, a shaft, bearings, and a structure or housing; and includes any transmissions, driver, and/or controls if integrated, assembled, or packaged by the manufacturer at the time of sale.

"Stand-alone fan" means a fan in at least a minimum testable configuration, as defined in section 4.1 of AMCA 208, including any motor, transmission, or motor controller if included in the rated fan, as well as any appurtenances included in the rated fan, excluding the impact of any surrounding equipment whose purpose exceeds or is different than that of the fan. Standalone fans do not include provisions for air conditioning, air filtration, air mixing, air treatment, or heating. Examples include power roof ventilators, side-wall exhaust fans, whole house fans, inline fans, ceiling fans, jet tunnel fans, and induced flow laboratory exhaust fans.

"Axial panel fan" means a fan with an axial impeller mounted in a short housing that can be a panel, ring, or orifice plate. The housing is typically mounted to a wall separating two spaces and the fans are used to increase the pressure across this wall. Inlets and outlets are not ducted.

"Axial inline fan" means a fan with an axial impeller and a cylindrical housing with or without turning vanes. Inlets and outlets can optionally be ducted.

"Centrifugal housed fan" means a fan with a centrifugal impeller in which airflow exits into a housing that is generally scroll shaped to direct the air through a single fan outlet. Inlets and outlets can optionally be ducted.

"Centrifugal unhoused fan" means a fan with a centrifugal impeller in which airflow enters through a panel and discharges into free space. Inlets and outlets are not ducted. This fan type also includes fans designed for use in fan arrays that have partition walls separating the fan from other fans in the array.

"Centrifugal inline fan" means a fan with a centrifugal impeller in which airflow enters axially at the fan inlet and the housing redirects radial airflow from the impeller to exit the fan in an axial direction. Inlets and outlets can optionally be ducted.

"Inline mixed flow fan" means a fan with a mixed flow impeller in which airflow enters axially at the fan inlet and the housing redirects radial airflow from the impeller to exit the fan in an axial direction. Inlets and outlets can optionally be ducted.

"Radial housed fan" means a fan with a radial impeller in which airflow exits into a housing that is generally scroll shaped to direct the air through a single fan outlet. Inlets and outlets can optionally be ducted.

"Power roof/wall ventilator (PRV)" means a fan with an internal driver and a housing to prevent precipitation from entering the building and with a base designed to fit, usually by means of a roof curb, over a roof or wall opening.

"Centrifugal PRV supply" means a PRV with a centrifugal impeller that supplies air to a building. Inlets are not ducted and outlets are typically ducted.

"Radial housed unshrouded fan" means TBD.

"Safety fan" means TBD.

"Circulating fan" means a fan used for moving air within a space that has no provision for connection to ducting or separation of the fan inlet from its outlet, designed to be used for the general circulation of air.

"Induced flow fan" means a housed fan with a nozzle and windband whose outlet airflow is greater than its inlet airflow due to induced airflow. All of the flow entering the inlet will exit through the nozzle. The flow exiting the windband will include the nozzle flow plus the induced flow.

"Jet fan" means a fan used for producing a high velocity flow of air in a space. Typical function is to add momentum to the air within a tunnel. Inlets and outlets are not ducted.

"Cross flow fan" means a fan with a housing that creates an airflow path through the impeller in a direction at right angles to its axis of rotation and with airflow both entering and exiting the impeller at its periphery. Inlets and outlets can optionally be ducted.

"Embedded fan" means a fan that is set or fixed firmly inside or attached to a surrounding piece of equipment whose purpose exceeds that of a fan or is different than that of a stand-alone fan. This equipment may have safety or energy efficiency requirements of its own. Examples of embedded fans include supply fans in air handling units, condenser fans in heat rejection equipment, tangential blowers in air curtain units, and induced or forced draft combustion blowers in boilers or furnaces.

"Fan air power" means the fan output power as determined in accordance with the test procedure specified in Section 1604(x).

Section 1604 Test Methods for Specific Appliances.

(x) Fans.

The test method for fans is AMCA 208. (once finalized) Each fan category must be tested according to the pressure basis and installation type outlined in the following table:

Fan Category	Pressure Basis	Installation Type
Axial inline fans	Total	D
Axial panel fans	Static	A
Centrifugal housed fans and centrifugal PRV supply fans	Total	B
Centrifugal unhoused fans	Static	A
Centrifugal inline fans and inline mixed flow fans	Total	B

Radial housed fans	Total	D
Power roof/wall ventilators (excluding centrifugal PRV supply fans)	Static	A

When calculating the default motor efficiency, the coefficients for 60 Hz IE3 motors shall be used.

Section 1605.3 State Standards for Non-Federally Regulated Appliances.

(x) Fans.

The FEI of fans manufactured on or after a date which is 2 years after the date of adoption at each manufacturer-declared operating point shall be not less than 1.00.

Proposed Definitions

The definitions proposed above were developed based on discussions in the ASRAC Working Group and contained in a draft term sheet.[2] These definitions were also considered in the development of AMCA 208, and some of these definitions have been incorporated into the latest version. We believe that these definitions provide a clear, unambiguous basis to establish the scope of the proposed fan regulations, as well as the testing and rating requirements for the subject fans. These fan definitions present the consensus position of the industry, with extensive input from manufacturers on the technical specifications of the equipment, as well as energy efficiency advocates, who reviewed the definitions to ensure that they were robust and comprehensive (i.e. avoided loopholes).

There are two definitions that we are still developing for “radial housed unshrouded fan” and “safety fan.” We have included placeholders for these definitions in the section above on “Proposed Standards and Recommendations.” We plan to submit our recommendations for these two definitions once we have developed them.

Proposed Test Procedure

We propose that the test procedure be based on the industry test standards ANSI/AMCA Standard 210-16,[3] ANSI/AMCA Standard 207-17,[4] and AMCA 208 (once finalized[5]). The combination of these three AMCA standards allows for calculating a comparable FEI for any fan at any duty point regardless of the fan configuration (i.e. bare-shaft fan, fan sold with motor, fan sold with motor and controller) or the way the fan is tested (i.e. measuring fan shaft power and using a calculation approach to determine fan electrical input power or directly measuring fan electrical input power).

AMCA 210 includes methods for measuring airflow, pressure, fan shaft power, and fan air power. AMCA 210 also includes a method for conducting a wire-to-air test.

[2] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0143. pp. 18-19.
[3] All references to AMCA 210 in this document refer to ANSI/AMCA Standard 210-16.
[4] All references to AMCA 207 in this document refer to ANSI/AMCA Standard 207-17.
[5] AMCA 208 has recently been approved by the AMCA 208 Committee and is expected to be publicly available in winter 2017.

AMCA 207 provides a method for calculating fan electrical input power for cases when a manufacturer is selling a fan with a motor but chooses not to conduct a wire-to-air test. AMCA 207 includes default values for transmission efficiency, motor efficiency, and motor controller efficiency.

Finally, AMCA 208 is a standard for calculating FEI for any fan at any duty point. AMCA 208 specifies methods for determining both a fan's actual electrical input power and the reference electrical input power at any duty point.

We also propose that the test procedure incorporate three existing provisions of AMCA Publication 211-13 (Rev. 09-17),[6] which prescribes the procedures to be used for AMCA's Certified Ratings Program. Specifically, we propose that the test procedure incorporate:

1. Section 8.3.1, which specifies that "The manufacturer is responsible for determining the product sizes to be tested and the number of tests that must be performed to provide the data necessary for the development of certified ratings." This section allows for just a single test to be conducted to determine certified ratings while also not prohibiting a manufacturer from conducting more than one test.
2. Section 8.3.2, which allows for using the fan laws to calculate the ratings of geometrically similar fans at other speeds and/or smaller sizes.
3. Section 10, which specifies the process for verification testing, including the specification that check tests can be conducted at any published speed and the specifications of check test tolerances.

While AMCA 208 describes the determination of FEI_t and FEI_s based on total or static efficiency, respectively, we recommend only one pressure basis and installation type be allowed for determining compliance with the Title 20 standard in order to the ensure that the standard is fair, equitable, and consistently applied for a given fan type. Table 2 shows the ducted and unducted fan categories, which reflect the ASRAC term sheet (Appendix C of the term sheet). We note that some fan types can be used in both ducted and unducted applications. However, most fans within each fan category are applied in the same configuration (ducted or unducted), and the categorization in Table 2 reflects the most common application for each fan category.

Table 2. Ducted and unducted fan categories

Ducted fans	Unducted fans
Axial inline	Axial panel
Centrifugal housed and centrifugal PRV supply fans	Centrifugal unhoused
Centrifugal inline and inline mixed flow	Power roof/wall ventilators (except centrifugal PRV supply fans)
Radial housed	

We are also recommending a particular installation type for testing for each fan category, which also reflect the ASRAC term sheet (Recommendation 7). The four installation types (from AMCA 210) are:

A: free inlet, free outlet

B: free inlet, ducted outlet

[6] All references to AMCA 211 in this document refer to AMCA Publication 211-13 (Rev. 09-17).

C: ducted inlet, free outlet

D: ducted inlet, ducted outlet

Table 3 shows our recommended installation types for testing for each fan category:

Table 3. Installation type for testing of each fan category

Fan category	Installation type
Axial inline	D
Axial panel	A
Centrifugal housed and centrifugal PRV supply fans	B
Centrifugal unhoused	A
Centrifugal inline and inline mixed flow	B
Radial housed	D
Power roof/wall ventilators (except centrifugal PRV supply fans)	A

Finally, we are recommending that centrifugal power roof/wall ventilator supply fans be tested as centrifugal housed fans, which is consistent with the intent of the ASRAC term sheet (Recommendation 30). Most power/roof wall ventilators are exhaust fans and do not have an outlet duct. In contrast, PRV supply fans do typically have an outlet duct, and therefore it is appropriate to rate PRV supply fans using total pressure and in a ducted configuration.

We are also recommending that the following sentence be included in the test procedure: “When calculating the default motor efficiency, the coefficients for 60 Hz IE3 motors shall be used.” AMCA 208 is intended to be applicable both within and outside North America, and it therefore includes default motor efficiency coefficients for both 50 Hz and 60 Hz motors. Our suggested clarification would make it explicit that the 60 Hz coefficients should be used when calculating FEI to determine compliance with any Title 20 standards.

As noted above, in addition to AMCA 208, which provides the method for determining FEI for a given fan, we recommend referencing certain applicable sections of AMCA 211, which specify processes for determining certified ratings (based on test data) and for verifying those ratings. In particular, AMCA 211 specifies the sample size of fans that must be tested for a given model (which may be one fan if deemed sufficient by the manufacturer) and the process for translating test data to additional speeds and/or smaller, geometrically similar fans, which allows a fan manufacturer to test one or several sizes/speeds of a given fan model and use those test data to develop ratings for the entire fan performance range and for other sizes of the same fan. These provisions significantly reduce test burden, as a given fan model family may have multiple impeller diameters (i.e. sizes) and speeds for each size at which the fan can be sold. This could result in as many as 100 unique tests for a single fan model family. AMCA and the Efficiency Advocates agree that the Fan Laws provide well understood, consistent, and theoretically sound methods for translating test data from a few tests to the entire product family.

Section 10 of AMCA 211 describes the process for verification testing employed by the AMCA Certified Ratings Program, which randomly tests fans at any published size and speed to ensure the published ratings are within a reasonable tolerance of the tested fan performance. AMCA 211 also specifies those tolerances that, based on manufacturer experience, AMCA believes are appropriate and reasonable to apply to fans, given the expected manufacturing uncertainty and testing uncertainty inherent in the verification process.

We recommend that CEC follow these same procedures for developing certified ratings for Title 20 compliance and for verifying Title 20 compliance, as this will significantly reduce burden on manufacturers and allow them to use the vast amounts of existing data and certifications they have for their fan models based on the AMCA Certified Ratings Program. Leveraging this data makes sense and will allow manufacturers to work towards the proposed compliance date of 2 years after adoption of the regulation, focusing their efforts on non-compliant fans. If new and/or different certification or verification processes are used, fan manufacturers may have to retest and recertify all or most of their fan models, which would be a significant and unnecessary burden on manufacturers, as it would not lead to significantly greater energy savings and would likely extend the compliance date that manufacturers could reasonably achieve.

Proposed Standard Metrics

We propose that the efficiency metric be the fan energy index (FEI) as defined in AMCA 208. FEI is the ratio of the electrical input power of a reference fan to the electrical input power of a given fan model, both calculated at the same duty point, i (airflow and pressure). A higher FEI value indicates higher efficiency and lower power consumption. FEI provides an easy way to compare the power consumption of different fans at the same duty point. For example, a fan with an FEI of 1.2 at a given duty point would consume 17% less power than a fan with an FEI of 1.0.[7]

The FEI metric is a "wire-to-air" metric, which means that it incorporates not only the efficiency of the bare-shaft fan, but also that of any transmission, motor, and/or motor controller sold with the fan. The advantages of a wire-to-air metric include that it more fully represents the actual power consumption of a fan and that it encourages not only more-efficient fan selections and fan designs, but also more-efficient transmission, motors, and motor controllers.

FEI is calculated using total pressure for ducted fans and static pressure for unducted fans. A fan's total pressure is composed of static pressure and velocity pressure components. The rationale for using total pressure for ducted fans and static pressure for unducted fans is that ducted fans can use both static pressure and velocity pressure to overcome system pressure losses. In contrast, with unducted fans, any velocity pressure at the fan discharge is immediately dissipated, making it unusable for any further work.

To illustrate the importance of using static pressure for unducted fans, Table 4 shows three actual selections of wall mounted fans for a design point of 30,000 CFM at 0.1 in. wg. Based on total efficiency, the first selection (Model SBE-2L42) would appear to be the most efficient. However, this model actually consumes the most power at the design point: 50% more power than that consumed by the second selection (Model SBE-2L48) and more than double the power consumed by the third selection (Model SBE-2L54).

Table 4. Three selections of wall mounted fans for a design point of 30,000 CFM at 0.1 in. wg.

Model	Static Efficiency	Total Efficiency	Brake Horsepower (HP)
SBE-2L42	10%	70%	5.1
SBE-2L48	15%	66%	3.4
SBE-2L54	21%	65%	2.4

Source: https://ecaps.greenheck.com/.

[7] (1.2 – 1.0) / 1.2

While total efficiency thus is a poor predictor of actual power consumption for unducted fans since the velocity pressure is wasted, static efficiency correlates with power consumption. In Table 4, the third selection has the highest static efficiency and the lowest power consumption.

AMCA 208 defines FEI based on total pressure (FEI_t) and static pressure (FEI_s) as follows:

$$FEI_{t,i} \text{ or } FEI_{s,i} = \frac{\text{Reference Fan Electrical Input Power}}{\text{Actual Fan Electrical Input Power}} = \frac{FEP_{ref,i}}{FEP_{act,i}}$$

The reference fan electrical input power (in kW) is calculated as:

$$FEP_{ref,i} = \mathrm{H_{i,ref}}\left(\frac{1}{\eta_{\mathrm{trans,ref}}}\right)\left(\frac{1}{\eta_{\mathrm{mtr,ref}}}\right)\left(\frac{1}{\eta_{\mathrm{ctrl,ref}}}\right) \times 0.7457$$

The reference fan electrical input power is calculated using reference values for fan shaft power ($\mathrm{H_{i,ref}}$), transmission efficiency ($\eta_{\mathrm{trans,ref}}$), motor efficiency ($\eta_{\mathrm{mtr,ref}}$), and motor controller efficiency ($\eta_{\mathrm{ctrl,ref}}$). The determination of these values for different fan configurations is described in detail in AMCA 208.

The reference fan shaft power is calculated as a function of the airflow and pressure at the specific duty point. For ducted fans, $\mathrm{H_{i,ref}}$ (in HP) is calculated as:

$$\mathrm{H_{i,ref}} = \frac{(Q_i + 250)(P_{t,i} + 0.40 \times \frac{\rho}{\rho_{std}})}{6343 \times 0.66}$$

And for unducted fans, $\mathrm{H_{i,ref}}$ (in HP) is calculated as:

$$\mathrm{H_{i,ref}} = \frac{(Q_i + 250)(P_{s,i} + 0.40 \times \frac{\rho}{\rho_{std}})}{6343 \times 0.60}$$

In the equations for calculating reference fan shaft power, Q_i is the fan airflow at duty point i; $P_{t,i}$ and $P_{s,i}$ are fan total pressure at duty point i and fan static pressure at duty point i for ducted and unducted fans, respectively; ρ is the fan air density; and ρ_{std} is standard air density.

The values of 0.66 for ducted fans and 0.60 for unducted fans in the equations for reference fan shaft power are reference fan efficiency values. However, the equations include an airflow constant (250) and a pressure constant (0.40), which have the effect of lowering the required fan efficiency for fans that deliver low airflows and/or pressures. The FEI metric thus accounts for the inherent efficiency differences of fans that deliver different combinations of airflows and pressures, making it applicable to the wide range of applications served by commercial and industrial fans and comparable across these diverse applications.

To illustrate how FEI accounts for the inherent efficiency differences of fans that deliver different airflows and pressures, Figure 1 below shows how the required fan total efficiency for a ducted fan varies as a function of airflow for various total pressures (0.2, 0.5, 1.0, 2.0, and 3.0 in. wg.) for an FEI of 1.0. FEI in particular accounts for the inherent lower efficiency of fans that provide duty points with low pressures. For example, as can be seen in Figure 1, at an airflow of 10,000 CFM, the required fan total efficiency at a total pressure of 3.0 in. wg. is 57%, while the required efficiency at a total pressure of 0.2 in. wg. is just 21%.

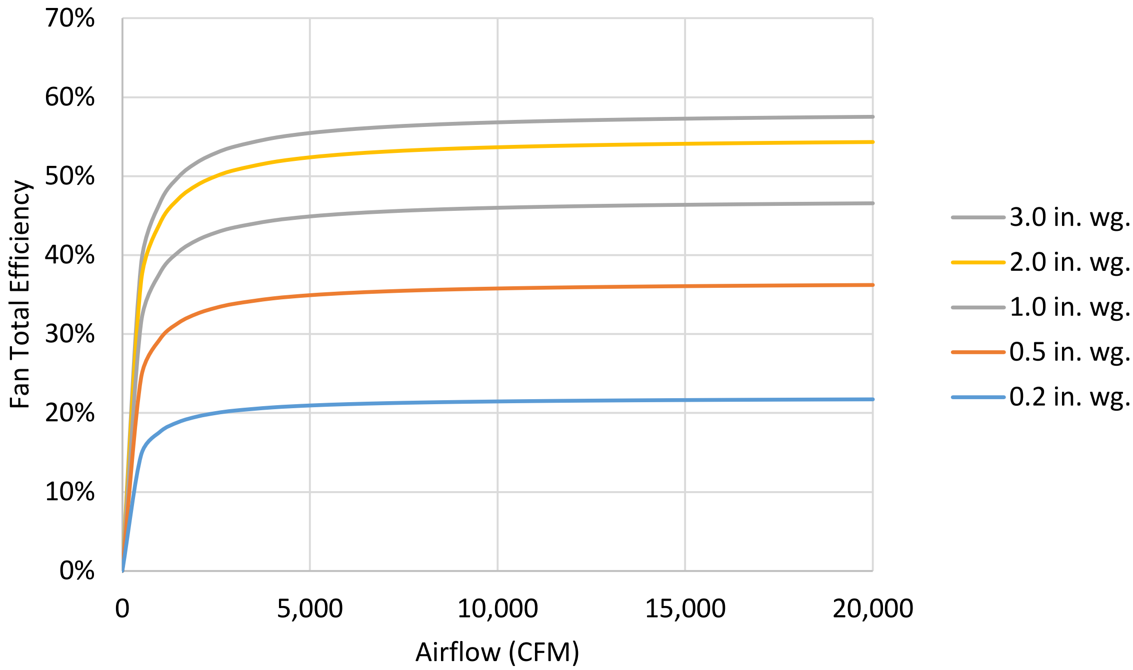

Figure 1. Required fan total efficiency as a function of airflow at different total pressures for an FEI of 1.0

Proposed Framework

Our proposed framework for standards for fans is unique in that the standards would apply to the entire certified operating range of each fan model. The rationale for this approach is that it would encourage better fan selection, which has a huge impact on actual efficiency and power consumption. Since the efficiency of a fan varies widely across its operating range, the peak efficiency of a fan has little relevance to actual efficiency and energy consumption in the field. Therefore, an approach for standards focused on driving better fan selection has the potential to provide significantly greater savings than an approach based on the efficiency of a fan at just one or a few operating points. (The importance of fan selection is further discussed in the section on "Product Efficiency Opportunities.")

Under our proposed approach, manufacturers would certify the compliant operating range of each fan model. The compliant operating range would encompass the operating points that meet the minimum FEI level. We are also proposing requirements regarding marketing materials and selection software to help ensure that purchasers are selecting fans that meet the minimum FEI level at their design point. These additional requirements are essential in order to capture the energy savings anticipated by the standard.

Figure 2 shows an example of the compliant operating range of a fan model along with the rated maximum speed (RPM), which would be the highest rated speed at which at least one operating point meets the standard.

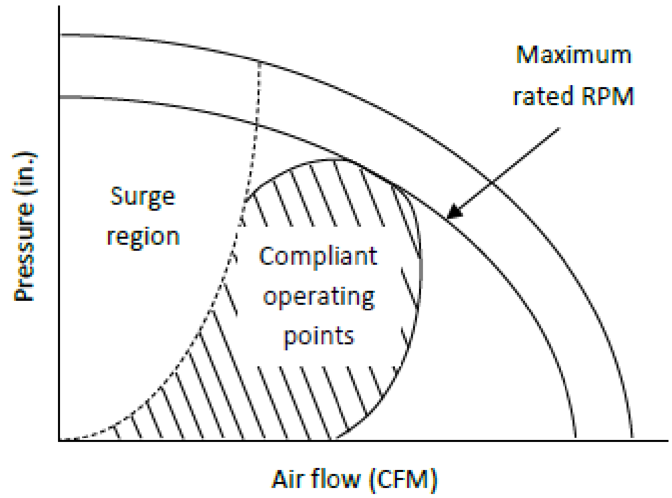

Figure 2. Example of a fan's compliant operating range and rated maximum speed (RPM)

Proposed Standard Levels

We are proposing that all fans in our recommended scope of coverage would need to meet a minimum FEI of 1.00 at all manufacturer-declared operating points as shown in Table 5.

Table 5. Proposed standard levels

Fan Type	Impeller Type	Minimum FEI
Centrifugal Housed	AF, BC, BI, Radial Tipped	1.00
	Radial	1.00
	FC[8]	1.00
Centrifugal Unhoused	AF, BC, BI, MF	1.00
Inline and Mixed Flow	AF, BC, CI, MF, FC, Propeller	1.00
Power Roof/Wall Ventilators	AF, BC, CI, MF, FC, Propeller	1.00
Panel	Propeller	1.00

Notes: AF = airfoil, BC = backward curved, BI = backward inclined, MF = mixed flow, and FC = forward curved.

An FEI of 1.00 is approximately equivalent to EL3 in DOE's NODA III analysis.[9] We believe that our recommended FEI level appropriately balances potential energy savings and burdens on manufacturers.

[8] The parties submitting this proposal have not resolved the issue of whether forward curved fans should be considered separately from other centrifugal housed fans. However, this issue does not need to be resolved now since we are recommending the same FEI level for all fans.

[9] EL 3 in the NODA III analysis corresponds to target efficiencies of 66% and 62% for ducted and unducted fans, respectively. An FEI of 1.00 based on the draft AMCA 208 Standard corresponds to target efficiencies of 66% and 60%, respectively.

Proposed Reporting Requirements

As noted above, our proposed standards are unique in that they would apply to the entire certified operating range of each fan model. We have a suggested approach for reporting requirements that consists of two parts, with the goal of providing information about each fan model in a format similar to that for other products currently in CEC's Modernized Appliance Efficiency Database System (MAEDS), while also providing access to information about each of the certified operating points for each fan model.

Information about each fan model

The first part of our suggested approach for reporting requirements would address information about each fan model. The table below shows our suggestions for what the fields of the MAEDS could look like for fans. Like with other products, we envision that the MAEDS would contain one row for each certified fan model. The suggested fields are based on the reporting requirements recommended by the DOE ASRAC working group (Recommendation 27).

Manufacturer	Fan Type	Product Line	Model #	Motor manufacturer (or N/A)	Motor model # (or N/A)	Controller manufacturer (or N/A)	Controller model # (or N/A)	Belt-driven or direct-drive	Maximum rated speed (RPM)	Link to full performance information
ABC	Centrifugal housed	DEF	1234	N/A	N/A	N/A	N/A	Belt-driven	2,612	Link to cut sheet, separate data table, or software

Each fan model would, at a minimum, contain the fan manufacturer name, fan type, model number, whether the fan is belt-driven or direct-drive, the fan's maximum rated speed, and a link to full performance information. Fan models that are part of a product line would also list the product line. Fans that are sold with motors would also include the motor manufacturer and model number, and fans that are sold with motors and controls would include information about the motor as well as the controller.

We note that the ASRAC working group did not specifically recommend that the reporting requirements include fan type, product line, or whether the fan is belt-driven or direct-drive. However, we believe that it would be useful for this information to be provided. Fan type would assist in identifying whether a fan is rated based on total pressure or static pressure. Product line may be useful since a manufacturer can have many models that are part of the same product line, and this may help manufacturers, consumers, and CEC better compare and evaluate the relationship among different fan models. This differentiation is common in the industry today and will help consumers associate the correct FEI rating with the appropriate fan model.

Indicating whether a fan is belt-driven or direct-drive could help consumers be able to better compare the ability of fans to serve a given operating point. With belt-drive fans and direct-drive fans with controllers, the fan speed can be adjusted to meet a variety of different operating points, whereas direct-drive fans without controllers provide only a number of discrete operating speeds and associated performance curves. Therefore, while the speed of a belt-drive fan (or a direct-drive fan with a controller) can be adjusted to meet the specified operating point, a direct-drive fan without a controller will operate on one of the fixed performance curves, which may overshoot the specified operating point, resulting in increased power consumption. This is illustrated in Figure 3.

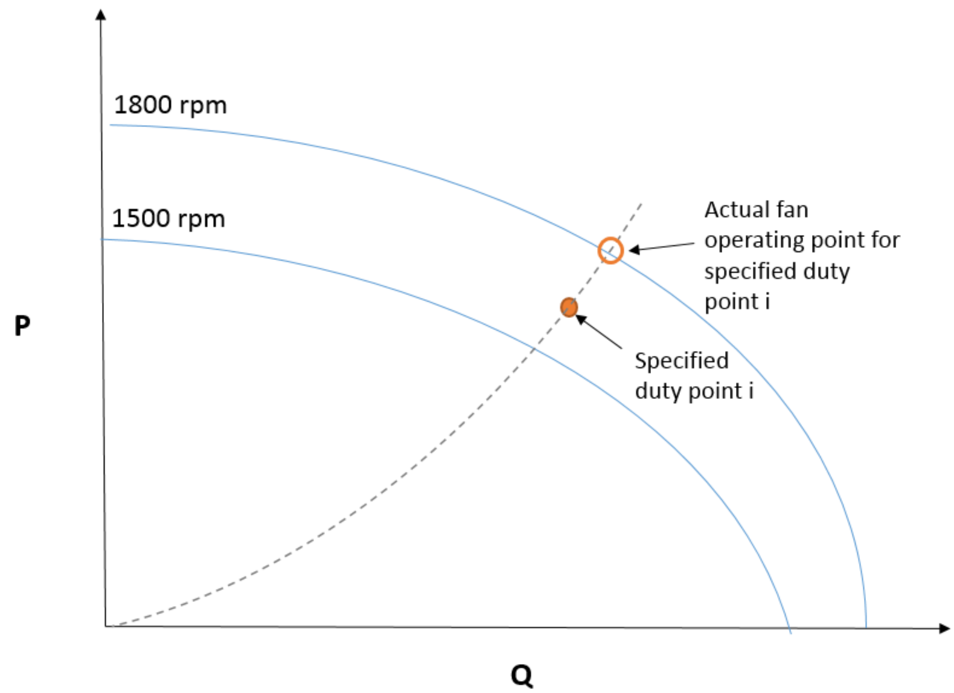

Figure 3. Relationship of actual operating point and specified duty point for direct-drive fans without a controller

Therefore, information about whether a fan is belt-driven or direct-drive (in addition to whether a fan is sold with a controller would help consumers understand the flexibility of different fan models in serving a specific operating point. For bare shaft fans that have the ability to be sold either way, the database could also contain “either” or “both” or “N/A” for those fans.

The maximum rated speed for each fan model would be the highest rated speed at which at least one operating point meets the standard.

We also believe that it may be useful for the MAEDS to contain general information about the certified operating range. In the table below we suggest some additional potential fields for the MAEDS. These additional fields would describe the minimum and maximum values for airflow, pressure, fan speed, fan shaft power, FEP, and FEI for the compliant operating range. This information may be useful for consumers and the market to compare the efficiency of different fan models without accessing the detailed performance information. For example, one could compare two fan models with similar operating ranges, but one with a higher FEI range across the specified operating range. Or, one could compare two different fan models, but one has a large operating range and one has a very small operating range due to its inefficiency. Users could also consult these general summary fields and use them to filter the database to determine which models they wanted to retrieve detailed information for.

Min airflow (CFM)	Max airflow (CFM)	Min static/ total pressure (in. wg)	Max static/ total pressure (in. wg)	Min speed (RPM)	Max speed (RPM)	Min fan shaft power (HP) (or N/A)	Max fan shaft power (HP) (or N/A)	Min FEP (kW)	Max FEP (kW)	Min FEI	Max FEI
7,500	20,000	0	5	1010	2612	1.65	27.34	0.95	18.35	1.01	1.67

Information about each certified operating point

The link to the full performance information (which we are suggesting could be contained in one of the fields in the MAEDS) would be the second part of our suggested reporting requirements. Since our proposed standards apply to the entire certified operating range of each fan model, it is important that information be available about each operating point. While one potential approach would be for the MAEDS to contain a row for each operating point, we recognize that this could be cumbersome to implement. Instead, we are suggesting that the row of data for each fan model in MAEDS could include a link to the full performance information. The link could potentially go to a manufacturer's selection software, a model's cataloged performance information, or a standardized data table. This standardized data table could be maintained by CEC, or potentially by a third party, such as AMCA.

We suggest that the following information be required for each manufacturer-declared operating point, which reflects the recommendations of the ASRAC working group (Recommendation 27):

- Airflow (CFM)
- Pressure (in. wg. static and total for unducted and ducted fans, respectively)
- Speed (RPM)
- Fan shaft power (HP)
- FEP (kW)
- FEI (FEI_S for unducted fans, FEI_T for ducted fans)

We note that the fan shaft power would not be required to be reported for fans tested wire-to-air (since a wire-to-air test does not involve measurement of shaft power).

The table below shows an example of what a standardized data table could look like (in this case for an unducted fan).

Manufacturer ABC - Model 1234

Airflow (cfm)		Static Pressure (in.wg) 0	1	2	3	4	5
7500	RPM	1010	1180	1331	1468		
	BHP	1.65	3.07	4.6	6.18		
	FEP	1.23	2.29	3.43	4.61		
	FEI_S	1.67	1.54	1.46	1.40		
10000	RPM	1230	1378	1505	1626	1738	1843
	BHP	2.56	4.32	6.18	8.19	10.23	12.29
	FEP	1.91	3.22	4.61	6.11	7.63	9.17
	FEI_S	1.42	1.45	1.43	1.40	1.38	1.36
12500	RPM	1467	1590	1709	1814	1912	2009
	BHP	3.86	5.93	8.16	10.43	12.83	15.36
	FEP	2.88	4.42	6.09	7.78	9.57	11.46
	FEI_S	1.18	1.31	1.35	1.37	1.36	1.35
15000	RPM	-	1819	1921	2021	2112	2196
	BHP	-	8.02	10.55	13.22	15.93	18.7
	FEP	-	5.98	7.87	9.86	11.88	13.95
	FEI_S	-	1.16	1.25	1.29	1.31	1.33
17500	RPM	-	2058	2146	2233	2320	2402
	BHP	-	10.7	13.54	16.5	19.58	22.77
	FEP	-	7.98	10.10	12.31	14.61	16.99
	FEI_S	-	1.01	1.13	1.20	1.24	1.27
20000	RPM	-	-	2382	2459	2535	2612
	BHP	-	-	17.22	20.48	23.86	27.34
	FEP	-	-	12.85	15.28	17.80	20.40
	FEI_S	-	-	1.02	1.11	1.17	1.21

While we have suggested a specific approach for reporting requirements, we look forward to working with CEC Staff on any necessary clarifications and/or modifications such that the reporting requirements can be successfully implemented.

We also encourage CEC to make the database available as soon as possible and to allow manufacturers to voluntarily certify early. The availability of data certified to CEC would help facilitate complementary efficiency program efforts.

Proposed Requirements Regarding Marketing Materials and Selection Software

Manufacturers typically provide information about a fan's operating range in catalogs or other marketing materials. Many manufacturers also have selection software, which allows a user to input a design flow and pressure, and the software returns a list of potential selections. Today, the operating points shown in catalogs and the fan selections returned by software are typically limited only by the surge region and the fan's maximum speed (which is dependent on the structural integrity of the fan wheel). However, under our proposed approach for standards, the compliant operating range of a given fan will likely be smaller than the currently-advertised operating range.

In order for our proposed standards to be effectively implemented, it is important that there be requirements regarding marketing materials and selection software in order to help ensure that purchasers are selecting fans that meet the standard at the design point. Specifically, it is important that manufacturers be allowed to market their fans for only the compliant operating range.

For catalogs or other marketing materials showing the fan operating range, we are suggesting that a manufacturer must either:

- Show only those operating points that meet the California standards, or
- Produce separate catalogs and marketing materials that contain only those operating points that meet the California standards

For selection software, we are suggesting that software must either:

- Return only those selections that meet the California standards, or
- Require location as an input (e.g. address, zip code) and for locations in California, return only those selections that meet the California standards

Manufacturers would have the choice of setting up their software so that only California-compliant selections are shown, regardless of where the fan is being sold, or setting up their software so that only California-compliant selections are shown when a user inputs a California location.

As with our suggestions for reporting requirements, we look forward to working with CEC Staff on any necessary clarifications and/or modifications to these suggested requirements regarding marketing materials and selection software such that they can be successfully implemented.

Proposed Labeling Requirements

We believe that a required label would be valuable both to help with enforcement and to facilitate complementary efforts by efficiency programs and energy codes (e.g. ASHRAE 90.1). A label could be something temporarily affixed to the fan and included at the time of sale or it could be required information to be included on a fan's physical nameplate.

We are suggesting specific information to be required on a label for cases when the design point is known as well as for cases when the design point is unknown. The suggested labeling requirements reflect Recommendations 31 and 32 of the ASRAC term sheet. Table 5 shows our suggested labeling requirements.

Table 5. Proposed labeling requirements when the design point is known and unknown

Design point known	Design point unknown
Model number	Model number
Serial number or date of manufacturing	Serial number or date of manufacturing
Design flow and pressure (static/total for unducted/ducted fans)	Maximum RPM
FEI at design point	Link to complete performance map of the fan
Maximum RPM	
Link to complete performance map of the fan	

For all fans, the label would display the model number, serial number or date of manufacturing, the fan's rated maximum speed (RPM), and a link to the complete performance map of the fan. For fans where the design point is known, the label would also display the design flow and pressure and the FEI at the design point.

We envision that the link to the complete performance map of the fan could link to the same information on the operating range described above in the section on reporting requirements.

Analysis of Proposal

Scope

Our proposed standards would apply to stand-alone fans.[10]

Horsepower range

For all fans where fan shaft power is rated, our proposed standards would apply to fan duty points (i.e. airflow and pressure combinations) for which:

- Fan shaft input power is greater than or equal to 1 HP; and
- Fan air power[11] is less than or equal to 150 HP

This horsepower range is equivalent to that recommended by the ASRAC working group (Recommendation 5). The intent of the recommended horsepower range is to cover fans that represent the majority of total fan energy consumption while limiting burdens on manufacturers. AMCA found through their survey of 2012 fan sales that about 85% of the total connected load is greater than or equal to 1 HP.[12] Further, there are a large number of small manufacturers who make fans below 1 HP. Fans with air power greater than 150 HP also make up a relatively small portion of the total connected load. In addition, fans with air powers above 150 HP are often custom products used in industrial applications where customers are highly sensitive to efficiency due to the very high operating cost of fans at these high power levels. Therefore, we believe that our recommended horsepower range strikes an appropriate balance between capturing potential energy savings and limiting burdens on manufacturers.

The 1 HP lower bound is also consistent with the lower bound of DOE's electric motor standards and commercial and industrial pump standards. The upper bound of 150 HP based on air power is roughly equivalent to the upper bound of 200 HP based on shaft power in the standards for commercial and industrial pumps. The use of fan airpower (rather than fan shaft power) to define the upper limit of the horsepower range helps avoid a potential situation at the upper end of the horsepower range where one fan would be covered by the standards, while another fan that delivers the same service (i.e. fan airpower) is excluded because it is less efficient and therefore has a shaft power just above the upper limit.

Since the conclusion of the ASRAC working group, we have identified one small issue related to the lower bound of the horsepower range. For fans that are tested in a wire-to-air method in accordance with AMCA 210 the fan shaft power is not measured or published, and thus it is not possible to determine which duty

[10] ASAP, NEEA, NRDC, ACEEE, PG&E, SDG&E, SCE, and SoCalGas® are submitting a separate proposal for embedded fans.
[11] Also referred to as fan air power (H_o), as measured in accordance with AMCA 210.
[12] https://www.amca.org/adovacy/documents/DOEFanEfficiencyProposal-AMCAAnnualMeetingRedux1-24-15.pdf. p. 14.

points fall above or below the 1 HP threshold. Therefore, for fans rated in fan electrical input power, we propose that the standards apply to fan duty points (i.e. airflow and pressure combinations) for which:

- Fan electrical input power is greater than or equal to 1 kW; and
- Fan air power is less than or equal to 150 HP

The lower bound of 1 kW fan electrical input power is roughly equivalent to a fan shaft power of 1 HP. To illustrate this, we can apply the default values for transmission and motor efficiency in the draft AMCA 208 Standard to a fan with a shaft power of 1 HP:

1. 1 HP is equivalent to **0.7457 kW**

2. Per equation 5.5 (SI) in AMCA 208, the default transmission efficiency for a shaft power of 0.7457 kW is:

$$\eta_{\mathrm{trans,ref}} = 0.96\left(\frac{H_{i,ref}}{H_{i,ref}+1.64}\right)^{.05} = 0.96\left(\frac{0.7457}{0.7457+1.64}\right)^{.05} = \mathbf{90.6}\%$$

3. Per equation 5.6 in AMCA 208, the reference fan motor output is:

$$H_{t,ref} = \frac{H_{i,ref}}{\eta_{\mathrm{trans,ref}}} = \frac{0.7457}{0.906} = \mathbf{0.823\ kW}$$

4. Per equation 5.7 (SI) in AMCA 208, the reference fan motor efficiency is:

$$\eta_{\mathrm{mtr,ref}} = A\cdot\left[\log_{10}\left(H_{t,ref}\right)\right]^4 + B\cdot\left[\log_{10}\left(H_{t,ref}\right)\right]^3 + C\cdot\left[\log_{10}\left(H_{t,ref}\right)\right]^2 + D\cdot\left[\log_{10}\left(H_{t,ref}\right)\right]^1 + E$$

$$= -0.0038\cdot[\log_{10}(0.823)]^4 + 0.0258\cdot[\log_{10}(0.823)]^3 - 0.0726\cdot[\log_{10}(0.823)]^2 + 0.1256\cdot[\log_{10}(0.823)]^1 + 0.8503 = \mathbf{83.9}\%$$

5. Finally, fan electrical input power is calculated as:

$$FEP = fan\ shaft\ power \times \frac{1}{transmission\ efficiency} \times \frac{1}{motor\ efficiency} = 0.7457 \times \frac{1}{0.906} \times \frac{1}{0.839} = \mathbf{0.98\ kW}$$

Thus, based on the default values for transmission efficiency and motor efficiency in AMCA 208, a fan shaft power of 1 HP is almost exactly equivalent to a fan electrical input power of 1 kW.

For all fans, fan air power would be calculated based on static pressure for unducted fans and total pressure for ducted fans, according to the testing basis laid out in Table 2.

Fan categories included and excluded

Our proposed standards would apply to the following fan categories:

- Axial inline
- Axial panel
- Centrifugal housed
- Centrifugal unhoused
- Centrifugal inline and inline mixed flow

- Radial housed
- Power roof/wall ventilators

And our proposed standards would exclude the following fan categories:

- Radial housed unshrouded fans with diameter less than 30 inches or a blade width of less than 3 inches
- Safety fans
- Circulating fans
- Induced flow fans
- Jet fans
- Cross flow fans

These recommendations for fan categories to be included and excluded reflect the ASRAC term sheet (Recommendations 1 and 2). The fan categories we are recommending for inclusion cover those used in a wide variety of common commercial and industrial applications. The excluded fan categories are fan types that are primarily used in specialty applications and represent a small connected load. The particular radial housed unshrouded fans proposed for exclusion are typically used to handle materials such as textile thread and paper scraps. Safety fans are either intended only for emergency use and thus have very low operating hours or have characteristics that significantly reduce efficiency while also increasing cost, which means that they would not pose a loophole risk. Many circulating fans are ceiling fans, which are covered by DOE standards. In addition, unlike other fans, circulating fans are not tested using AMCA 210. Induced flow fans are often used in laboratory exhaust systems, and jet fans are typically used to ventilate tunnels. Finally, cross flow fans are rarely available above 1 HP.

Product Efficiency Opportunities

The most important product efficiency opportunity associated with commercial and industrial fans is improved fan selection. Additional opportunities include improved fan design and more-efficient transmission, motors, and motor controllers.

Improved fan selection

Every fan has an efficiency curve, which describes the efficiency of the fan at each potential operating point along the fan curve. A fan's peak efficiency occurs at a single point, and efficiency drops off significantly at operating points away from the peak efficiency point. In the example shown in Figure 4, the fan's actual operating point (where the fan curve and system curve intersect) is very close to the peak efficiency point. However, if a given system curve instead intersects the fan curve at a point far from the peak efficiency point, the fan will operate at an efficiency significantly lower than its peak efficiency.

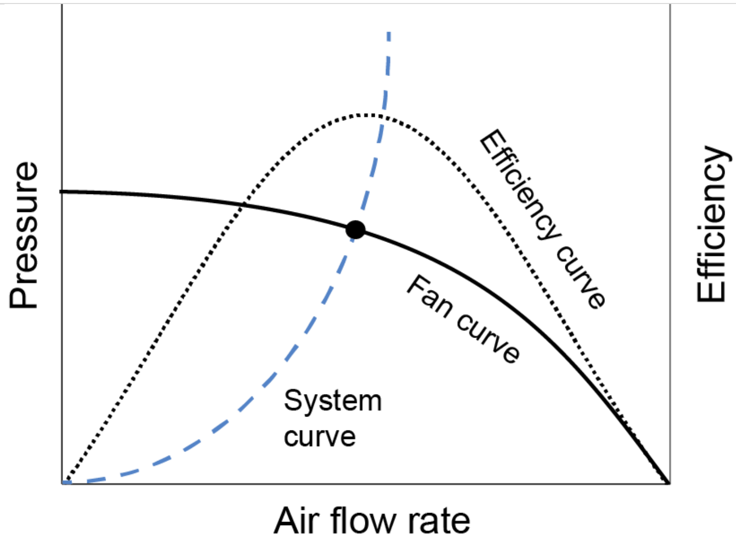

Figure 4. Example of a fan curve, its corresponding efficiency curve, and a system curve

Actual fan selections vary widely in terms of efficiency at the design point. For example, Figure 5 shows actual 2012 fan selections of centrifugal power roof ventilators. At the design point, total efficiency ranged from about 12% to 85%.

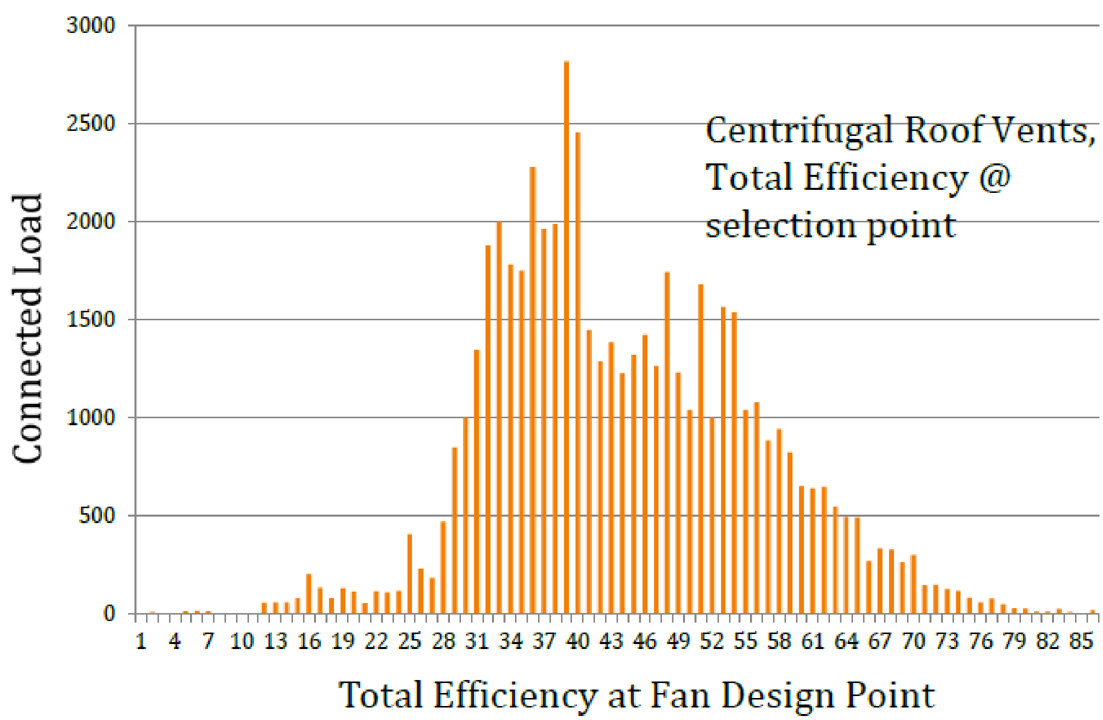

Figure 5. Actual fan selections of centrifugal power roof ventilators from 2012 AMCA database. ***Source***: https://www.amca.org/adovacy/documents/DOEFanEfficiencyProposal-AMCAAnnualMeetingRedux1-24-15.pdf.

Similarly, Figure 6 shows actual 2012 fan selections for one model of a centrifugal inline fan. While the peak efficiency of this fan is about 53%, efficiency at the design point for some selections was below 20%.

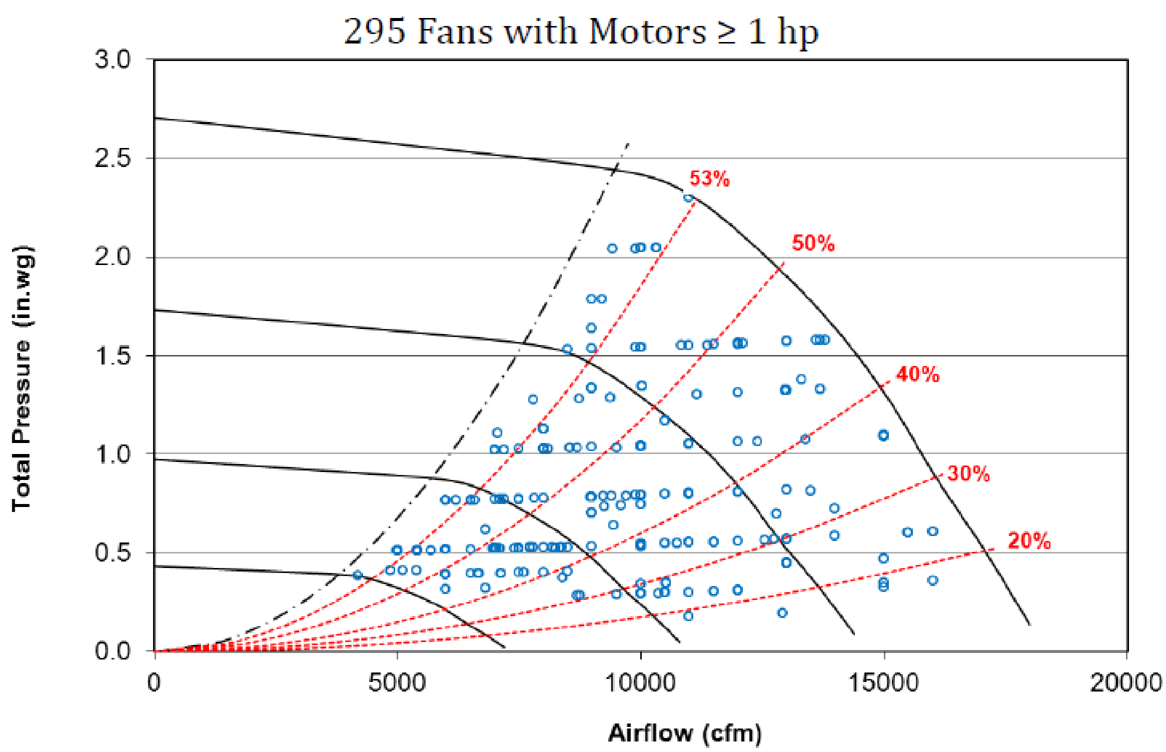

Figure 6. Actual 2012 fan selections of a centrifugal inline fan model. ***Source*****:** https://www.amca.org/adovacy/documents/DOEFanEfficiencyProposal-AMCAAnnualMeetingRedux1-24-15.pdf.

Significant reductions in fan power consumption can thus be achieved by addressing fan efficiency at a customer's actual design point and by shifting the market to better fan selections that consume less power. Our proposed approach for fan efficiency standards would improve fan selections by applying standards to the entire certified operating range of each fan model and by establishing requirements regarding marketing materials and selection software.

Improved fan design

Improved fan design can increase efficiency across a range of duty points. The most significant opportunity for improving fan design is improving aerodynamic efficiency.

In the framework document for DOE's rulemaking on commercial and industrial fans, DOE also identified additional opportunities for improving fan design including blade shape, material selection, guide vanes, and housing optimization. Blade shape can significantly impact fan efficiency. Most fans have single-thickness blades. Changing the curvature and the direction of curvature can provide efficiency improvements for fans with single-thickness blades. Further improvements can be made by switching to airfoil blades. Fan impellers can be constructed using a variety of materials including aluminum, steel, fiberglass, and plastic, and the choice of material can impact efficiency. Guide vanes direct and straighten the airflow, which results in lower pressure drop through the impeller. Finally, housing design can significantly impact efficiency. For example, a housing that is too wide allows for recirculation of the air, while a housing that is too narrow may interfere with the inlet.

Our proposed approach for fan efficiency standards would encourage improved fan design since more-efficient designs would allow manufacturers to advertise a larger compliant operating range. For example Figure 7 shows fan curves for two different fans along with the compliant operating ranges (in this case for an FEI of 1.0). While both fans have a range of duty points that are compliant, the fan on the left has a more-efficient design and thus has a much larger compliant operating range, which means that it can meet the needs of more applications.

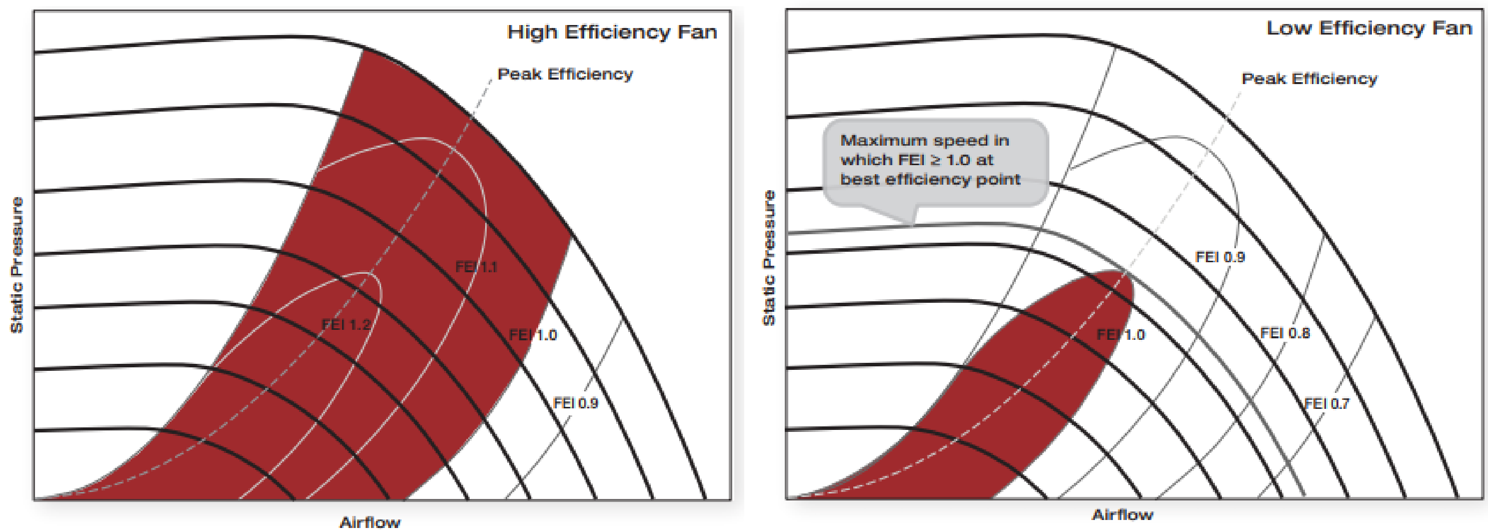

Figure 7. Example of the compliant operating ranges of two different fan models.
***Source*:**
https://www.amca.org/resources/documents/Introducing%20the%20Fan%20Energy%20Index%20Metric.pdf.

Transmission

More-efficient transmission can improve wire-to-air efficiency. As described earlier, fans can either be direct-drive or belt-drive. Direct-drive fans inherently have no transmission losses. Since FEI is a wire-to-air metric, our proposed approach for fan efficiency standards would encourage direct-drive designs since these fans would achieve a higher FEI than comparable belt-drive fans.

Our proposed approach would also encourage more-efficient belts. Most belt drives use V-belts. Standard V-belts have a trapezoidal cross section. Cogged V-belts have notches or grooves that run perpendicular to the belt's length, which reduce the bending resistance of the belt and improve efficiency. Cogged V-belts can improve efficiency by about 2% relative to standard V-belts.[13]

[13] https://energy.gov/sites/prod/files/2014/04/f15/replace_vbelts_motor_systemts5.pdf.

Source: https://www.nrel.gov/docs/fy14osti/61448.pdf.

Further improvements in belt efficiency can be achieved by using synchronous belts. Synchronous belts are toothed and reduce both belt slippage and frictional losses. Synchronous belts may improve efficiency by up to 5% relative to standard V-belts.[14]

Motors

Similar to more-efficient transmission, more-efficient motors also improve wire-to-air efficiency. More-efficient motors include more-efficient induction motors as well as advanced motor designs such as electronically commutated motors (ECMs) and switched reluctance motors. Motors meeting the “Super Premium” (IE4) efficiency levels reduce losses by about 15% relative to “NEMA Premium” motors.[15] Our proposed approach for fan efficiency standards would encourage more-efficient motors.

Motor controllers

Motor controllers, such as variable-speed drives, are used to control the speed of a fan. While significant energy savings can be achieved by reducing the speed of a fan to match the required airflow rate, there are also losses associated with motor controllers. Motor controllers with lower losses improve wire-to-air efficiency relative to less-efficient controllers. Our proposed approach for fan efficiency standards would encourage more-efficient motor controllers.

Technical Feasibility

Our proposed efficiency levels are technically feasible based on their current availability in the market. As described above, the most significant opportunity for reducing the energy use of commercial and industrial fans is improved fan selection. Most fan models will not need to be redesigned in order to comply with our proposed standards. Instead, the manufacturer would certify the compliant operating range of current models, which in most cases will be smaller than the currently-advertised operating range.

Statewide Energy Savings

Per-unit electricity savings

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[14] https://www.nrel.gov/docs/fy14osti/61448.pdf.
[15] http://www.novatorque.com/downloads/NovaTorque_FAQs.pdf.

DOE's NODA III analysis provides estimates of first-year operating costs for each category of stand-alone fans.[16] Based on these first-year operating costs and average electricity prices, we can estimate per-unit annual electricity consumption at the baseline level and our proposed standard level for each category of stand-alone fans. (Our proposed standard level is approximately equivalent to EL 3 in the NODA III analysis.) DOE estimated the percentage of fans used in the commercial and industrial sectors, respectively, for each fan type by horsepower range.[17] As summarized in Table 6 below, the information from the NODA III suggests that most stand-alone panel, centrifugal housed, centrifugal unhoused, inline and mixed flow, and power roof/wall ventilator fans are used in the commercial sector, while all stand-alone axial cylindrical housed and radial fans are used in the industrial sector.

Table 6. Primary application sector for each stand-alone fan category

Fan type	Primary sector
Axial cylindrical housed	Industrial
Panel	Commercial
Centrifugal housed	Commercial
Centrifugal unhoused	Commercial
Inline and mixed flow	Commercial
Radial	Industrial
Power roof ventilator	Commercial

For the assumed compliance date (2022) in the NODA III analysis, DOE assumed average electricity prices for the commercial and industrial sectors of about $0.13/kWh and $0.10/kWh, respectively.[18] Table 7 shows the per-unit annual electricity use at the baseline level and our proposed standard level for each stand-alone fan type calculated from the first-year operating costs and average electricity prices. The table also shows the resulting per-unit annual electricity savings.

Table 7. Per-unit annual electricity savings

Fan type	Average electricity price in NODA III analysis ($/kWh)	First-year U.S. operating cost at baseline level ($)	First-year U.S. operating cost at proposed standard level ($)[19]	Per-unit annual electricity use at baseline level (kWh)	Per-unit annual electricity use at proposed standard level (kWh)	Per-unit annual electricity savings (kWh)
Axial cylindrical housed	0.10	4,027	3,945	40,269	39,446	823
Panel	0.13	1,325	1,271	10,193	9,776	417
Centrifugal housed	0.13	6,559	6,515	50,454	50,115	338
Centrifugal unhoused	0.13	5,133	5,119	39,482	39,380	103
Inline and mixed flow	0.13	2,209	2,087	16,996	16,055	941
Radial	0.10	5,660	5,503	56,598	55,034	1,565
Power roof ventilator	0.13	1,066	966	8,197	7,428	769

[16] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0190. "Summary by EC" tab.
[17] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0190. "Sectors and Applications" tab.
[18] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0190. "Electricity Prices & Trends" tab. Calculated by multiplying 2014 average prices by the price trend index for 2022 for the commercial and industrial sectors, respectively.
[19] At EL 3 in the NODA III analysis.

The per-unit electricity savings take into account the base case efficiency distribution of fan sales (i.e. they take into account the portion of sales that would have met our recommended standard level even in the absence of a standard). Therefore, these per-unit savings estimates represent average savings for all purchasers. Savings would be significantly greater for a customer who would have purchased a fan at the baseline efficiency level in the absence of a standard.

Sales and stock

DOE's NODA III analysis contains estimates of 2012 U.S. shipments of both stand-alone and embedded fans by fan type.[20] Using this information we can calculate the percentage of total 2012 fan shipments that were shipments of stand-alone fans as shown in Table 8.

Table 8. 2012 U.S. fan shipments

Fan type	2012 U.S. fan shipments			Stand-alone fan shipments as % of total fan shipments
	Stand-alone	Embedded	Total	
Axial cylindrical housed	33,500	3,717	37,217	90%
Panel	148,000	125,786	273,786	54%
Centrifugal housed	88,000	266,067	354,067	25%
Centrifugal unhoused	65,000	319,064	384,064	17%
Inline and mixed flow	26,500	-	26,500	100%
Radial	36,000	-	36,000	100%
Power roof ventilator	67,500	-	67,500	100%
Total	**464,500**	**714,633**	**1,179,133**	**39%**

The NODA III analysis also contains estimates of total U.S. shipments by fan type for each year from 2019 through 2052.[21] We can estimate 2019 California sales of stand-alone fans by fan type using the estimates of total 2019 U.S. shipments by fan type, the percentage of total fan shipments in each category that are stand-alone fans (from Table 9), and assuming that California shipments represent 12% of total U.S. shipments.[22] Table 9 shows estimated 2019 sales of stand-alone fans in California by fan type. Total estimated 2019 sales of stand-alone fans in California are about 70,000.

[20] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0192. "Shipments 2012" tab.

[21] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0192. "Shipments" tab.

[22] The population of California is about 12% of the total U.S. population. https://www.census.gov/quickfacts/fact/table/CA,US/PST045216.

Table 9. 2019 California shipments of stand-alone fans

Fan type	2019 total U.S. fan shipments	Stand-alone shipments as % of total shipments	2019 U.S. stand-alone fan shipments	2019 California stand-alone fan sales
Axial cylindrical housed	44,870	90%	40,389	4,847
Panel	344,006	54%	185,959	22,315
Centrifugal housed	448,704	25%	111,521	13,383
Centrifugal unhoused	493,574	17%	83,534	10,024
Inline and mixed flow	29,914	100%	29,914	3,590
Radial	44,870	100%	44,870	5,384
Power roof ventilator	89,741	100%	89,741	10,769
Total	**1,495,679**	**39%**	**585,928**	**70,311**

Figure 8 shows estimated annual California sales of stand-alone fans by fan type for 2019-2049 based on the same methodology as that used for calculating 2019 shipments in Table 9.

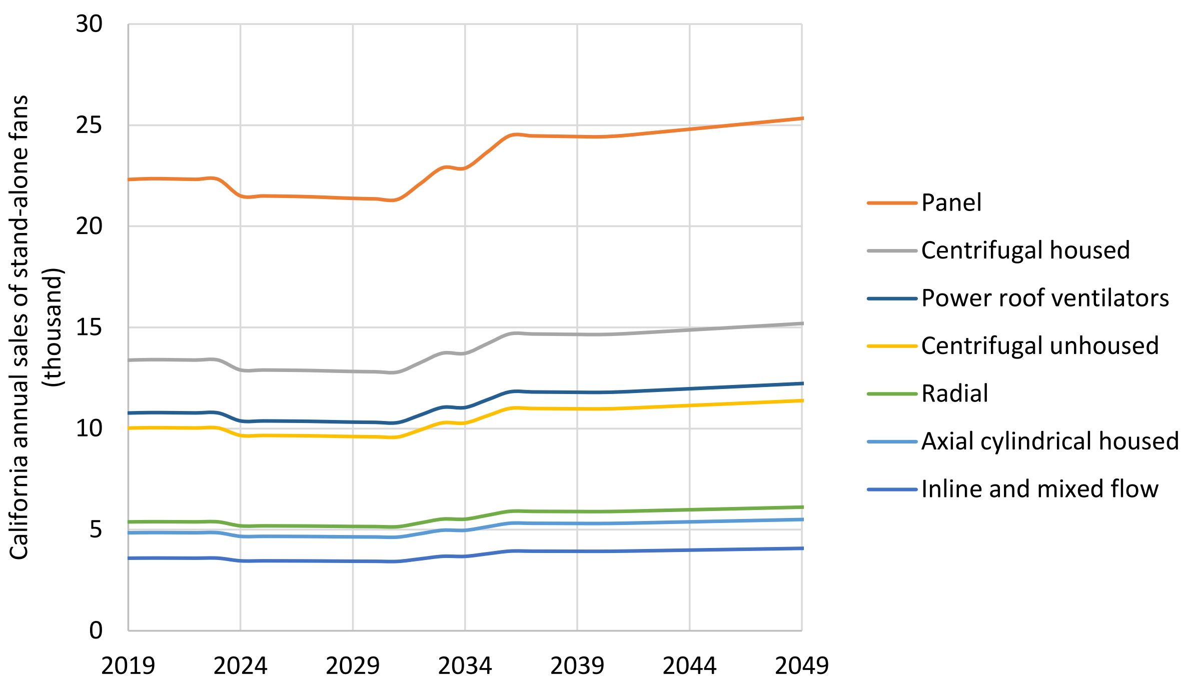

Figure 8. California annual sales of stand-alone fans by category for 2019-2049.

We can estimate the current stock in California by multiplying estimated annual shipments of each fan type by their respective average lifetimes as shown in Table 10. The estimated total California stock (i.e. the stock of fans that were sold as stand-alone fans) is almost 2 million.

Table 10. Estimated California stock of stand-alone fans

Fan type	2019 California stand-alone fan shipments	Average lifetime[23]	Estimated California stock
Axial cylindrical housed	4,847	29	140,554
Panel	22,315	28	624,822
Centrifugal housed	13,383	27	361,329
Centrifugal unhoused	10,024	27	270,650
Inline and mixed flow	3,590	27	96,920
Radial	5,384	30	161,533
Power roof ventilator	10,769	30	323,067
Total	**70,311**	-	**1,978,874**

Statewide energy savings and peak demand reductions

We can use the estimates of per-unit electricity savings, 2019 sales in California, and California stock to generate statewide estimates of energy savings and peak demand reductions as shown in Table 11. Estimated first-year savings are 39 GWh, and savings after stock turnover are 1,118 GWh per year.

Table 11. First-year savings and savings after stock turnover for California

Fan type	Per-unit savings (kWh)	Annual sales	Stock	First-year savings (GWh/yr)	Savings after stock turnover (GWh/yr)
Axial cylindrical housed	823	4,847	140,554	4.0	115.7
Panel	417	22,315	624,822	9.3	260.3
Centrifugal housed	338	13,383	361,329	4.5	122.2
Centrifugal unhoused	103	10,024	270,650	1.0	27.8
Inline and mixed flow	941	3,590	96,920	3.4	91.2
Radial	1,565	5,384	161,533	8.4	252.7
Power roof ventilator	769	10,769	323,067	8.3	248.3
Total	-	**70,311**	**1,978,874**	**39**	**1,118**

Stand-alone fans on average have very high operating hours. For example, DOE estimates that typical operating hours of stand-alone fans are about 6,000 hours per year.[24] Therefore, we can assume a relatively flat load profile and calculate peak demand reductions by dividing energy savings after stock turnover by 8,760 hours. Table 12 shows estimated peak demand reductions by fan type. Total estimated peak demand reductions after stock turnover are 128 MW.

[23] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0190. "Summary by EC" tab.
[24] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0190. "Lifetime" tab.

Table 12. Estimated peak demand reductions for each stand-alone fan type

Fan type	Peak demand reduction after stock turnover (MW)
Axial cylindrical housed	13.2
Panel	29.7
Centrifugal housed	13.9
Centrifugal unhoused	3.2
Inline and mixed flow	10.4
Radial	28.8
Power roof ventilator	28.3
Total	**128**

Cost-effectiveness

As part of DOE's NODA III, DOE estimated average fan lifetimes by fan type including estimates for all fans, stand-alone fans, and embedded fans.[25] DOE noted that these estimates were developed using a variety of sources including an ASHRAE HVAC service life and maintenance database and an industry expert interview.[26] DOE also estimated per-unit incremental costs by fan type.[27] We can use these estimates of average lifetime and per-unit incremental cost in conjunction with per-unit electricity savings (from the section above) to calculate average lifecycle savings, lifecycle net benefits, and benefit/cost ratios for our proposed standards as shown in Table 13.

Table 13. Lifecycle savings, net benefits, and benefit/cost ratio for each stand-alone fan type

Fan type	Per-unit electricity savings (kWh)	Per-unit incremental cost ($)	Average lifetime (years)	Lifecycle savings (kWh)	Lifecycle savings ($)	Net benefits ($)	Benefit/ cost ratio
Axial cylindrical housed	823	399	29	23,866	2,864	2,465	7.2
Panel	417	53	28	11,664	1,866	1,814	35.4
Centrifugal housed	338	33	27	9,129	1,461	1,428	44.9
Centrifugal unhoused	103	39	27	2,775	444	405	11.4
Inline and mixed flow	941	689	27	25,403	4,064	3,376	5.9
Radial	1,565	221	30	46,935	5,632	5,412	25.5
Power roof ventilator	769	595	30	23,061	3,690	3,094	6.2

Note: Lifecycle savings ($) and net benefits ($) calculated assuming electricity prices of $0.16/kWh and $0.12/kWh for the commercial and industrial sectors, respectively. The commercial electricity price was assumed for panel, centrifugal housed, centrifugal unhoused, inline and mixed flow, and power roof ventilator fans. The industrial electricity price was assumed for axial cylindrical housed and radial fans.

Average net benefits range from $405 over the lifetime of a centrifugal unhoused fan to $5,412 over the lifetime of a radial fan. Benefit/cost ratios range from 5.9 to 44.9 depending on the fan type.

[25] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0190. "Summary by EC" tab.
[26] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0190. "Lifetime" tab.
[27] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0190. "Summary by EC" tab.

Environmental Impacts/Benefits

Our proposed standards would provide environmental benefits by reducing energy consumption. Reduced energy consumption results in reduced pollutant emissions from power plants and reduced pressure on energy resources. We do not expect our proposal to have any adverse environmental impacts.

Impact on California's Economy

We can estimate annual electricity bill savings for California after stock turnover by multiplying statewide electricity savings by average electricity prices. Table 14 shows estimated electricity bill savings for stand-alone fans by fan type. Total estimated electricity bill savings for California after stock turnover are $164 million per year.

Table 14. Estimated electricity bill savings for California after stock turnover by fan type

Fan type	Electricity bill savings after stock turnover (million $/yr)
Axial cylindrical housed	13.9
Panel	41.6
Centrifugal housed	19.5
Centrifugal unhoused	4.5
Inline and mixed flow	14.6
Radial	30.3
Power roof ventilator	39.7
Total	**164**

Note: Calculated assuming electricity prices of $0.16/kWh and $0.12/kWh for the commercial and industrial sectors, respectively. The commercial electricity price was assumed for panel, centrifugal housed, centrifugal unhoused, inline and mixed flow, and power roof ventilator fans. The industrial electricity price was assumed for axial cylindrical housed and radial fans.

Consumer Utility/Acceptance

Our proposed approach for standards would provide consumers with an easy way to evaluate the efficiency of different fans for a particular application and would drive consumers to make better fan selections. It would also allow consumers to specify an FEI level above the minimum standard, which would drive additional savings. Our proposed requirements regarding marketing materials and selection software would help ensure that purchasers are selecting fans that meet the minimum FEI level at their design point.

Manufacturer Supply Chain Timelines

We propose an effective date for the standards of 2 years after adoption of the standards. Our proposed effective date balances the benefits of the energy savings achieved from an earlier effective date with the time necessary for manufacturers to prepare for the implementation of the standard, including any necessary testing.

Other Regulatory Considerations

This standards proposal is not currently at risk of federal preemption. In 2015 DOE convened an ASRAC working group to negotiate test procedures and efficiency standards for fans. However, the term sheet from the ASRAC working group did not include recommended standards, and DOE has yet to publish a proposed rule for either test procedures or standards.

This standards proposal will help enable complementary efforts by efficiency programs and energy codes (e.g. ASHRAE 90.1). In particular, the implementation of this standards proposal will provide a standardized test method for evaluating fan efficiency, certified fan performance data based on our proposed metric, and an established efficiency level for determining savings at even higher efficiency levels.

Conclusion

Our proposed standards for fans are technically feasible and will achieve significant cost-effective energy savings. Based on DOE's analysis for the NODA III, we estimate that our proposed standards would save 1,118 GWh per year after stock turnover, which translates to $164 million per year for California consumers. Our proposed standards would also reduce peak electricity demand by an estimated 128 MW after stock turnover. Our proposed approach for fan efficiency standards would drive better fan selection to reduce power consumption in addition to encouraging improved fan design. Further, our proposed standards would facilitate complementary efforts by efficiency programs and energy codes that would drive even greater savings.

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