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Efficiency Advocates Proposal for Embedded Fans

Additional submitted attachment is included below.

Proposal Information Template – Commercial and Industrial Fans and Blowers

2017 Appliance Efficiency Standards

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 embedded 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. This proposal specifically addresses fans embedded in equipment.

Embedded fans are used in a wide variety of equipment types such as commercial unitary air conditioners and heat pumps, air handling units, and air-cooled chillers. Common applications of embedded fans include supply fans, condenser fans, return fans, and exhaust fans.

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.

Embedded 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.

Embedded 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).

There are four types of fans that are commonly embedded in equipment: axial inline; panel; centrifugal housed (excluding inline and radial); and centrifugal unhoused. Below are descriptions of each of these fan types.

Axial inline fans

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 inline fan can be ducted. Embedded axial inline fans are typically used as supply fans in air handling units.

http://www.novenco-building.com/products/axial-flow-fans/axial-flow-fans-zerax-azl/

Axial panel fans

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. Embedded panel fans are typically used as condenser fans in equipment such as air-cooled chillers and remote air-cooled condensers.

Source: http://www.trane.com/commercial/north-america/us/en/products-systems/equipment/chillers/air-cooled-chillers.html

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. Embedded centrifugal housed fans are commonly used as supply fans in equipment such as air handling units.

Source: https://www.ahe.co.uk/components/components/

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. Embedded centrifugal unhoused fans are typically used as supply fans in air handling units.

Source: https://www.ahe.co.uk/components/components/

Overview

In this proposal we are recommending test procedures and efficiency standards for commercial and industrial fans that are embedded in equipment. 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	Embedded fans are used in a wide variety of equipment types such as commercial unitary air conditioners and heat pumps, air handling units, and air-cooled chillers. We are proposing efficiency standards for embedded 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. Embedded fans would be tested outside of the equipment, which would allow the ratings of embedded fans to be directly comparable to those of stand-alone fans. The standards would apply to the entire certified operating range of each fan model. Our proposed approach for standards for embedded fans would drive better fan selection in embedded equipment and would also encourage equipment design that results in lower pressure drops, which would save energy.
Technical Feasibility	The most important product efficiency opportunity associated with embedded fans is better fan selection. Additional opportunities include improved fan design, equipment design to reduce pressure drops, and more-efficient transmission, motors, and motor controllers. The proposed efficiency levels are technically feasible based on their current availability in the market.
Energy Savings and Demand Reduction	Our proposed standards would provide 20 GWh of estimated first-year electricity savings for California and 360 GWh per year after stock turnover. Estimated peak demand reductions after stock turnover are 41 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 $58 million for California consumers after stock turnover.
Consumer Acceptance	Our proposed approach for standards would provide consumers with information about the energy performance of fans embedded in equipment and would drive consumers to select equipment with lower fan energy consumption. It would also allow consumers to specify an FEI level above the minimum standard for fans embedded in equipment, 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

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, including the treatment of embedded fans. 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 embedded 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.

Our proposal is generally consistent with our separate proposal for stand-alone fans. Many fans that are sold as stand-alone fans end up embedded in equipment. Similarly, an original equipment manufacturer (OEM) has the option of purchasing a stand-alone fan in a testable configuration for use in a piece of equipment or of manufacturing the fan in-house (e.g. purchasing just the impeller). Therefore, we believe that it makes sense for standards for stand-alone fans and embedded fans to be aligned so that all fans ultimately embedded in equipment are tested and rated the same way and are subject to the same standards.

Below is our recommended regulatory language for scope, definitions, test methods, and standards.

Section 1601 Scope.

(x) Fans which are: embedded 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;

(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

(2) excluding the following:

1. Radial housed unshrouded fans with diameter less than 30 inches or a blade width of less than 3 inches;
2. Safety fans;
3. Circulating fans;

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[1] With the exception of ACEEE.

4. Induced flow fans;

5. Jet fans;

6. Cross flow fans.

7. Fans embedded in central air conditioners and central air conditioning heat pumps as defined at 10 CFR 430.2, small commercial packaged air conditioning and heating equipment as defined at 10 CFR 431.92 with cooling capacity less than 65,000 Btu/h, furnaces as defined at 10 CFR 430.2, transport refrigeration and fans exclusively powered by internal combustion engines, vacuums, heat rejection equipment, and air curtains; and

8. Supply and condenser fans embedded in air-cooled commercial package air conditioning and heating equipment as defined at 10 CFR 431.92 with cooling capacity greater than or equal to 65,000 Btu/h and less than 760,000 Btu/h, water-cooled and evaporatively-cooled commercial package air conditioning and heating equipment as defined at 10 CFR 431.92 with cooling capacity less than 760,000 Btu/h, water-source heat pumps as defined at 10 CFR 431.92 with cooling capacity less than 135,000 Btu/h, single package vertical air conditioners and single package vertical heat pumps as defined at 10 CFR 431.92 with cooling capacity less than 240,000 Btu/h, packaged terminal air conditioners and packaged terminal heat pumps as defined at 10 CFR 431.92, computer room air conditioners as defined at 10 CFR 431.92 with cooling capacity less than 760,000 Btu/h, and variable refrigerant flow multi-split air conditioners and variable refrigerant flow multi-split heat pumps as defined at 10 CFR 431.92 with cooling capacity less than 760,000 Btu/h.

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.

“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.

“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.

“Heat rejection equipment” means a packaged evaporative open circuit cooling tower, evaporative field erected open circuit cooling tower, packaged evaporative closed circuit cooling tower, evaporative field erected closed circuit cooling tower, packaged evaporative condenser, field erected evaporative condenser, packaged air cooled (dry) cooler, field erected air cooled (dry) cooler, air cooled steam condenser, or hybrid (water saving) versions of any of the above listed equipment that contains both evaporative and air cooled heat exchange sections.

“Packaged evaporative open circuit cooling tower” means a device which rejects heat to the atmosphere though the direct cooling of a water stream to a lower temperature by partial evaporation.

“Evaporative field erected open circuit cooling tower” means a structure which rejects heat to the atmosphere though the direct cooling of a water stream to a lower temperature by partial evaporation.

“Packaged evaporative closed circuit cooling tower” means a device which rejects heat to the atmosphere though the indirect cooling of a process fluid stream in an internal coil to a lower temperature by partial evaporation of an external recirculating water flow.

“Evaporative field erected closed circuit cooling tower” means a structure which rejects heat to the atmosphere though the indirect cooling of a process fluid stream to a lower temperature by partial evaporation of an external recirculating water flow.

“Packaged evaporative condenser” means a device which rejects heat to the atmosphere though the indirect condensing of a refrigerant in an internal coil by partial evaporation of an external recirculating water flow.

“Field erected evaporative condenser” means a structure which rejects heat to the atmosphere though the indirect condensing of a refrigerant in an internal coil by partial evaporation of an external recirculating water flow.

“Packaged air cooled (dry) cooler” means a device which rejects heat to the atmosphere from a fluid, either liquid, gas or mixture thereof, flowing through an air-cooled internal coil.

“Field erected air cooled (dry) cooler” means a structure which rejects heat to the atmosphere from a fluid, either liquid, gas or mixture thereof, flowing through an air-cooled internal coil.

“Air cooled steam condenser” means a device for rejecting heat to the atmosphere through the indirect condensing of steam inside air-cooled finned tubes.

“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

Embedded fans shall be tested outside of the equipment in which they are ultimately installed in a stand-alone fan testable configuration, as defined in Section 4.1 of AMCA 208. If necessary, non-impeller components of the fan that are geometrically similar to the ones used by the fan as embedded in the larger piece of equipment shall be used to complete the fan testable configuration.

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

When calculating the FEI for fans in fan arrays in air handling units, the testing method included in Annex C of AMCA 208 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] The definitions are consistent with our proposed definitions for stand-alone fans. 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.

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[2] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0143. pp. 18-19.

Proposed Test Procedure

We propose that embedded fans be tested outside of the equipment in a stand-alone fan testable configuration as specified in the ASRAC term sheet (Recommendation 8). For fans that cannot be tested outside of the equipment (e.g. fans where the housing is part of the equipment), non-impeller components of the fan that are geometrically similar to the ones used by the fan as embedded in the larger piece of equipment would be used to complete the fan testable configuration. This testing approach would allow the ratings of embedded fans to be directly comparable to those of stand-alone fans and would limit burdens on OEMs by requiring only the fan, not the equipment, to be tested.

We propose that the test procedure be consistent with the test procedure for stand-alone fans and 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.

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.

As with stand-alone fans, we recommend only one pressure basis and installation type be allowed for embedded fans for determining compliance with the Title 20 standard in order to the ensure that the

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[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.

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

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).

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 the same installation types for testing for each embedded fan category as those for stand-alone fans, 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

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

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.

Finally, we are recommending that when calculating the FEI for fans in fan arrays in air handling units, the testing method included in Annex C of AMCA 208 should be used. As explained in Annex C, treating fan arrays in air handling units as a single fan ensures a consistent calculation of FEI regardless of the number of fans used.

Proposed Standard Metrics

We propose that the efficiency metric be consistent with the metric for stand-alone fans and 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.

Our proposal for stand-alone fans contains more detail on the FEI metric. We note that the metric is equally applicable to embedded fans.

Proposed Framework

As noted above, we are proposing that embedded fans be tested as stand-alone fans outside of the equipment. This approach would allow the ratings of embedded fans to be directly comparable to those of stand-alone fans.

When embedded in a piece of equipment, a fan must be selected to overcome both the internal pressure losses of the cabinet and the external pressure losses of the system (e.g. of a duct system). Figure 1 shows an example of fan curves for a fan when tested as a stand-alone fan (solid curve) and when embedded in equipment (dashed curve) at the same fan speed, *n*. When embedded in equipment, the pressure available to the system is lower than the pressure produced by the fan due to the internal cabinet pressure losses. In Figure 1, point B represents the required airflow and the system pressure losses at that required airflow. However, due to the cabinet losses, point A represents the required performance of the fan. At point A, the airflow is the same as the required airflow (i.e. the same as that at point B), but the pressure is higher in order to overcome the cabinet pressure losses.

As described in section 4.3 of the draft AMCA 208 standard, for an embedded fan (which is similar to the situation of a fan with appurtenances), the FEI at any operating point would be determined based on the stand-alone performance curve (i.e. the solid curve in Figure 1) at the same airflow and fan speed as that of the embedded fan (i.e. at point A in Figure 1). That is, points A and B, while at different pressures, occur at the same operating speed. Therefore, stand-alone fan performance data (from the test procedure) can be used to describe the performance of fans as embedded in equipment, based on the specified airflow and operating speed. This approach leverages the fact that any given operating point can be described by any two of the following three quantities: airflow, pressure, and/or speed. By determining FEI based on the stand-alone fan performance, it is not necessary to know the internal pressure losses of the equipment and the same stand-

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[7] (1.2 – 1.0) / 1.2

alone fan performance data can be used to determine the operating point FEI of the embedded fan in different pieces of equipment, potentially with different pressure losses.

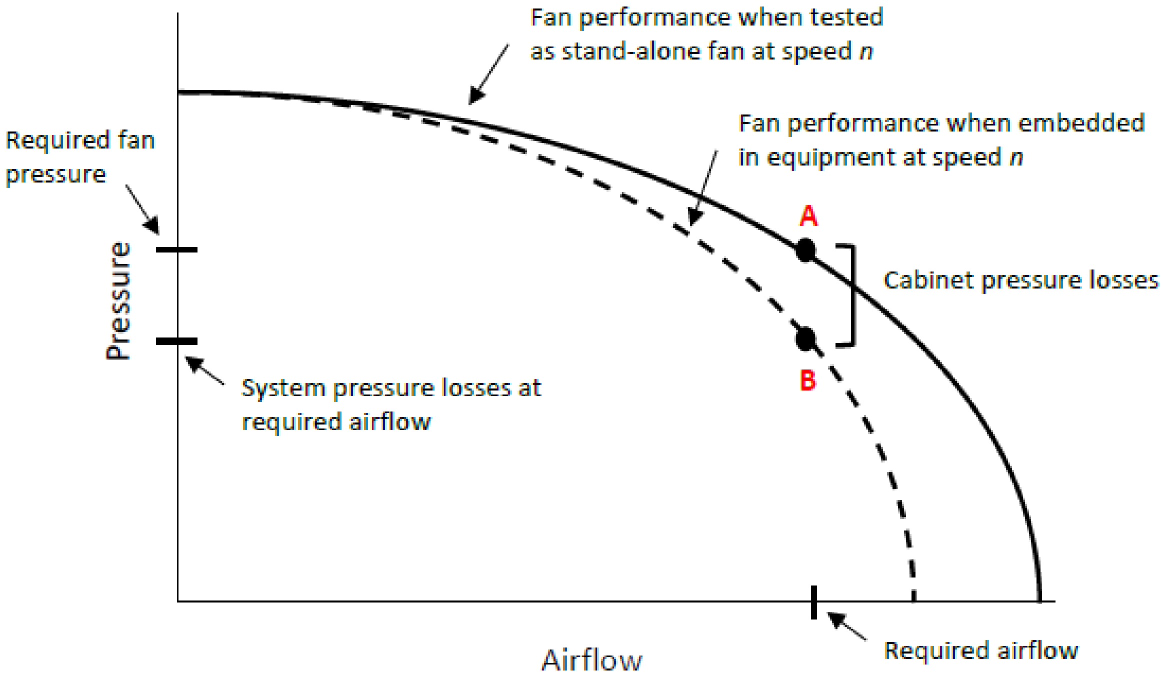

Figure 1. Fan performance when tested as stand-alone fan and when embedded in equipment

As with our proposed standards for stand-alone fans, our proposed standards for embedded fans would apply to the entire certified operating range of each fan model. This approach would encourage better fan selection to reduce the actual power consumption of fans embedded in equipment.

Under our proposed approach, manufacturers would certify the compliant operating range of each fan model (as tested in a stand-alone fan configuration). The compliant operating range would encompass the operating points that meet the minimum FEI level.

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.

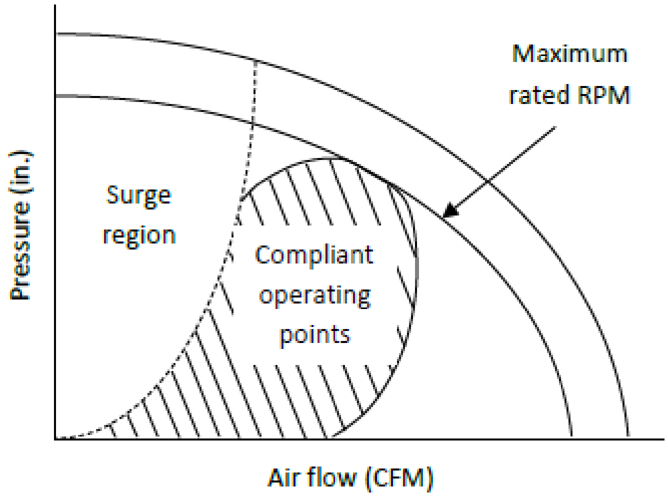

Figure 2. Example of a fan's compliant operating range and rated maximum speed (RPM)

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. An FEI of 1.00 is approximately equivalent to EL3 in DOE's NODA III analysis.[8] Our proposed standards are consistent with our proposed standards for stand-alone fans, and we believe that our recommended FEI level appropriately balances potential energy savings and burdens on manufacturers. Aligning standards for stand-alone and embedded fans would help establish a level playing field for both fan manufacturers and OEMs. In particular, fans ultimately embedded in equipment would be subject to the same requirements regardless of whether the fan manufacturer or the OEM is the "manufacturer" of a given fan.

Proposed Reporting Requirements

Our suggested approach for reporting requirements for embedded fans is consistent with our suggested approach for stand-alone fans and 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.

Our proposal for stand-alone fans contains more detail on our suggested approach for reporting requirements.

We note that many fans that are embedded in equipment are purchased by the OEM as a stand-alone fan in a testable configuration. Under our proposed approach, an OEM would not need to certify a fan embedded in their equipment if that fan was already certified as a stand-alone fan. However, in cases where the OEM is the fan "manufacturer" (e.g. when the OEM purchases only an impeller), the OEM would need to certify the embedded fan.

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[8] 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 Requirements Regarding Marketing Materials and Selection Software

Manufacturers often provide information about an embedded fan's operating range in catalogs or other marketing materials. Many manufacturers also have selection software, which assists customers and designers in selecting equipment that contains embedded fans. 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 equipment with fans that meet the standard at the design point. Specifically, it is important that manufacturers be allowed to market their fans, or equipment containing fans, for only the compliant operating range.

We are suggesting the same requirements for marketing materials and selection software as those in our proposal for stand-alone fans.

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.

In addition, for some embedded fans, manufacturers may not have specific materials describing the performance of the fan, but rather materials describing the operating range of the equipment. In this case, manufacturers would not be allowed to advertise operating ranges of equipment that would result in non-compliant fan operating points. That is, the range of advertised equipment performance must correspond to fan operating points in the compliant range.

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). We recommend that labels for embedded fans be required to be on the equipment (rather than on the fan) so that the information is visible.

We understand that there are two general categories of embedded fans: those where the design point is specified by the customer, and those where the design point is specified by the OEM. The design point for supply, return, and exhaust fans is typically specified by the customer. For example, the design point for the supply fan for an air handling unit is typically specified by the customer. On the other hand, the design point for condenser fans is typically specified by the OEM. For example, with an air-cooled chiller, the OEM will design the condenser fans and choose an appropriate airflow rate.

We are suggesting specific information to be required on a label based on the design point of the fan, regardless of whether the customer or the OEM specifies the design point. The suggested labeling requirements reflect Recommendation 31 the ASRAC term sheet with one exception. Recommendation 31 of the term sheet specifies that the design flow and pressure should be on the label when the design point is known. However, since embedded fans would be tested outside of the equipment and the internal pressure losses of the equipment will not be known to a third-party, the key pieces of information describing the design point are the airflow and operating speed. Knowing the labeled airflow and operating speed, one can then determine that the operating point is within the compliant range by looking at the certified fan performance at the same airflow and speed.

For example, consider an embedded fan labeled with a design point of 15,000 CFM at an operating speed of 1650 RPM. Figure 3 shows an example of the certified operating range for this fan at a speed of 1650 RPM. As can be seen in the figure, at the 1650 RPM design speed, the design airflow of 15,000 CFM is within in the certified operating range of this fan.

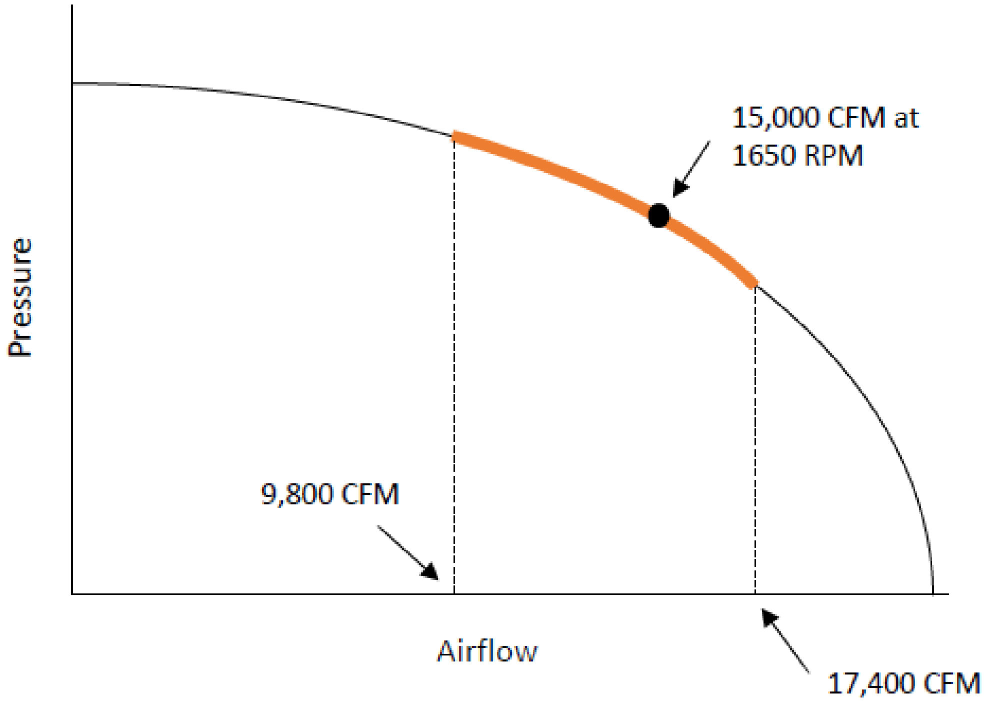

Figure 3. Example of the certified operating range of a fan at one fan speed

Table 4 shows our suggested labeling requirements.

Table 4. Proposed labeling requirements for embedded fans

Model number
Serial number or date of manufacturing
Design flow and operating speed (RPM)
FEI at design point
Maximum RPM
Link to complete performance map of the fan

We recognize that for some equipment there may be multiple design points for the selected fan (e.g. for different stages of multi- or variable-speed equipment). In this case, the label would contain only the maximum design point of the equipment at full load.

Analysis of Proposal

Scope

Our proposed standards would apply to embedded fans.[9]

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[10] is less than or equal to 150 HP

This horsepower range is equivalent to that recommended by the ASRAC working group (Recommendation 5) and is consistent with our proposal for stand-alone fans. More detail on the horsepower range is provided in our proposal for stand-alone fans.

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 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 as described in detail in our proposal for stand-alone fans.

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.

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[9] We are submitting a separate proposal with AMCA for stand-alone fans.

[10] Also referred to as fan air power (H_o), as measured in accordance with AMCA 210.

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

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

Our proposed standards would also exclude the following fans:

- Fans embedded in:
  - Regulated central air conditioners and heat pumps (single-phase, <65,000 Btu/h)
  - Regulated commercial air conditioners and heat pumps that are three-phase and <65,000 Btu/h (air-cooled)
  - Regulated residential furnaces
  - Transport refrigeration and fans exclusively powered by internal combustion engines
  - Vacuums
  - Heat rejection equipment
  - Air curtains

- Supply and condenser fans embedded in:
  - Air-cooled commercial air conditioners and heat pumps (≥65,000 and <760,000 Btu/h)
  - Water-cooled and evaporatively-cooled air conditioners and water-source heat pumps
  - Single package vertical air conditioners and heat pumps
  - Packaged terminal air conditioners and heat pumps
  - Computer room air conditioners
  - VRF multi-split air conditioners and heat pumps

The recommendations for fan categories to be included and excluded reflect the ASRAC term sheet (Recommendations 1 and 2) and are consistent with our recommendations for stand-alone fans. Our proposal for stand-alone fans contains more detail on the rationale for excluding certain fan categories. We note that not all of the recommended fan categories for inclusion and exclusion are applied as embedded fans in equipment. For example, we understand that centrifugal inline and inline mixed flow, radial housed, and power roof/wall ventilator fans are typically not embedded in equipment. However, we believe that it makes sense to harmonize the categories of embedded fans that would be included and excluded with those for stand-alone fans and that this approach would simplify the regulations.

Our recommendations for fans embedded in certain equipment types and supply and condensers fans embedded in certain regulated equipment that would be excluded from our proposed standards also reflect the ASRAC term sheet (Recommendations 2 and 3).

First, we are recommending that embedded fans in seven equipment types be excluded (consistent with the term sheet recommendations). For regulated central air conditioners and heat pumps (single-phase, <65,000 Btu/h) and regulated commercial air conditioners and heat pumps that are three-phase and <65,000 Btu/h (air-cooled), the energy consumption of the fans embedded in this equipment is already captured in the DOE efficiency metric. For regulated residential furnaces, the furnace fan is already subject to a DOE efficiency standard. Fans used in transport refrigeration and fans exclusively powered by internal combustion engines represent a small connected load. Unlike other fans included in our proposed scope, fans in vacuums are not designed to move air. For fans used in the specific types of heat rejection equipment recommended to be excluded by the ASRAC working group, such as those used in cooling towers, regulating the fan efficiency could have unintended consequences in terms of overall energy consumption. Finally, for air curtains, in order to successfully reduce energy use it would be important to utilize a metric that captures the effectiveness of air curtains in preventing the infiltration of outside air.

Second, we are recommending that supply and condenser fans embedded in certain types of regulated equipment be excluded (again consistent with the term sheet recommendations). The purpose of these exemptions of certain supply and condenser fans is to reduce burdens on OEMs in cases where they are the “manufacturer” of the fan and the energy use of the fan is already captured (at least to some extent) in the DOE efficiency metric. For example, for a supply fan that is part of a commercial air conditioner or heat pump ≥65,000 Btu/h, in many cases the HVAC manufacturer is not purchasing a supply fan in a “testable configuration” from a fan manufacturer, but may be purchasing just the impeller, for example. In these cases, the HVAC manufacturer would be considered the “manufacturer” of the supply fan, and these particular fans may exist only as part of a commercial air conditioner or heat pump. In these cases, our recommendation would mean that these fans would not be subject to any test procedures or efficiency standards. The ASRAC working group also agreed that in the future, modifications should be considered for test procedures for regulated equipment containing supply and condenser fans to more fully capture their energy use, which will yield additional savings (Recommendation 3).

Product Efficiency Opportunities

The most important product efficiency opportunity associated with embedded fans is improved fan selection. Additional opportunities include improved fan design, equipment design that results in lower pressure drops, 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.

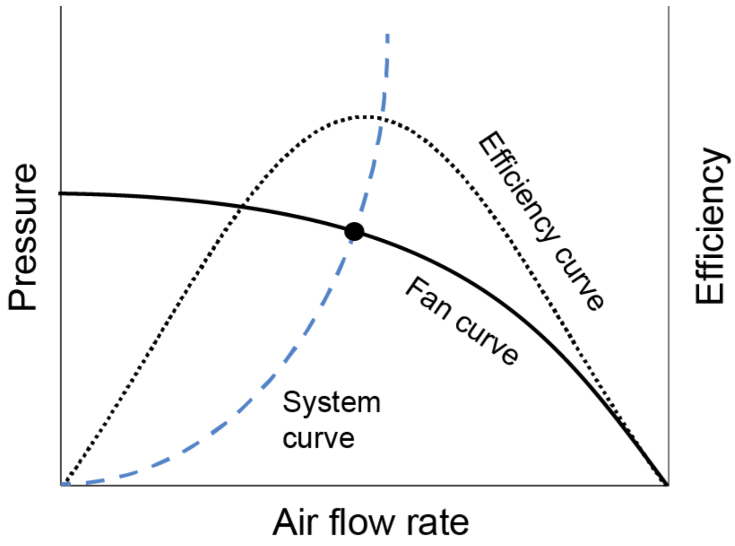

Figure 4. Example of a fan curve, its corresponding efficiency curve, and a system curve

Actual fan selections vary widely in terms of efficiency at the design point. Significant reductions in fan power consumption can thus be achieved by addressing fan efficiency at the actual design point and by shifting the market to better fan selections that consume less power. Our proposed approach for efficiency standards for embedded fans would improve fan selections in equipment by applying standards to the entire certified operating range of each fan model and by establishing requirements regarding labeling, 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 efficiency standards for embedded fans would encourage improved fan design since more-efficient designs would allow manufacturers to advertise a larger compliant operating range and to provide fans for a broader range of applications.

Equipment design to reduce pressure drops

Under our proposed approach, embedded fans would be tested as stand-alone fans outside of the equipment. However, the FEI at any given design airflow would be calculated based on the fan's operating speed needed to deliver that airflow, which is dependent in part on the internal pressure losses of the equipment: for a given airflow, higher internal pressure losses result in a higher operating speed to provide that airflow. In general, FEI decreases at higher speeds since the required fan efficiency increases with flow and pressure. Therefore, our proposed efficiency standards for embedded fans would encourage equipment designs that reduce internal pressure drops, which would ultimately save energy.

Transmission

More-efficient transmission can improve wire-to-air efficiency. As described earlier, embedded 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 efficiency standards for embedded fans 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.[11]

Standard V-Belt Cogged V- Belt Synchronous Drive Belt

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.[12]

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.[13] Our proposed approach for efficiency standards for embedded fans would encourage more-efficient motors.

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

[12] https://www.nrel.gov/docs/fy14osti/61448.pdf.

[13] http://www.novatorque.com/downloads/NovaTorque_FAQs.pdf.

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 efficiency standards for embedded fans would encourage more-efficient motor controllers.

Technical Feasibility

Our proposed efficiency levels are technically feasible for embedded fans based on their current availability in the market. As described above, the most significant opportunity for reducing the energy use of embedded fans is improved fan selection. Complying with our proposed standards in most cases would not require new fan designs, but rather the selection of fans that will reduce power consumption for given design points.

Statewide Energy Savings

Per-unit electricity savings

DOE's NODA III analysis provides estimates of first-year operating costs for each category of embedded fans.[14] 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 embedded fans. (Our proposed standard level is approximately equivalent to EL 3 in the NODA III analysis.) According to the NODA III analysis, all embedded fans are used in the commercial sector.[15]

For the assumed compliance date (2022) in the NODA III analysis, DOE assumed an average electricity price for the commercial sector of about $0.13/kWh.[16] Table 5 shows the per-unit annual electricity use at the baseline level and our proposed standard level for each embedded fan type calculated from the first-year operating costs and average electricity price. The table also shows the resulting per-unit annual electricity savings.

Table 5. 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 ($)	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	0.13	2,965	2,926	22,808	22,504	303
Panel	0.13	335	324	2,576	2,495	81
Centrifugal housed	0.13	1,048	1,007	8,063	7,748	316
Centrifugal unhoused	0.13	2,618	2,604	20,141	20,028	113

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

[15] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0190. "Sectors and Applications" tab.

[16] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0190. "Electricity Prices & Trends" tab. Calculated by multiplying the 2014 average commercial price by the price trend index for 2022 for the commercial sector.

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.[17] Using this information we can calculate the percentage of total 2012 fan shipments that were shipments of embedded fans as shown in Table 6.

Table 6. 2012 U.S. fan shipments

Fan type	2012 U.S. fan shipments			Embedded fan shipments as % of total fan shipments
	Stand-alone	Embedded	Total	
Axial cylindrical housed	33,500	3,717	37,217	10%
Panel	148,000	125,786	273,786	46%
Centrifugal housed	88,000	266,067	354,067	75%
Centrifugal unhoused	65,000	319,064	384,064	83%

The NODA III analysis also contains estimates of total U.S. shipments by fan type for each year from 2019 through 2052.[18] We can estimate 2019 California sales of embedded 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 embedded fans (from Table 6), and assuming that California shipments represent 12% of total U.S. shipments.[19] Table 7 shows estimated 2019 sales of embedded fans in California by fan type. Total estimated 2019 sales of embedded fans in California are about 110,000.

Table 7. 2019 California shipments of embedded fans

Fan type	2019 total U.S. fan shipments	Embedded shipments as % of total shipments	2019 U.S. embedded fan shipments	2019 California embedded fan sales
Axial cylindrical housed	44,870	10%	4,481	538
Panel	344,006	46%	158,047	18,966
Centrifugal housed	448,704	75%	337,183	40,462
Centrifugal unhoused	493,574	83%	410,040	49,205
Total	--	--	-	**109,170**

Figure 5 shows estimated annual California sales of embedded fans by fan type for 2019-2049 based on the same methodology as that used for calculating 2019 shipments in Table 7.

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

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

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

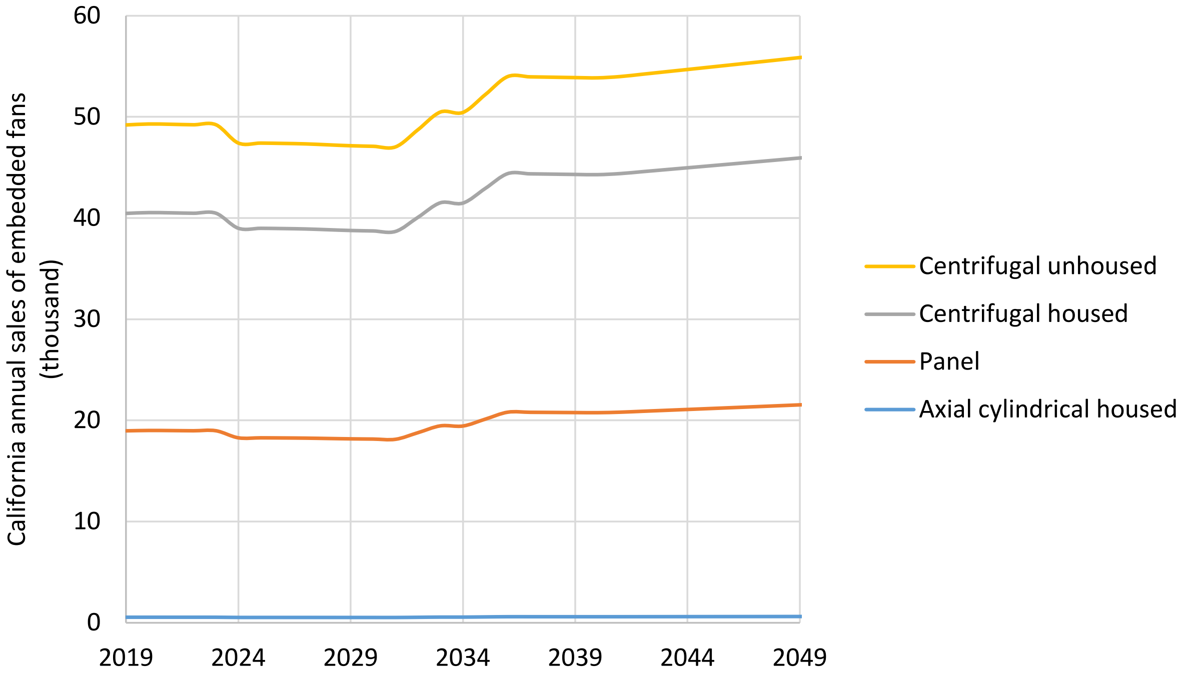

Figure 5. California annual sales of embedded fans by category for 2019-2049.

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 8. The estimated total California stock is almost 2 million.

Table 8. Estimated California stock of embedded fans

Fan type	2019 California embedded fan shipments	Average lifetime[20]	Estimated California stock
Axial cylindrical housed	538	18	9,680
Panel	18,966	21	398,279
Centrifugal housed	40,462	18	728,314
Centrifugal unhoused	49,205	17	836,482
Total	**109,170**	**-**	**1,972,755**

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 9. Estimated first-year savings are 20 GWh, and savings after stock turnover are 360 GWh per year.

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

Table 9. 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	303	538	9,680	0.2	2.9
Panel	81	18,966	398,279	1.5	32.2
Centrifugal housed	316	40,462	728,314	12.8	229.8
Centrifugal unhoused	113	49,205	836,482	5.6	94.6
Total	**-**	**109,170**	**1,972,755**	**20**	**360**

We can conservatively assume a relatively flat load profile and calculate peak demand reductions by dividing energy savings after stock turnover by 8,760 hours. Table 10 shows estimated peak demand reductions by fan type. Total estimated peak demand reductions after stock turnover are 41 MW.

Table 10. Estimated peak demand reductions for each embedded fan type

Fan type	Peak demand reduction after stock turnover (MW)
Axial cylindrical housed	0.3
Panel	3.7
Centrifugal housed	26.2
Centrifugal unhoused	10.8
Total	**41**

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.[21] 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.[22] DOE also estimated per-unit incremental costs by fan type.[23] 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 11.

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

Table 11. Lifecycle savings, net benefits, and benefit/cost ratio for each embedded 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	303	187	18	5,460	874	687	4.7
Panel	81	56	21	1,699	272	216	4.8
Centrifugal housed	316	178	18	5,679	909	731	5.1
Centrifugal unhoused	113	47	17	1,923	308	261	6.5

Note: Lifecycle savings ($) and net benefits ($) calculated assuming an electricity price of $0.16/kWh.

Average net benefits range from $216 over the lifetime of a panel fan to $731 over the lifetime of a centrifugal housed fan. Benefit/cost ratios range from 4.7 to 6.5 depending on the fan type.

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 12 shows estimated electricity bill savings for embedded fans by fan type. Total estimated electricity bill savings for California after stock turnover are $58 million per year.

Table 12. 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	0.5
Panel	5.2
Centrifugal housed	36.8
Centrifugal unhoused	15.1
Total	**58**

Note: Calculated assuming an electricity price of $0.16/kWh.

Consumer Utility/Acceptance

Our proposed approach for standards would provide consumers with information about the energy performance of fans embedded in equipment and would drive consumers to select equipment with lower fan energy consumption. It would also allow consumers to specify an FEI level above the minimum standard for fans embedded in equipment, 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.

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, and is consistent with our proposed effective date for stand-alone fans.

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 embedded 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 360 GWh per year after stock turnover, which translates to $58 million per year for California consumers. Our proposed standards would also reduce peak electricity demand by an estimated 41 MW after stock turnover. Our proposed approach for efficiency standards for embedded fans would drive better fan selection for equipment to reduce power consumption in addition to encouraging improved fan design as well as equipment design that reduces internal pressure drops. Further, our proposed standards would facilitate complementary efforts by efficiency programs and energy codes that would drive even greater savings.

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