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California Energy Commission

DRAFT STAFF REPORT

Analysis of Efficiency Standards and Test Procedures for Commercial and Industrial Fans and Blowers

2017 Appliance Efficiency Pre-Rulemaking
Docket Number 17-AAER-06

California Energy Commission
Edmund G. Brown Jr., Governor

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PREFACE

On May 15, 2017, California Energy Commission staff released an invitation to participate to provide interested parties the opportunity to inform the Energy Commission about the product, market, and industry characteristics of commercial and industrial fans and blowers, general service lamps (expanded scope), spray sprinkler bodies, tub-spout diverters, irrigation controllers, set-top boxes, low-power modes and power factor, and solar inverters. Staff reviewed the information and data received and hosted a workshop on July 19, 2017, to publicly vet the information submitted for commercial and industrial fans and blowers.

On July 18, 2017, staff released an invitation to submit proposals to seek proposals for standards, test procedures, labeling requirements, and other measures to improve efficiency and reduce the energy or water consumption of the identified appliances.

On August 1, 2017, staff hosted a public webinar to explain the participation process for anyone interested in submitting a proposal.

On October 24, 2017, staff hosted a public webinar to present the results of the invitation to submit proposals.

On January 19, 2018, the Energy Commission formally issued an order instituting rulemaking proceeding on commercial and industrial fans and blowers, as well as on compressors, hearth products, high color rendering index fluorescent lighting, portable air conditioners, and uninterruptible power supplies. The order directs staff to consider efficiency standards, test procedures, marking and labeling requirements, and other regulations for these appliances.

Staff reviewed all the information received. This report contains the proposed regulations for commercial and industrial fans and blowers, based on comments received at the workshop and in writing through the Energy Commission docket.

ABSTRACT

This report discusses proposed test procedures, efficiency standards, reporting requirements, and a label for commercial and industrial fans and blowers in the *Appliance Efficiency Regulations* (California Code of Regulations, Title 20, Sections 1601 to 1609). These proposed updates are part of the 2017 Appliance Efficiency Rulemaking Phase II (Docket 17-AAER-06). California Energy Commission staff analyzed the cost-effectiveness and technical feasibility of the proposed efficiency standards for commercial and industrial fans and blowers and determined statewide energy use and savings and related environmental impacts and benefits.

Staff proposes standards for commercial and industrial fans and blowers, which would take effect on January 1, 2020, or at least one year after the Energy Commission adopts the standards. The standards would apply to all commercial and industrial fans and blowers with a shaft horsepower (HP) of 1HP but no more than 150 air HP.

The proposed standard would save about 74 gigawatt-hours (GWh) the first year the standard is in effect. When all existing fans are replaced with fans that meet the proposed efficiency standards, the proposed standards would save about 1,800 GWh a year. This amount equates to about $529 million in savings per year after full stock turnover or 4.8 billion in net cumulative benefit to California businesses and industries after full stock turnover.

Staff analyzed available market data and concluded that the standards for commercial and industrial fans and blowers would significantly reduce energy consumption and are technically feasible and cost-effective.

Keywords: Appliance Efficiency Regulations, appliance regulations, energy efficiency, commercial and industrial fans and blowers, fans, blowers.

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EXECUTIVE SUMMARY

The California Energy Commission intends to take advantage of significant energy efficiency opportunities for commercial and industrial fans and blowers through the Title 20 Appliance Efficiency Regulations.

Commercial and industrial fans and blowers are used throughout California for a variety of applications, such as heating, ventilation, and air conditioning systems in commercial buildings, commercial kitchen exhaust systems, industrial processes, agricultural ventilation, and embedded applications. About 179,000 commercial and industrial fans and blowers are sold every year in California, for a total energy use of about 4,100 gigawatt-hours (GWh) each year.

The proposed standards cover commercial and industrial fans and blowers used in building applications, including axial-inline fan (also known as axial cylindrical housed fans), axial-panel fans (also known as panel fans), centrifugal housed fans, centrifugal unhoused fans, centrifugal-inline and inline mixed-flow fans (also known as inline and mixed-flow fans), radial-housed fans (also known as radial fans), and power roof/wall ventilators (also known as power roof ventilators).

By regulating the efficiency of these products, Energy Commission staff estimates that consumers will save around $210 to $6,100 lifecycle net benefit per unit. Statewide energy use would be reduced by 74 GWh in the first year standards are in effect, and about 1,800 GWh annually after all existing fans in California are replaced with minimally compliant fans. Commission staff arrived at this savings figure by analyzing the data available under the U.S. Department of Energy's (DOE) third Notice of Data Availability (NODA).[1] Commission staff analyzed the types of fans listed in DOE's analyses (Life-Cycle Cost Analysis[2] and National Impact Analysis[3]) and concluded that all are within the scope of the proposed standard.

To ensure that only commercial-scale fans are covered, staff proposes to cover those with a minimum input shaft power of 1 horsepower and a maximum air horsepower of 150. Staff proposes to exclude certain types of fans because they either serve niche applications or the associated use profile is not a good fit for the framework of these standards. Excluded fans include radial housed unshrouded fans with diameter less than 30 inches or a blade width of less than 3 inches, circulating fans, induced-flow fans, jet fans, and cross-flow fans.

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[1] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0194

[2] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0190

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

Staff proposes to use the Air Movement and Control Association (AMCA) Standard 208-18 Calculation of the Fan Energy Index (FEI) as the test procedure. The FEI is an energy efficiency metric for fans inclusive of motors and drives that provides a standardized and consistent basis to compare fan energy performance across fan types and sizes at a given fan duty point. The FEI is a ratio of the electrical input power of a reference fan to the electrical input power of the actual fan at the same duty point (air flow and pressure characteristics). Staff proposes that fans sold in California and manufactured on or after January 1, 2020, will need to have a minimum FEI of 1.00.

Staff's analysis demonstrates that the proposed standards for commercial and industrial fans and blowers are technically feasible because there are a large number of existing commercial and industrial fans and blowers that operate at or above the proposed standard and can achieve the desired operating airflow. Moreover, staff's analysis demonstrates that the proposed standard is cost-effective, since the cost savings from operating a compliant unit outweigh the incremental cost needed to purchase a compliant unit instead of a noncompliant unit.

The following tables show the statewide energy and monetary savings from the proposed fan standards. Tables ES-1 and ES-2 reflect the gross first-year savings, as well as the net savings after full stock turnover. Please note that the tables included in this Staff Report have maintained the fan names used in DOE's third NODA in order to avoid confusion in the cost analysis. The correlation between the fan names used in the proposed standards and the DOE's third NODA is included above.

Table ES-1: Stand-Alone Fans Savings

Fan Type	Per-Unit Savings[4] (kWh)	First-Year Savings (GWh)	Savings After Stock Turnover (GWh/yr)	First-Year Savings ($ in Millions)	Savings After Stock Turnover ($ in Millions per year)
Axial cylindrical housed	1155	5.6	162.3	0.82	23.71
Panel	500	11.2	312.4	1.89	53.04
Centrifugal housed	408	5.5	148.2	0.93	25.17
Centrifugal unhoused	130	1.3	35.3	0.22	5.99
Inline and mixed-flow	1131	4.1	109.6	0.69	18.61
Radial	2211	11.9	357.2	1.74	52.19
Power roof ventilator	927	10.0	299.4	1.69	50.84
Total		**49.5**	**1424.4**	**7.99**	**229.54**

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary

Source: Energy Commission staff

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[4] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0194.

Table ES-2: Embedded Fans Savings

Fan Type	Per-Unit Savings[5] (kWh)	First-Year Savings (GWh)	Savings After Stock Turnover (GWh/yr)	First-Year Savings ($ in Millions)	Savings After Stock Turnover ($ in Millions per year)
Axial cylindrical housed	361	0.2	3.5	0.03	0.59
Panel	102	1.9	40.7	0.33	6.90
Centrifugal housed	380	15.3	276.2	2.61	46.90
Centrifugal unhoused	130	6.4	108.4	1.08	18.41
Total		**24**	**429**	**4.05**	**299.73**

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary

Source: Energy Commission staff

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[5] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0194.

CHAPTER 1:
Legislative Criteria

Section 25402(c)(1) of the California Public Resources Code mandates that the California Energy Commission (Energy Commission) reduce the inefficient consumption of energy and water on a statewide basis by prescribing efficiency standards and other cost-effective measures for appliances that require a significant amount of energy or water to operate. Such standards must be technologically feasible and attainable and must not result in any added total cost to the consumer over the designed life of the appliance.

In determining cost-effectiveness, the Energy Commission considers the value of the water or energy saved, the effect on product efficacy for the consumer, and the life-cycle cost of complying with the standard to the consumer. The Energy Commission also considers other relevant factors including, but not limited to, the effect on housing costs, the statewide costs and benefits of the standard over the lifetime of the standard, the economic impact on California businesses, and alternative approaches and the associated costs.

CHAPTER 2: Efficiency Policy

The Warren-Alquist Act[6] establishes the California Energy Commission as California's primary energy policy and planning agency. The act mandates that the Energy Commission reduce the wasteful and inefficient consumption of energy and water in the state by prescribing statewide standards for minimum levels of operating efficiency for appliances that consume a significant amount of energy or water.

For nearly four decades, California has regularly increased the energy efficiency requirements for new appliances sold and new buildings constructed in the state. Through the Appliance Efficiency Program, appliance standards have shifted the marketplace toward more efficient products and practices, reaping significant benefits for California's consumers. California's Title 20 Appliance Efficiency Regulations, along with federal appliance standards, encompass a variety of appliance types and saved an estimated 30,065 GWh[7] of electricity in 2015 alone, resulting in about $4.84 billion in savings[8] to California consumers. In the 1990s, the California Public Utilities Commission (CPUC) decoupled the utilities' financial results from their direct energy sales, promoting utility support for efficiency programs. These efforts have reduced peak load needs by more than 8,645 megawatts (MW) and continue to save about 32,594 GWh per year of electricity.[9] The potential for additional savings remains by increasing the energy efficiency of appliances.

Reducing Electrical Energy Consumption to Address Climate Change

Appliance energy efficiency is identified as a key to achieving the greenhouse gas (GHG) emission reduction goals of Assembly Bill 32 (Núñez, Chapter 488, Statutes of 2006)[10]

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[6] The Warren-Alquist State Energy Resources Conservation and Development Act, Division 15 of the Public Resources Code § 25000 et seq., available at http://www.energy.ca.gov/2017pulications/CEC-140-2017-001/CEC-140-2017-001.pdf.

[7] California Energy Commission. January 2016. *California Energy Demand 2016-2026 Revised Electricity Forecast*, available at http://docketpublic.energy.ca.gov/PublicDocuments/15-IEPR-03/TN207439_20160115T152221_California_Energy_Demand_20162026_Revised_Electricity_Forecast.pdf.

[8] Using current average electric power and natural gas rates of residential electric rate of $0.164 per kilowatt-hour, commercial electric rate of $0.147 per kilowatt-hour. This estimate does not incorporate any costs associated with developing or complying with appliance standards.

[9] California Energy Commission, California Energy Demand 2016-2026 Revised Electricity Forecast, January 2016, available at http://docketpublic.energy.ca.gov/PublicDocuments/15-IEPR-03/TN207439_20160115T152221_California_Energy_Demand_20162026_Revised_Electricity_Forecast.pdf.

[10] AB 32, California Global Warming Solutions Act of 2006, available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=200520060AB32.

and Senate Bill 32 (Pavley, Chapter 249, Statutes of 2016),[11] as well as the recommendations contained in the California Air Resources Board's *Climate Change Scoping Plan.*[12] Energy efficiency regulations are also identified as key components in reducing electrical energy consumption in the Energy Commission's *2015 Integrated Energy Policy Report (IEPR)*[13] and the 2011 update to the CPUC's *Energy Efficiency Strategic Plan.*[14] Governor Edmund G. Brown Jr. and the Legislature have identified appliance efficiency standards as a key to doubling the energy efficiency savings necessary to put California on a path to reducing its GHG emissions to 80 percent below 1990 levels by 2050,[15] a commitment made to the Subnational Global Climate Leadership Memorandum of Understanding (Under MOU) agreement, along with 167 jurisdictions representing 33 countries.[16]

On October 7, 2015, the Governor signed the Clean Energy and Pollution Reduction Act of 2015 or Senate Bill 350 (De León, Chapter 547, Statutes of 2015), requiring the Energy Commission to establish annual targets for statewide energy efficiency savings and demand reduction that will achieve a doubling of energy savings from buildings and retail end uses by 2030.[17] Appliance efficiency standards will be critical in meeting this goal. In addition, the Energy Commission adopted the *Existing Buildings Energy Efficiency Action Plan* in September 2015 and updated it in December 2016 to transform existing residential, commercial, and public buildings into energy-efficient buildings.[18] Appliance efficiency standards are essential to the plans approach to reduce plug-load energy consumption in existing buildings.

The *California Long-Term Energy Efficiency Strategic Plan,*[19] adopted in 2008 by the CPUC and developed with the Energy Commission, the California Air Resources Board

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11 SB 32, California Global Warming Solutions Act of 2006, available at https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160SB32.

12 *Climate Change Scoping Plan* available at http://www.arb.ca.gov/cc/scopingplan/2013_update/first_update_climate_change_scoping_plan.pdf.

13 California Energy Commission, *2015 Integrated Energy Policy Report*, 2015, available at: http://www.energy.ca.gov/2015_energypolicy/

14 CPUC, *Energy Efficiency Strategic Plan,* updated January 2011, available at http://www.cpuc.ca.gov/NR/rdonlyres/A54B59C2-D571-440D-9477-3363726F573A/o/CAEnergyEfficiencyStrategicPlan_Jan2011.pdf.

15 Gov. Edmund G. Brown Jr., 2015 Inaugural Address, available at http://gov.ca.gov/news.php?id=18828

16 Subnational Global Climate Leadership Memorandum of Understanding, available at http://under2mou.org/background/.

17 *2016 Integrated Energy Policy Report Update*, available at http://docketpublic.energy.ca.gov/PublicDocuments/16-IEPR-01/TN216281_20170228T131538_Final_2016_Integrated_Energy_Policy_Report_Update_Complete_Repo.pdf.

18 *California's Existing Buildings Energy Efficiency Action Plan – 2016 Update,* available at http://docketpublic.energy.ca.gov/PublicDocuments/16-EBP-01/TN214801_20161214T155117_Existing_Building_Energy_Efficency_Plan_Update_Deceber_2016_Thi.pdf.

19 California Energy Commission and CPUC, *Long - Term Energy Efficiency Strategic Plan,* updated January 2011, available at http://www.cpuc.ca.gov/NR/rdonlyres/A54B59C2-D571-440D-9477-3363726F573A/0/CAEnergyEfficiencyStrategicPlan_Jan2011.pdf.

(CARB), the state's utilities, and other key stakeholders, is California's roadmap to achieving maximum energy savings in the state between 2009 and 2020 and beyond. It includes four "big, bold strategies" as cornerstones for significant energy savings with widespread benefit for all Californians:[20]

- All new residential construction in California will be zero-net-energy (ZNE) by 2020.
- All new commercial construction in California will be ZNE by 2030.
- Heating, ventilation, and air conditioning (HVAC) will be transformed to ensure that energy performance is best for California's climate.
- All eligible low-income customers will have the opportunity to participate in the low-income energy efficiency program by 2020.

These strategies were selected based on the ability to achieve significant energy efficiency savings and bring energy-efficient technologies and products into the market.

Loading Order for Meeting the State's Energy Needs

California's loading order places energy efficiency as the top priority for meeting energy needs. The *Energy Action Plan 2008 update* strongly supports the loading order, which describes the priority sequence for actions to address increasing energy needs. Energy efficiency and demand response are the preferred means of meeting the state's growing energy needs.[21]

For the past 30 years, while per-capita electricity consumption in the United States has increased by nearly 50 percent, California electricity use per capita has been nearly flat. Continued progress in cost-effective buildings and appliance standards and ongoing enhancements to efficiency programs implemented by investor-owned utilities (IOUs), publicly owned utilities, and other entities have contributed significantly to this achievement.

Zero-Net-Energy Goals

On April 25, 2012, Governor Brown further targeted ZNE consumption for state-owned buildings. Executive Order B-18-12[22] requires ZNE consumption for 50 percent of the

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[20] California Energy Commission and CPUC, *Long-Term Energy Efficiency Strategic Plan*, available at http://www.cpuc.ca.gov/NR/rdonlyres/14D34133-4741-4EBC-85EA-8AE8CF69D36F/0/EESP_onepager.pdf , p. 1.

[21] *Energy Action Plan 2008 update,* available at http://www.energy.ca.gov/2008publications/CEC-100-2008-001/CEC-100-2008-001.PDF , p. 14.

[22] Office of Edmund G. Brown Jr., Executive Order B-18-12, April 25, 2012, available at https://www.gov.ca.gov/news.php?id=17508

square footage of existing state-owned buildings by 2025 and ZNE consumption from all new or renovated state buildings beginning design after 2025.

To achieve these goals, the Energy Commission has committed to adopting and implementing building and appliance regulations that reduce wasteful energy and water consumption. The *Long-Term Energy Efficiency Strategic Plan* directs the Commission to develop a phased and accelerated "top-down" approach to more stringent codes and standards.[23] It also calls for expanding the scope of appliance standards to plug loads, process loads, and water use. The Commission adopted its detailed plan for fulfilling these objectives in the 2013 *IEPR*.[24]

Governor's Clean Energy Jobs Plan

On June 15, 2010, as part of his election campaign, Governor Brown proposed the *Clean Energy Jobs Plan*,[25] which directed the Energy Commission to strengthen appliance efficiency standards for lighting, consumer electronics, and other products. The Governor noted that energy efficiency is the cheapest, fastest, and most reliable way to create jobs, save consumers money, and cut pollution from the power sector. He also stated that California's efficiency standards and programs have triggered innovation and creativity in the market. Today's appliances are not only more efficient, but they are less expensive and more versatile than ever due, in part, to California's leadership in this area.

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23 California Energy Commission and CPUC, *Long-Term Energy Efficiency Strategic Plan*, p. 64.

24 California Energy Commission, *2013 IEPR*, pp. 21-26.

25 Office of Edmund G. Brown Jr., *Clean Energy Jobs Plan,* available at http://gov.ca.gov/docs/Clean_Energy_Plan.pdf.

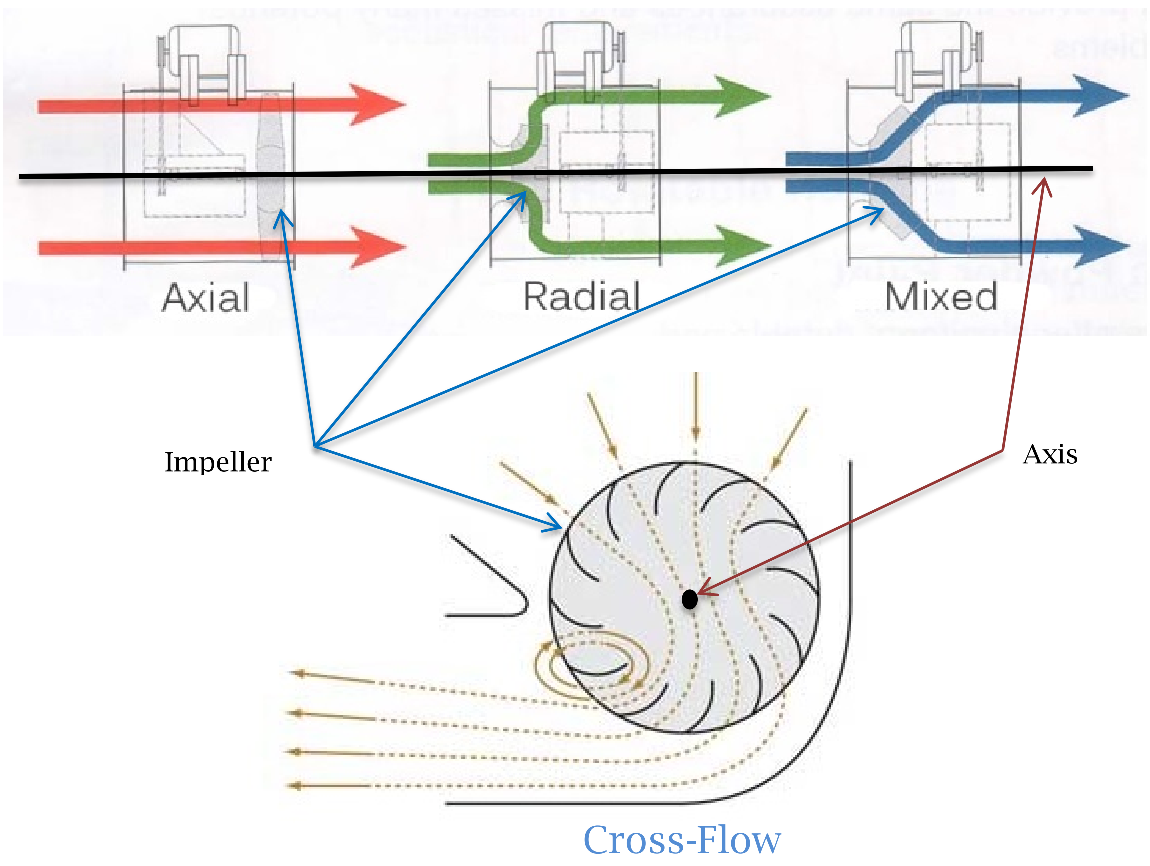
CHAPTER 3:
Product Description

There are an estimated 3.9 million commercial and industrial fans and blowers in California, with a combined energy use of nearly 98,000 gigawatt-hours (GWh) per year. Efficiency improvements in fans can drive down the energy use in the desired application. This chapter describes fans in terms of airflow, construction, auxiliary parts (for example, motors), application, and utility.

Overview of Fans and Blowers

A fan is a device that produces a current of air (airflow). Commercial and industrial fans and blowers are used in a wide variety of applications such as commercial buildings heating, ventilation, air-conditioning, and refrigeration (HVACR) systems; commercial kitchen exhaust systems; industrial processes; agricultural ventilation; and embedded applications such as unitary air conditioners and heat pumps, air handling units, and air-cooled chillers. One of the characteristics by which fans are classified is the nature of how the air moves through the impeller. Axial flow, radial flow, mixed-flow, and cross-flow are all possible characteristics for fan impellers. (See **Figure 3-1.**) These flow characteristics often define the type of fan, although other fan characteristics are often used to further delineate the type of fan, for example, induction fans, propeller fans, vane-axial, centrifugal unhoused, and so forth.

Figure 3-1: Axial-Flow, Radial-Flow, Mixed-Flow, and Cross-Flow



Source: Engineering 360 and Oriental motor

Airflow Characteristics

Axial-Inline Fans

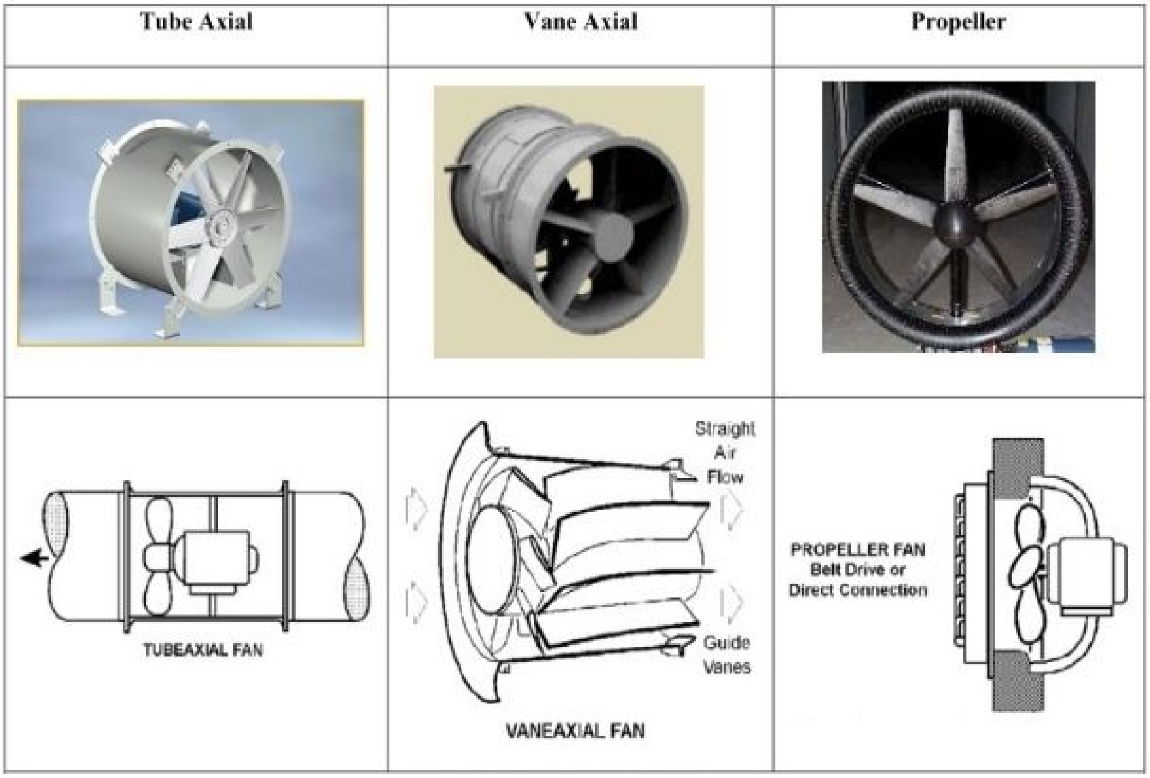
Axial-inline fans, as shown in **Figure 3-2,** are also known as axial-cylindrical housed fans. Examples of axial-inline fans are shown in **Figure 3-3**, and include tube-axial fans, vane-axial fans, and some propeller fans that use an axial-flow impeller, where the air enters and exits the fan in the same direction as that of the axis or fan axle, as shown in **Figure 3-1** above. In addition to the axial impeller, axial-inline fans have cylindrical housing, may or may not have turning vanes, and may or may not have ducted inlets and outlets. These fans are used in applications such as general ventilation and industrial processes.

Tube-axial and vane-axial fans use a tubular casing. Unlike tube-axial fans, a vane-axial fan has stationary guides (vanes). A great deal of energy transferred to the air in axial-flow fans is in kinetic form, which can be transformed into pressure energy by straightening the swirl of air by using vanes or by reducing the exit velocity with the use of a diffuser. Vane-axial fans can be equipped for maximum transformation, as well as high transfer of energy, and have a high pressure-producing potential depending on tip speed and blade angles.

Figure 3-2: Axial-Inline Fan

Source: Greenheck

Figure 3-3: Propeller, Tube-Axial, and Vane-Axial Fans



Source: mechanicalgalaxy.blogspot.com

Axial-Panel Fans

Axial-panel fans, also known as *propeller fans* or *panel fans*, are fans with an axial impeller mounted in 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 the wall when inlets and outlets are not ducted. Panel fans achieve very little transformation and for this reason have very low pressure-producing capability. Panel fans transport air from one space to another, such as for ventilation through a wall in factories and warehouses. An axial-panel fan is shown in **Figure 3-4**.

Figure 3-4: Axial-Panel Fan

Source: Loren Cook Company

Centrifugal Housed and Unhoused Fans

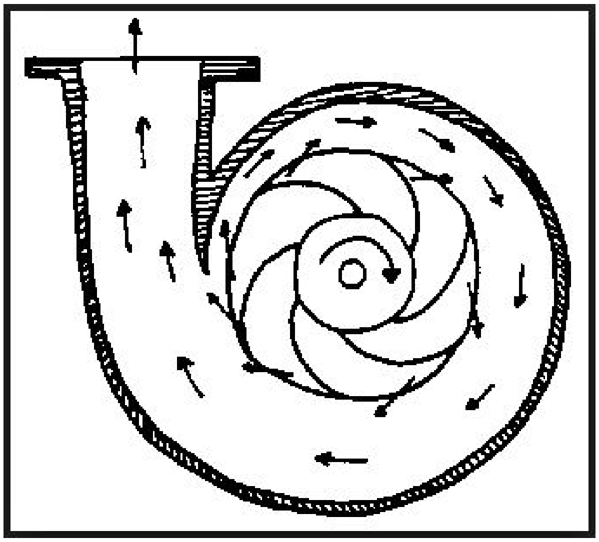
Centrifugal fans move air from an axial to a radial flow due to centrifugal action by the impeller. Centrifugal fans usually use a scroll-type casing or housing (**Figure 3-5**), where the flow enters at the middle of the case in an axial direction and leaves the impeller in a tangential direction from the axle of the impeller. Centrifugal fans can come without a casing, also known as centrifugal unhoused fan (**Figure 3-6**), or with a scroll-type casing, also known as centrifugal housed fans (**Figure 3-7**). Tubular centrifugal fans use a tubular casing so that the flow enters and leaves axially. (See **Figure 3-8.**) The pressure-producing capability of radial flow fans varies depending on blade depth, tip velocity, and blade angles. (See **Figure 3-9.**)

A *centrifugal-housed fan* (with casing) has a centrifugal or radial impeller in which airflow exits into a housing that is generally scroll-shaped to direct the air through a single outlet. Inlets and outlets can optionally be ducted. Centrifugal-housed fans include forward-curved, backward-curved, backward-incline, and airfoil impellers (see **Figure 3-9).** Forward-curved, backward-curved, and backward-incline impellers have blades of a single thickness, while airfoil fans have a backward-incline airfoil blade. An *airfoil* is the shape of a wing that produces an aerodynamic force when it moves through a fluid. Centrifugal-housed fans are used to supply ventilation air and are used in industrial process applications.

A *centrifugal-unhoused fan* (without a casing) has a centrifugal or radial impeller **(Figure 3-10)** in which airflow enters through a panel and discharges into free space, and the inlet and outlet are not ducted. Centrifugal-unhoused fans include fans designed for use in fan arrays that have partition walls separating the fan from other fans in the array.

Centrifugal-unhoused fans, often referred to as “plenum fans,” are commonly used in air-handling applications.

Figure 3-5: Scroll-Type Casing



Source: Wells Construction

Figure 3-6: Centrifugal-Unhoused Fan

Source: peerlessblowers.com

Figure 3-7: Centrifugal-Housed Fan

Source: The New York Blower Company

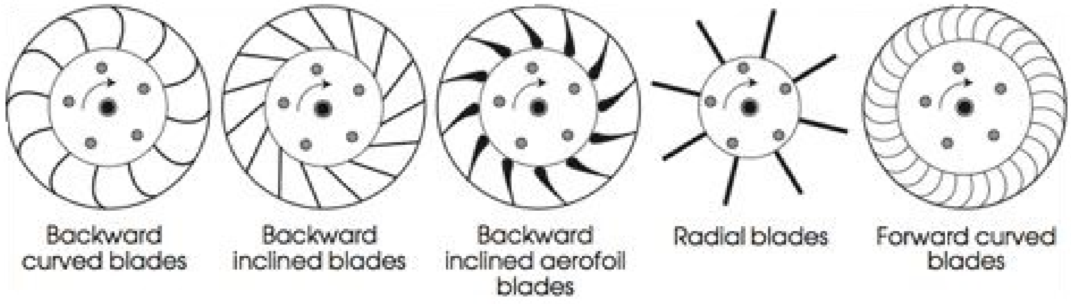
Centrifugal-Inline and Mixed-Flow Fans

Centrifugal-inline and *inline mixed-flow fans*, **Figure 3-8**, often have cylindrical housing similar to axial-inline fans but have either a centrifugal or a mixed-flow impeller design. Airflow enters axially at the fan inlet, and the housing redirects radial airflow from the impeller to exit the fan in an axial direction. The inlets and outlets may be ducted. Centrifugal-flow impellers will discharge the air in a radial direction (**Figure 3-1)**, but the cylindrical housing will redirect the air to exit in an axial direction. Centrifugal-inline fans can also have square or rectangular housing. Inline mixed-flow fans are characterized by an axial and radial airflow taking place on the blades of the impeller. Mixed-flow impellers used in axial-flow casings have a hub similar to an axial-flow impeller, but the inlet portion of the blade extends down over the face of the hub, guiding air radially (**Figure 3-1**). Centrifugal and mixed inline-flow fans are typically used for general ventilation applications.

Figure 3-8: Centrifugal-Inline and Inline Mixed-Flow Fan

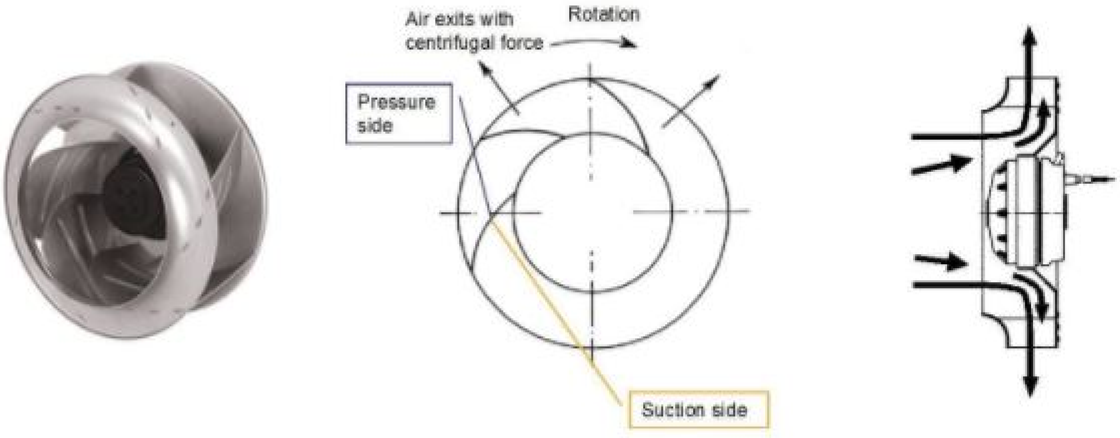
Source: Aerovent.com

Figure 3-9: Centrifugal Impellers



Source: cibsejournal.com

Figure 3-10: Radial Impeller



Source: DesignSpark

Radial-Housed Fans

Radial-housed fans, also known as radial fans, are a type of centrifugal fan that has blades that extend radially from the central hub (**Figure 3-9** and **Figure 3-10**). The air enters in an axial direction and exits in a centrifugal or radial direction. Radial housed fans are typically used in material handling. (See **Figure 3-11.**)

Figure 3-11: Radial Housed Fan

Source: Twin City

Power Roof/Wall Ventilators

Power roof/wall ventilators (PRV) can exhaust or supply air to a building. They can be designed with an axial flow, known as an axial power roof ventilator, or a centrifugal flow, known as a centrifugal power roof ventilator. A power roof/ wall ventilator has an internal driver and housing to prevent precipitation from entering the building, as well as a base designed to fit over the roof or wall opening. A centrifugal PRV exhaust fan has a centrifugal impeller that exhausts air from a building; the inlet is typically ducted, and the outlet is not. A centrifugal PRV supply fan has a centrifugal impeller that supplies air to a building; the inlet is typically not ducted and the outlet is typically ducted. An axial PRV has an axial impeller that either supplies or exhausts air to a building; the inlet and outlets of an axial PRV are typically not ducted. See **Figure 3-12** for an example of an exhaust PRV.

Figure 3-12: Exhaust Power Roof/Wall Ventilator

Source: Captive Air

Characteristics of Excluded Fans

Induction Fans

An induction fan (**Figure 3-13**) is a fan designed specifically for exhausting contaminated air vertically away from a building. An induction fan is defined as a housed fan where outlet airflow is greater than its inlet airflow due to induced airflow through an outlet nozzle and a windband. The outlet nozzle is specially designed to create a high velocity jet from the inlet airflow that when combined with a windband induces ambient air to create a larger volume of diluted air that is discharged out the top of the windband. These fans are generally installed in laboratory or hazardous exhaust air systems and are used as an alternative to a traditional centrifugal or axial fan that exhausts into a tall stack. Inlets can optionally be ducted, and outlets are not ducted.

Jet Fan

A jet fan, also known as jet tunnel fan, is used for producing high-velocity flow of air in a space. It's a fan that is tested using either International organization for Standardization (ISO) standard 13350:2015 Fans – Performance testing of jet fans or AMCA 250 – Laboratory Methods of testing jet tunnel fans for performance The typical function of a jet fan is to add momentum to the air within a tunnel. Inlets and outlets are not ducted. (See **Figure 3-14**.)

Figure 3-13: Induction Fan

Source: Twin City Fan & Blower

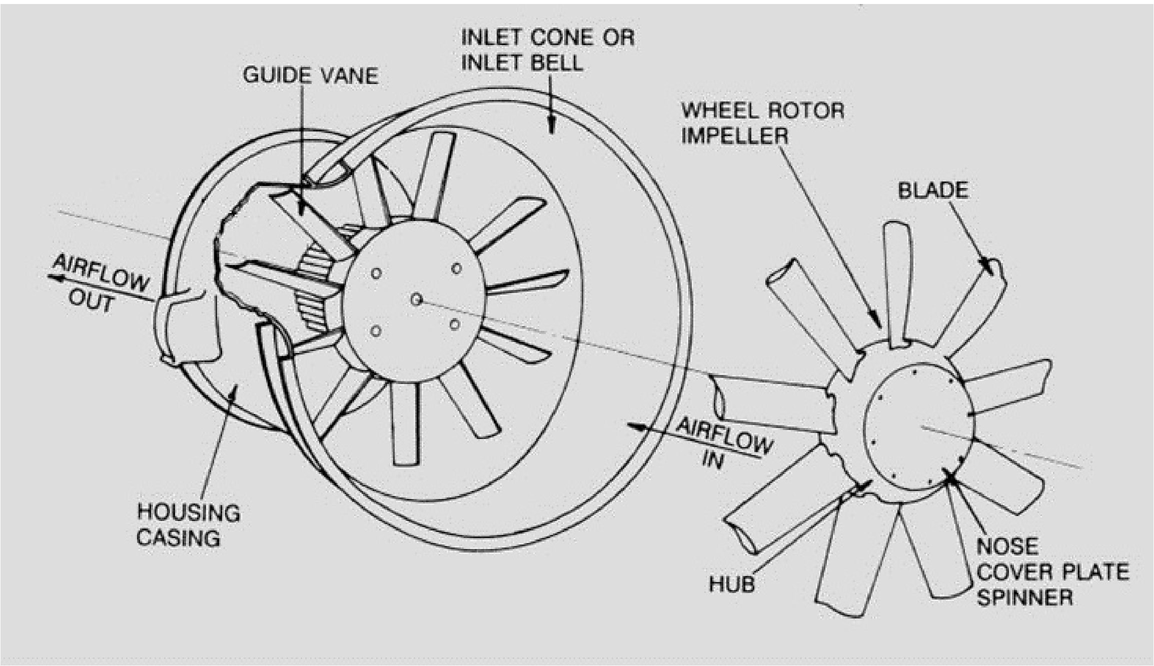
Figure 3-14 Jet Fan

Source: Kruger Fan

Fan Construction

Axial fans (**Figure 3-15**) may use blades shaped to airfoil (shape of a wing) sections or blades of uniform thickness that can be fixed, adjustable at standstill, or variable in operation. These fans are designed to take in air and discharge it in a direction that is generally parallel to the shaft of the impeller. The larger the hub, the more important it is to have an inner cylinder roughly the size of the hub located downstream of the impeller. The guide vanes of a vane-axial fan are in the annular space between the casing and the inner cylinder and are used or designed to straighten the airflow.

Figure 3-15: Vane-Axial Fan, Exploded View

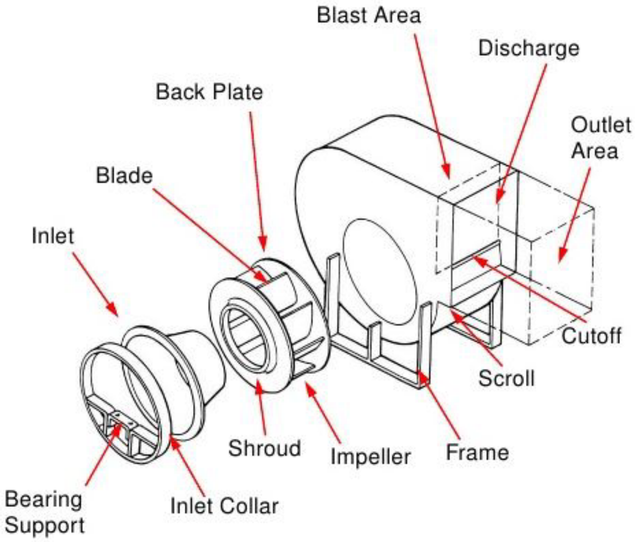


Source: *ASHRAE Handbook*

Centrifugal fans (**Figure 3-16**) use forward-curved blades; radial and radial-tip blades; backward-curved, backward-incline blades; and airfoil blades. Forward-curved blades are shallow and curved so that both the tip and the heel point in the direction of rotation. Radial and radial-tip blades both have fins that are straight or perpendicular to the hub; however, radial-tip blades are curved at the heel to point in the direction of rotation. Backward-curved and backward-incline blades point in the direction opposite rotation at the tip and in the direction of rotation at the heel. All the above blades are of uniform thickness and are designed for radial flow.

Airfoil blades have backward-curved chord lines so that the leading edge of the airfoil is pointing forward at the heel, and the trailing edge is pointing backward at the tip with respect to rotation. Impellers for all blade shapes are usually shrouded and may have single or double inlets. Blade widths are related to the inlet-to-tip-diameter ratio. Tubular centrifugal fans may be designed for backward-curve, air foil, or mixed-flow impellers. An inlet bell and discharge guide vanes are required for good performance.

Figure 3-16: Centrifugal Fan Parts



Source: Loren Cook Company

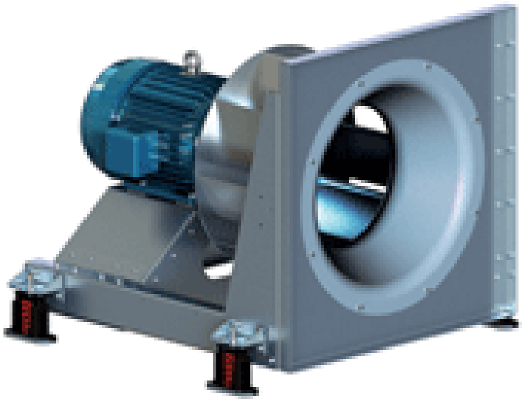
Cross-flow fans use impellers with blades similar to that of a forward-curved centrifugal blade, but the end shrouds have no inlet holes. Blade-length-to-tip-diameter ratios are limited only by structural considerations.

Fan Motor, Transmission, and Controls

Fan efficiency can depend on the fan itself, as described above, as well as on the related auxiliary components, including the motor, transmission, and motor controls. Fans use a variety of motors to operate, each with its own efficiency. The motors vary in horsepower and technology. In addition, the type of transmission used to move the fan also affects the efficiency of the motor and fan. The transmission of power from the motor to the shaft of the fan can be achieved by mounting the motor directly to the shaft, or by a belt mechanism.

In direct-shaft-driven fans, the motor is directly mounted onto the fan shaft, and the power is transmitted to the fan directly from the motor. (**Figure 3-17**) On a belt-driven fan, the motor shaft and the fan shaft are connected by a belt. (**Figure 3-18**)

Figure 3-17: Direct-Driven Fan



Source: Greenheck

Figure 3-18: Belt-Driven Fan

Source: Greenheck

Controls are often used to improve the efficiency of the fan. To have the fan operate at a specific number of revolutions per minute, or to provide the required volumetric flow, some fans use a variable-speed electric motor and a control to change the speed or power at which the motor operates. In other cases, a change of belt tension or gear ratio can be used to control or change the velocity of the fan.

Stand-Alone and Embedded Fans

Fans can be sold as either stand-alone products and installed as such, or they can be sold to an original equipment manufacturer (OEM) of a product that requires a fan (such as a unitary air conditioner), or it can be manufactured by an OEM and sold with the product that requires a fan.

A stand-alone fan moves air through a system and is installed as an independent piece of equipment. A stand-alone fan will do work, or move air, through a system of vents. An *embedded fan* is a fan that operates within a piece of equipment that has another function in addition to the movement of air. Some examples of embedded fans are the fans that are used in unitary air-conditioning units, air chillers, and air handlers.

Unfortunately, there is no way to differentiate based on a description of the fan itself between a stand-alone and an embedded fan. For example, a 27-inch diameter axial-cylindrical fan that operates as an embedded fan can also be installed as a stand-alone fan.

CHAPTER 4:
Regulatory Approaches

This chapter provides an overview of different regulatory and nonregulatory approaches to testing and improving the efficiency of commercial and industrial fans and blowers.

Metrics

Cubic Feet per Minute per Watt

A cubic-feet-per-minute-per-watt metric (CFM/watt) approach is the volumetric flow rate compared to the energy or watts needed by the motor to generate a flow rate. Although the approach is simple, it does not consider the efficiency of the electric motor, transmission, and controls. The fans described by a CFM/watt metric are fans that have no system restriction or pressure drop to overcome.

Fan Efficiency Grade

The fan efficiency grade (FEG) is a numerical rating that classifies fans by the associated aerodynamic ability to convert mechanical shaft power, or impeller power in the case of a direct-driven fan, to air power. Essentially, it reflects fan energy efficiency, allowing engineers to more easily differentiate between fan models: More efficient fan models will have higher FEG ratings. FEG applies to the efficiency of the fan only and not to the motor or drives or both.

Fan Electrical Input Power

The fan electrical input power (FEP) is calculated for both the motor (actual) and the fan (reference) driven by the motor at a specific pressure and volumetric flow. Both FEPs are calculated under the standard developed by the AMCA: ANSI/AMCA Standard 208-18 “Calculation of the Fan Energy Index” to calculate the duty points at which the fan will be most effective. Both FEP calculations take into consideration the motor, transmission, and controllers efficiency.

Fan Energy Index

The fan energy index, or FEI, is a ratio of the electrical input power of a reference fan to the electrical input power of the actual fan calculated at the same duty point and calculated under ANSI/AMCA Standard 208-18, “Calculation of the Fan Energy Index.” FEI can be calculated for each duty point (airflow and pressure) of a fan curve. The FEI metric takes into consideration the motor, transmission, and control efficiencies as part of the calculation. This allows the consumer to pick the most efficient fan for the application based an energy index, rather than a specific flow rate or pressure point. Because FEI is a ratio it is based on an efficiency level discussed in Chapter 6.

Federal Regulations

There are no federal standards or test procedures for commercial and industrial fans and blowers.

The U.S. Department of Energy (DOE) issued a notice of proposed determination[26] on June 28, 2011, proposing that commercial and industrial fans, blowers, and fume hoods meet the criteria for covered equipment under the Energy Policy and Conservation Act (EPCA). On December 10, 2014, DOE issued a notice of data availability (NODA),[27] followed by a second NODA[28] on May 1, 2015. Due to the different suggestions and the lack of agreement in the first and second NODA, the Appliance Standards and Rulemaking Federal Advisory Committee (ASRAC) formed a working group to negotiate potential efficiency standards and test procedures for fans. The negotiations resulted in a term sheet[29] that included scope, test procedures, and standards for fans. The DOE released a third NODA[30] to support the recommendations in the term sheet on November 1, 2016.

The ASRAC term sheet for fans recommended the following:

1. Defining the scope of covered fans to include both stand-alone and embedded fans, and to establish specific exclusions for both stand-alone and embedded fans. The scope was agreed upon consensus of 24 votes in the affirmative, 0 votes in the negative, 0 abstention votes, and 1 absent vote.
2. Basing the test procedure on "AMCA 210 Laboratory Methods of Testing Fans for Certified Aerodynamic Performance Rating" (latest version) under a specific installation type or testable configuration dependent on the fan category, and using fan electrical input power (FEP) and fan energy index (FEI) as the metric for efficiency. The test method, testable configuration, and metric were agreed upon with a consensus of 24 votes in the affirmative, 0 votes in the negative, 0 abstention votes, and 1 absent vote.
3. Testing embedded fans outside of the equipment in the same configuration as a stand-alone fan. This was agreed by consensus with 22 votes in the affirmative and 3 absent votes.
4. Using fan laws to determine the represented values of FEP and FEI for geometrically similar fans if a manufacturer offers geometrically similar fans. Consensus was reached with 24 votes in the affirmative and only 1 absent vote.

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[26] https://www.regulations.gov/document?D=EERE-2011-BT-DET-0045-0001.
[27] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0037.
[28] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0062.
[29] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0179.
[30] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0194.

> Other recommendations did not reach consensus, including how to calculate part-load motor losses and labeling requirements.

DOE suspended its rulemaking for commercial and industrial fans and blowers in January 2017.

California Regulations

California does not have appliance efficiency regulations under Title 20 of the California Code of Regulations for commercial and industrial fans and blowers.

The California building code has requirements under Title 24, Part 6, Section 110.2 of the California Code of Regulations, for equipment that has an embedded commercial and/or industrial fan and blower. These requirements are for efficiency related to space conditioning and not for air movement, including requirements for minimum energy efficiency ratio (EER), integrated energy efficiency ratio (IEER), coefficient of performance (COP), integrated part load value (IPLV), or kilowatt per ton of refrigeration (kW/ton).

Moreover there are direct fan requirements under Title 24, Part 6, Section 140.4(c) of the California Code of Regulations, but these requirements are applicable only to new building and not every installation. These requirements are for fan systems used for space conditioning that shall meet the following:

1. For constant-volume fan systems, the total fan power index at design conditions of each fan system with total horsepower over 25 HP shall not exceed 0.8 watts per CFM.
2. For variable-air-volume systems, the fan power index at design conditions of each fan system with total horsepower over 25 HP shall not exceed 1.25 watts per CFM of supply air, have a static pressure sensor at a specific location, and, for systems with individual zone control boxes, the ability to reset static pressure set points.
3. Air-treatment or filtering systems need to calculate the total adjusted fan power index using Equation 140.4-A.

Regulations in Other States

There are no regulations in other states for commercial and industrial fans and blowers.

International Approaches

The European Union has Regulation Number 327/2011,[31] which sets eco-design requirements for fans driven by motors with an electric input power between 125 watts and 500 watts. The regulation has two efficiency tiers, with the first tier effective on January 1, 2013, and the second tier on January 1, 2015. The regulation is applicable to axial fans, centrifugal forward-curved fans, centrifugal radial-bladed fans, centrifugal backward-curved fans without housing, centrifugal backward-curved fans with housing, mixed-flow fans, and cross-flow fans. The European Union approach is based on a metric called fan motor efficiency grade (FMEG). The regulation does not limit the fan selection point. Instead, an indirect mechanism discourages poor fan selection: the higher the electrical input power, the greater the required reference efficiency to stay within a given FMEG, and the greater the associated costs. The FMEG classification is based on full-speed operation at the optimum duty point and it includes a small credit for the use of certain high-efficiency, variable-speed drives.

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[31] https://publications.europa.eu/en/publication-detail/-/publication/c765ffb6-5f03-4a3f-ac61-08fc3f3874b7/language-en.

CHAPTER 5:
Alternative Considerations

Energy Commission staff considered different potential regulatory pathways to achieving energy savings in fans, including reviewing the proposals submitted to the docket for this proceeding and a more stringent standard based on the efficiency levels presented in the DOE's third NODA. Staff will continue to analyze and consider alternative proposals as they are provided to the Energy Commission to determine if the alternatives would be more effective in achieving energy savings, would be as effective as and less burdensome to affected private persons than the staff proposal, or would be more cost-effective to affected private persons and equally effective in implementing cost-effective and technically feasible efficiency standards for fans.

Alternative 1: No Standard

Under this alternative, the Energy Commission would not have efficiency standards or test procedures for commercial and industrial fans and blowers. No costs would be imposed, and no energy savings would be achieved under this proposal. Staff believes that proposing no standard for commercial and industrial fans and blowers would represent a lost opportunity for energy savings in California and would not meet California's greenhouse gas emission reduction and energy efficiency goals.

Alternative 2: CFM per Watt

The Energy Commission reviewed the proposed volumetric flow rate (cubic feet per minute) per watt (CFM/watt) option.[32] Staff found insufficient evidence of energy savings and technical feasibility since no information was provided to analyze. Furthermore, the CFM/watt analysis is applicable to fans that have no system restriction and, therefore, is not representative of all the fans suggested under this proposal. Therefore, staff did not propose the CFM/watt as the metric for this standard.

Alternative 3: FEI With an Efficiency Level 3

Energy Commission staff reviewed the proposed fan energy index (FEI) with a standard level equivalent to the DOE's third NODA's Efficiency Level 3 for commercial and

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[32] http://docketpublic.energy.ca.gov/PublicDocuments/17-AAER-06/TN221209_20170918T144452_HARRY_M_GRAVES_Comments_FAN_EFFICIENCY_INDEX_A_FALSE_METRIC.pdf..

industrial fans and blowers for both stand-alone[33] and embedded fans.[34] The FEI metric using the Efficiency Level 3, as explained in the metrics section under the Fan Energy Index of chapter 4 above, provides significant energy savings for California. Furthermore, there was sufficient data supporting and concluding that the FEI standards at Efficiency Level 3 is technically feasible and cost-effective for both stand-alone and embedded fans.

Alternative 4: FEI With an Efficiency Level of 4 or Higher

Staff reviewed the FEI standards with an efficiency level of four or higher by using information associated with the DOE's third NODA. Although an FEI metric at Efficiency Level 4 would provide greater energy savings that are cost-effective and technically feasible, it may not strike the right balance for a first-time regulation. The Energy Commission would be interested in receiving more data and analysis on market effects and impacts on consumers at higher efficiency levels than Efficiency Level 3.

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[33] http://docketpublic.energy.ca.gov/PublicDocuments/17-AAER-06/TN221217_20170918T163210_AMCA_ASAP_NEEA_NRDC_ACEEE_PGE_SDGE_SCE_SoCalGas_Comments_AMCA_a.pdf.

[34] http://docketpublic.energy.ca.gov/PublicDocuments/17-AAER-06/TN221220_20170918T163646_ASAP_NEEA_NRDC_ACEEE_PGE_SDGE_SCE_SoCalGas_Comments_Efficiency.pdf.

CHAPTER 6:
Staff Proposal

Scope

Energy Commission staff proposes to cover fans, both stand-alone and embedded, that include axial-inline fans, axial-panel fans, centrifugal-housed fans, centrifugal-unhoused fans, centrifugal-inline fans, inline mixed-flow fans, and power roof/wall ventilators. The fans covered under this regulation must have a rated shaft input power, also known as brake horse power greater than 1 horsepower (HP), or, for fans without a rated shaft input power, an electrical input power greater than or equal to 1 kW. In addition, covered fans must have a fan airpower less than or equal to 150 HP. Fans smaller or larger than described are excluded from the scope of the staff proposal.

Staff also proposes to explicitly exclude the following types of fans:

a. Radial housed unshrouded fans with diameter less than 30 inches or a blade width of less than 3 inches

b. Circulating fans

c. Induced-flow fans

d. Jet fans

e. Cross-flow fans

f. 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 British thermal units per hour (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[35]

g. 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 evaporative-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

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[35] https://www.merriam-webster.com/dictionary/air%20curtain

packaged terminal heat pumps as defined at 10 CFR 431.92 with cooling capacity less than 760,000 Btu/h; variable refrigerant flow multisplit air conditioners and variable refrigerant flow multisplit heat pumps as defined at 10 CFR 431.92 with cooling capacity less than 760,000 Btu/h.

For definitions related to included and excluded products, see Chapter 10, Proposed Regulatory Language.

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 its survey of 2012 fan sales that about 85 percent of the total connected load is greater than or equal to 1 HP.[36] According to a joint proposal presented by AMCA and efficiency advocates[37] there is a large number of small manufacturers who make fans below 1 HP. Fans with air power greater than 150 HP make up a relatively small portion of the total connected load and are usually custom products used in industrial applications where customers are highly sensitive to efficiency due to the high operating costs at high power levels. Energy Commission staff believes that the recommended horsepower range strikes an appropriate balance between capturing potential energy savings and limiting burdens on manufacturers.

The lower bound of 1 HP is 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 fan air power[38] is roughly equivalent to the upper bound of 200 HP based on shaft power. Fan air power measures the output power provided by the fan. Fan shaft power measures the power at which the shaft is rotating taking in consideration motor and transmission efficiency but it ignores the efficiency of the impeller. Energy Commission staff chose not to use fan shaft power because that measure does not take into consideration the efficiency of the impeller.

The lower bound of 1 kW fan electrical input power is roughly equivalent to a fan shaft power of 1 HP. To illustrate this, the default values for transmission and motor efficiency were applied to the AMCA 208 standard for a fan with a shaft power of 1HP are:

1. 1 HP is equivalent to 0.7457 kW
2. Per AMCA 208 equation 5.5 (SI), the default transmission efficiency for a shaft power of 0.7457 kW is:

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[36] https://www.amca.org/adovacy/documents/DOEFanEfficiencyProposal-AMCAAnnualMeetingRedux1-24-15.pdf. p. 14.

[37] AMCA and Efficiency Advocates Joint Proposal for Stand-Alone Fans https://efiling.energy.ca.gov/GetDocument.aspx?tn=221217. p. 21.

[38] Industry term used for fans, brief explanation can be found in https://www.amca.org/UserFiles/file/Nospreads_FanEfficGrades.pdf

$$\eta = .96\left(\frac{H_{i,ref}}{H_{i,ref}+1.64}\right)^{0.05} = 0.96\left(\frac{0.7457}{0.7457+1.64}\right)^{0.05} = \mathbf{90.6\%}$$

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

$$H_{t,ref} = \frac{H_{i,ref}}{\eta_{trans,ref}} = \frac{.7457}{.906} = \mathbf{0.823 \mathit{kW}}$$

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

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

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

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

$$FEP = fan\ shaft\ power * \frac{1}{transmission\ efficiency} * \frac{1}{motor\ efficiency}$$

$$FEP = 0.7457 * \frac{1}{.906} * \frac{1}{.839} = \mathbf{0.98\ \mathit{kW}}$$

Based on the default values for transmission efficiency and motor efficiency in AMCA 208, a fan shaft power of 1 HP is almost equivalent to 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, with fans categorized as shown in **Table 6-1**.

Table 6-1: 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 fans	

Source: AMCA and Efficiency Advocates joint proposal

The fan categories proposed to be covered include a wide variety of common commercial and industrial applications. In contrast, the excluded fan categories are fan types that are used primarily in specialty applications and represent a small connected load, or they are fans that are embedded in equipment that is already regulated under minimum appliance efficiency standards. 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 DOE efficiency standards already regulate the equipment and, to some extent, the fan efficiency as a component of the cooling or heating efficiency of the unit. For regulated residential furnaces, the furnace fan is already subject to a DOE efficiency standard.

Energy Commission staff proposes to include fans embedded in nonregulated equipment because of the energy savings that they represent to California. When compared to the volume of fans, preliminary figures show that the energy savings from embedded fans is about 30 percent of the total energy after stock turnover. Preliminary information also shows that embedded fans will perform the same as stand-alone fans when tested outside the embedded appliance. For example, a 27-inch forward-curved inline fan that is embedded will perform and generate the same fan curve as a 27-inch forward-curved inline fan that operates as a stand-alone fan. Energy Commission staff is aware that embedded fan performance might be worse in specific applications due to the differences in airflow and static pressure in the equipment in which the fans is embedded, but staff has not received information to demonstrate by how much.

Other fans are excluded because they do not fit into the framework of a fan efficiency standard. Fans used in transport refrigeration and fans exclusively powered by internal combustion engines are not grid-connected and therefore do not present an opportunity for electricity or natural gas savings. Fans in vacuums are not designed to move air. Fans used in the specific types of heat-rejection equipment, such as those used in cooling towers and regulating the fan efficiency could have unintended consequences in terms of overall energy consumption.

Framework and Metric

The Energy Commission staff proposal will apply to the entire certified operating range of each fan model. The rationale for this approach is that it will encourage better fan selection, which will significantly improve efficiency and decrease power consumption. Since the efficiency of a fan varies widely across the operating range, the peak efficiency of a fan has little relevance to actual efficiency and energy consumption in the field. Therefore, an approach 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 Chapter 8, Technical Feasibility.)

To capture the entire certified operating range of a fan, staff proposes to use the Fan Energy Index (FEI) as the metric for the efficiency of fans covered under this proposal. Energy Commission staff believes that the FEI metric will reflect the different duty points at which a fan will be performing above the proposed minimum level. FEI takes into consideration the motor, transmission, and control efficiencies as part of the calculation. This allows the consumer to pick the most efficient fan for the application based an energy index, rather than a specific flow rate or pressure point. 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 percent less power than a fan with an FEI of 1.0 at the same duty point.

The FEI metric is a metric that 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 the FEI metric are that it more fully represents the actual power consumption of a fan and that it encourages not only more efficient fan selection and fan design, but also more efficient transmission, motors, and motor controllers.

FEI is calculated using total pressure for ducted fans and static pressure for unducted fans. The total pressure of a fan 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 further work.

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 (FEP_{ref}) (in kW) is calculated as:

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

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

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

$$H_{i,ref} = \frac{(Q_i + 250)\left(P_{t,i} + .40 * \frac{\rho}{\rho_{std}}\right)}{6343 * 0.66}$$

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

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

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 un-ducted 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 or pressures. The FEI metric 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.

Test Procedure

Staff proposes to test fans using “ANSI/AMCA standard 210-16 Laboratory Methods of Testing Fan for Certified Aerodynamic Performance Rating” (AMCA 210) to gather the lab information that would be later required to certify the fan. Staff proposes to calculate the motor efficiency using “ANSI/AMCA Standard 207-17 Fan System Efficiency and Fan System Input Power Calculation” (AMCA 207). Staff proposes to use “ANSI/AMCA Standard 208-18 Calculation of the Fan Energy Index” (AMCA 208) to calculate the FEI. The combination of these three AMCA standards allows a comparable FEI for any fan at any duty point regardless of the fan configuration (that is, bare-shaft fan, fan sold with motor, fan sold with motor and controller).

AMCA 210 is a test procedure that includes methods for measuring airflow, pressure, fan shaft power, and fan air power. AMCA 208 also includes a method for conducting a wire-to-air test for fans that have motors that do not have a minimum efficiency standard or applicable test procedure.

AMCA 207 is a test procedure that provides a method for calculating fan electrical input power when a manufacturer sells a fan with a polyphase induction motor or a motor already regulated under Title 10 of the Code of Federal Regulations. AMCA 207 includes default values for transmission efficiency, motor efficiency, and motor controller efficiency.

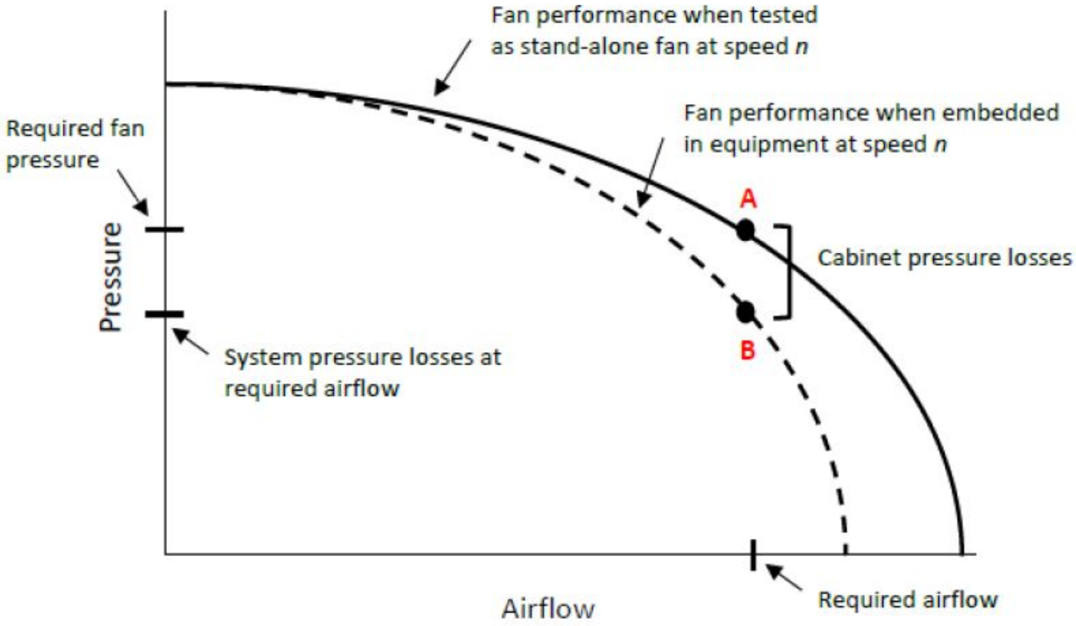
Finally, AMCA 208 is a test procedure that calculates FEI for any fan at any duty point. AMCA 208 specifies methods to determine both the actual electrical input power of a fan and the reference electrical input power at any duty point.

When testing fans, each fan category must be tested according to the pressure basis and installation configuration explained in AMCA 208. Moreover, manufacturers will be required to test a basic model fan for a family of fans to be sold in California. For example, a basic model test for a 1 HP forward-curved centrifugal-housed fan can be applicable to all 1 HP forward-curved centrifugal-housed fans. This will reduce testing burden on manufacturers.

Furthermore, Energy Commission staff proposes that embedded fans be tested as stand-alone fans. This approach will allow the ratings of embedded fans to be directly comparable to those of stand-alone fans.

A fan embedded in a piece of equipment must be selected to overcome both the internal pressure losses of the cabinet and the external pressure losses of the system. **Figure 6-1** shows an example of fan curves for a fan when tested as a stand-alone fan and when embedded in equipment (dashed curved) 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 6-1**, 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 (that is, the same as that at Point B), but the pressure is higher to overcome the cabinet pressure losses.

Figure 6-1: Embedded Fan Airflow vs. Pressure



Source: Efficiency Advocates Proposal

As described in Section 4.3 of AMCA 208 test procedure, for an embedded fan (which is similar to the situation of a fan with attachments), the FEI at any operating point would be determined based on the stand-alone performance curve (in other words, the solid line in **Figure 6-1**). 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 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 airflow and pressure. 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-alone fan performance data can be used to determine the operating point FEI of the embedded fan in different pieces of equipment, at different pressure losses.

Standard Levels

Energy Commission staff proposes that all fans meet a minimum FEI of 1.00. The proposed standard is based on Efficiency Level 3 analyzed using data under DOE's third NODA[39]. Since the FEI is defined as a ratio of the electrical input power of a reference fan to the electrical input power of the actual fan for which the FEI is calculated at the same duty point, characterized by airflow and pressure, the FEI will provide a weighted value. If the FEI if equal to or higher than 1, it means that the fan tested is compliant to the proposed standard. If the FEI is less than 1 then it means that the fan tested is not compliant to the proposed standard. The proposed FEI level achieves significant energy savings and minimizing cost impacts on consumers, as described in Chapter 7 of this report, and lower the test burdens on manufacturers.

Aligning standards for stand-alone fans and embedded fans would help establish a level playing field for 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.

Reporting Requirements

The first part of the suggested approach for reporting requirements would address information about each fan model. **Table 6-2** and **Table 6-3** shows what information manufacturers would need to report to the Energy Commission's Modernized Appliance Efficiency Database System (MAEDbS) to certify compliance with the regulations and example responses. This information is in addition to the already required under MAEDbS.

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[39] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0194

Table 6-2: MAEDbS Reporting

Fan Type	Motor Manufacturer (or N/A)	Motor Efficiency	Controller Manufacturer (or N/A)	Controller Efficiency	Belt-Drive or Direct-Drive	Trans-mission Efficiency	Maximum Rated Speed (RPM)
Centrifugal housed	N/A	N/A	N/A	N/A	Direct-driven	N/A	2,612

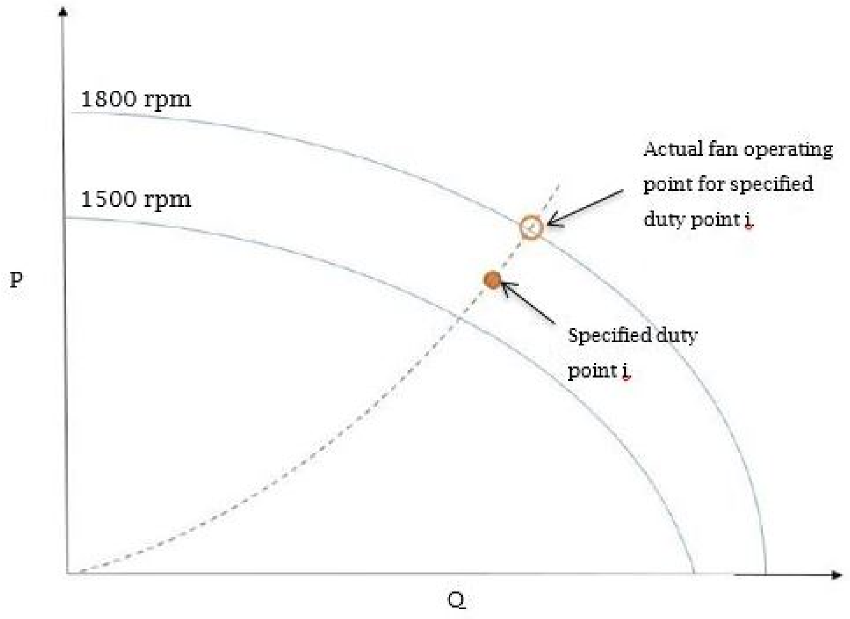
Source: AMCA

MAEDbs, is the database used by manufacturers and maintain by the Energy Commission which lists the applicable appliances authorized to be sold in California. In addition to the information proposed in **Tables 6-2** and **Table 6-**3, Each fan model shall report the fan manufacturer name, fan type, model number, whether the fan is belt-driven or direct-drive, and the maximum rated speed of the fan. Fan models that are part of a product line would also list the product line. Fans that are sold with motors would include the motor manufacturer and motor number, and fans that are sold with motors and controls.

Fan type would identify whether a fan is rated based on total pressure or static pressure. The model number will include options to list the basic model the fan is equivalent to and will help 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 could help consumers to better compare the ability of fans to serve a given operating point. With belt-driven 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 discrete operating speeds and associated performance curves. While the speed of a belt-driven fan (or a direct-drive fan with a controller) can be adjusted to meet a specified operating point, a direct-drive fan without a controller will operate on a fixed performance curve, which may overshoot the specified operating point, resulting in increased power consumption. (See **Figure 6-2.**)

Figure 6-2: Relationship of Actual to Specified Duty Point Direct-Drive Fans Without Controller



Source: AMCA

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

In addition to the fields explained in **Table 6-2**, the Energy Commission would require reporting of test results, including the maximum and minimum compliant points for each pressure curve tested for the airflow, air density, shaft power, actual FEP, reference FEP, and FEI for the compliant operating range. (See **Table 6-3.**) This information would be used to verify compliance with the FEI standard. The information would also be useful for consumers comparing two fan models with similar operating ranges, as the information would help determine which fan has a higher FEI across the specified operating range.

Table 6-3: Additional MAEDbS Reporting Fields

Static or Total Pressure (in. wg)	Min Air Flow (CFM)	Max Air Flow (CFM)	Air Density (lbm/ft^3)	Min FEP Actual (kW)	Max FEP Actual (kW)	Min Fan Shaft Power (HP or N/A)	Max Fan Shaft Power (HP or N/A)	Min FEP$_{ref}$ (kW)	Max FEP$_{ref}$ (kW)	Min FEI	Max FEI
0	7,500	12,500				1.65	3.86	1.23	2.88	1.67	1.18
1	7,500	17,500				3.07	10.7	2.29	7.98	1.54	1.01
2	7,500	20,000				4.6	17.22	3.43	12.85	1.46	1.02
3	7,500	20,000				6.18	20.48	4.61	15.28	1.40	1.11
4	10,000	20,000				10.23	23.86	7.63	17.80	1.38	1.17
5	10,000	20,000				12.29	27.34	9.17	20.40	1.36	1.21

Source: Energy Commission staff

Many fans that are embedded in equipment are purchased by the OEM as stand-alone fans in a testable configuration. Under this proposed approach, an OEM would not need to certify a fan embedded in its equipment if that fan was already certified as a stand-alone fan. However, in cases where the OEM is the fan "manufacturer" (for example, when the OEM purchases only an impeller), the OEM would need to certify the embedded fan.

Labeling

Energy Commission staff proposes a label as part of the physical nameplate of the fan. All regulated appliances must list the manufacturer name, brand name, or brand code; the model number; and the date of manufacture. One type of label would be required when the design point is known and a different type of label when the design point is unknown. **Table 6-4** shows the suggested labeling requirements. The label would verify compliance at the point of sale to the proposed standard for fans tested and listed in MAEDbS. The inclusion of a label will provide better guidance on the ranges where the fan is compliant to the proposed standards.

Table 6-4: Stand-Alone Labeling Requirements

Specific Operating point	Unknown Operating Points
Manufacturer Name, Brand Name, or Brand Code	Manufacturer Name, Brand Name, or Brand Code
Model Number	Model Number
Serial Number and date manufactured	Serial Number and date manufactured
Design Flow	List of pressures fan is compliant (in.wg)
Design pressure	List of volumetric flowrates (ft^3/min)
FEI	Static or total pressure
Designed RPM	Maximum RPM
Ducted or un-Ducted	Ducted or un-Ducted

*Note: Both the pressures and CFM should be related.

Source: Energy Commission staff

Embedded fans are designed to meet a specified design point set by either the customer or OEM. Since embedded fans would be tested outside the equipment and the internal pressure losses of the equipment will not be known, Energy Commission staff proposes that the label for embedded fans be the same stand-alone fans with a known design point. The label would be attached outside the equipment the fan is embedded into so that the information is easily accessible.

CHAPTER 7:
Savings and Cost Analysis

Energy Commission staff's proposal for commercial and industrial fans and blowers is cost-effective for consumers and will yield significant energy savings in California. This chapter demonstrates how the proposed standards are cost-effective and details the statewide energy savings of the proposed standards.

Cost-Effectiveness

Incremental Costs

The incremental cost is the difference between a fan that is compliant with the proposed standard and that of a noncompliant fan. The incremental costs to improve the efficiency of a fan through design changes vary in range, but the most significant is the improvement in aerodynamic efficiency. Staff used the same basis for incremental costs used by the U.S. Department of Energy, which includes the equipment, installation cost, and operating cost over the life of the equipment. The incremental costs differ per type of fan and are reflected in **Table 7-1**. Other additional cost increases are due to improvements in blade design, material selection, guide vanes, and housing optimization. For example, changing the material used for the fan from steel to aluminum will have an increased cost depending on the use of the material and the tolerances used.

The incremental costs for embedded fans include design optimization as well as installation of the fan into the embedded unit. Energy Commission staff has received information regarding incremental costs and will continue to analyze any new information received.

Per-Unit Savings

DOE's third NODA provides estimates of first-year operating costs and first-year operating savings at each efficiency level for each category of fan. Based on these first-year operating costs and average electricity prices, staff backed out the estimated baseline per-unit first year electricity consumption and the per-unit electricity consumption at each efficiency level for each category of stand-alone fans. Staff used commercial rates to back out the estimated energy use for stand-alone panel, centrifugal-housed, centrifugal-unhoused, power roof/wall ventilators, and inline and mixed-flow fans. Staff used industrial rates for stand-alone axial cylindrical-housed and radial fans. The commercial/industrial distinction is based on information presented in DOE's third NODA about where these fans are primarily used.

Since DOE's third NODA calculations where done in 2014, Energy Commission staff obtain commercial and industrial electricity rates for this analysis, Energy Commission staff assumed an average national electricity price in 2014 for the commercial sector and industrial sector of about 10.79 cents per kilowatt-hour ($0.1079/kWh) and $0.071/kWh,[40] respectively. Energy Commission staff then calculated per-unit energy use in kWh per year per fan type by:

- First dividing the first-year operating cost at baseline and the operating cost at the proposed standard by the applicable commercial or industrial electricity prices of 2014 to get a representative kWh per year for each fan in 2014.
- Second, subtracting the result for the efficiency level being proposed from the no-standard case.

Per-unit electricity savings for stand-alone fans was calculated to be 6,462 kWh per year, calculated by adding the per-unit savings for axial cylindrical-housed fans, panel fans, centrifugal-housed and -unhoused fans, inline mixed-flow fans, radial fans, and power roof ventilators. (See **Table A-2** Per-Unit Annual Electricity Savings Stand-Alone Fans in Appendix A).

Embedded fans resulted in per-unit annual electricity savings of 973 kWh per year, calculated by adding the per-unit savings for the embedded axial cylindrical-housed fans, panel fans, centrifugal-housed fans, and centrifugal-unhoused fans. (See **Table A-3** Per-Unit Annual Electricity Savings Embedded Fans in Appendix A.)

To determine the life-cycle net benefit for fans, first, staff calculated the per-unit average annual savings of dollars per year by multiplying the per-unit electricity savings per year by the applicable commercial or industrial electrical rate. Staff then calculated the net present value for the per-unit average annual savings based on a 3 percent discount rate. The final step was to subtract the per-unit incremental cost from the net present value at 3 percent discount rate to discern the life-cycle net benefit for each fan. To determine the savings at Efficiency Level 3 in California, staff then applied California electricity rates to the kWh savings. Staff used electricity rates of 16.98 cents per kWh for the commercial sector and 14.61 cents per kWh for the industrial sector for December 2017, based on the U.S. Energy Information Administration's California estimates.[41] Staff calculated the life-cycle savings per fan as described in **Table 7-1** Annual Energy and Monetary Savings.

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[40] U.S. Energy Information Administration. *Electric Power Monthly* With Data *for October 2014.* "Table ES1.B Total Electric Power Industry Summary Statistics, Year-to-Date 2014 and 2013, https://www.eia.gov/electricity/monthly/archive/december2014.pdf.

[41] https://www.eia.gov/electricity/monthly/archive/december2017.pdf , Table 5.6.A.

Table 7-1: Annual Energy and Monetary Savings

Stand-Alone Fan Type	Per-Unit Electricity Savings (kWh/yr)	Per-Unit Incremental Cost ($/unit)	Per-Unit Average Annual Savings ($/yr)	Average Lifetime (years)	Life-Cycle Net Benefit ($/unit)
Axial cylindrical housed	1,154.930	399	168.74	29	2,838.77
Panel	500.463	53	84.98	28	1,541.55
Centrifugal housed	407.785	33	69.24	27	1,236.00
Centrifugal unhoused	129.750	39	22.03	27	364.77
Inline and mixed flow	1,130.677	689	191.99	27	2,829.59
Radial	2,211.268	221	323.07	30	6,111.24
Power roof ventilator	926.784	595	157.37	30	2,489.48
Embedded Fan Type					
Axial cylindrical housed	361.446	187	61.37	18	657.10
Panel	101.946	56	17.31	21	210.84
Centrifugal housed	379.981	178	64.52	18	709.39
Centrifugal unhoused	129.750	47	22.03	17	243.07

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary

Source: Energy Commission staff

Cost-Benefit Analysis

By comparing the incremental cost of improving a fan to meet the proposed minimum standard to the utility bill savings over the lifetime of the fan from the higher efficiency, staff can assess the cost-effectiveness of the proposed efficiency standard. **Table 7-2 Net Benefit for Stand-Alone Fans** and **Table 7-3 Net Benefit for Embedded Fans** summarize the incremental costs, utility bill savings, and cost-benefit ratio for each category of fan.

Table 7-2: Net Benefit for Stand-Alone Fans

Fan Type	Per-Unit Electricity Savings (kWh)	Per-Unit Incremental Cost ($)	Average Lifetime (Years)	Life-Cycle Savings (kWh)	Life-Cycle Net Benefits ($)	Benefit/Cost Ratio
Axial cylindrical-housed	1,155	399	29	33,493	2,839	7:1
Panel	500	53	28	14,013	1,542	29:1
Centrifugal-housed	408	33	27	11,010	1,236	37:1
Centrifugal-unhoused	130	39	27	3,503	365	9:1
Inline and mixed-flow	1,131	689	27	30,528	2,830	4:1
Radial	2,211	221	30	66,338	6,111	27:1
Power roof ventilator	927	595	30	27,804	2,489	4:1
Total		2,029		186,689	27,305	

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary
Source: Energy Commission staff

Table 7-3: Net Benefit for Embedded Fans

Fan Type	Per-Unit Electricity Savings (kWh)	Per-Unit Incremental Cost ($)	Average Lifetime (Years)	Life-Cycle Savings (kWh)	Life-Cycle Net Benefits ($)	Benefit/Cost Ratio
Axial cylindrical housed	361	187	18	6,506	657	3:1
Panel	102	56	21	2,141	211	3:1
Centrifugal housed	380	178	18	6,840	709	4:1
Centrifugal unhoused	130	47	17	2,206	243	5:1

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary
Source: Energy Commission staff

As **Tables 7-2** and **7-3** above show, the efficiency standards for every category of fan are cost-effective to consumers.

Statewide Energy Savings

California Shipments

DOE's third NODA estimates 2012 U.S. shipments of both stand-alone and embedded fans by fan type. DOE based these estimates on various sources of data. For stand-alone fans, DOE used shipment data provided by the Air Movement and Control Association (AMCA). For embedded fans, DOE used data retrieved from the U.S. Census Bureau for June 2014 and catalogs from embedded fan manufacturers to estimate shipments of products that include embedded fans. In comments submitted to the Energy Commission as part of this rulemaking, the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) suggested that DOE's shipment estimates for embedded fans were overestimated, such that the DOE savings for embedded fans were likely much less. However, staff did not have sufficient information from these comments to make a determination about the appropriate shipments to assume for embedded fans. .

Fan shipments, derived from and weighted based on DOE's third NODA, were estimated to be:

- 37,217 units for axial cylindrical-housed fans consisting of 90 percent stand-alone units and 10 percent embedded units.
- 265,786 units for panel fans consisting of 54 percent stand-alone fans and 46 percent embedded fans.
- 354,067 units of centrifugal-housed fans composed of 25 percent stand-alone fans and 75 percent embedded fans.
- 384,067 units of centrifugal unhoused fans with 17 percent stand-alone fans and 83 percent embedded fans.
- 26,500 units of inline and mixed-flow fans shipped as stand-alone fans.
- 36,000 units of radial fans all shipped as stand-alone fans.
- 67,500 units of power roof ventilator fans shipped as stand-alone fans.

The values of shipments of embedded fans are the difference between total number of fans in heating, ventilation, air-conditioning and refrigeration (HVACR) equipment and the HVACR stand-alone fans purchased by original equipment manufacturers. DOE focused the embedded fans shipments data collection on a short list of HVACR equipment identified as representing the majority of the market.

To calculate the total number of fans that would be shipped into California in 2019, Energy Commission staff used the calculated national shipments for 2019 from the DOE's third NODA, broke them down into stand-alone and embedded fans based on the percentage of shipments of each, then multiplied by 12 percent, according to the latest U.S. Census, to get a California-population-weighted shipments number. (See **Tables A-5** and **A-6,** Stand-Alone Fan Sales in California and Embedded Fans Sales in California, respectively, in Appendix A.) **Table 7-4** shows California shipments for 2019.

Table 7-4: 2019 Shipments for Stand-Alone and Embedded Fans in California

Type of Fan	2019 Stand-Alone Shipments (Units)	2019 Embedded Shipments (Units)
Cylindrical-Housed Fans	4,846	538
Panel Fans	22,292	18,989
Centrifugal-Housed Fans	13,461	40,383
Centrifugal-Unhoused Fans	10,069	49,160
Inline and Mixed-Flow Fans	3,590	
Radial Fans	5,384	
Power Roof Ventilators	10,769	
Total	70,411	109,070

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary
Source: Energy Commission staff

California Stock

To calculate the existing stock of fans in California, Energy Commission staff assumed a no-growth market and therefore multiplied the shipments for 2019 and the lifetime of the fan. Since stand-alone and embedded fans have different lifetimes, two calculations were made. (See Appendix A.) **Table 7-5** shows the estimated fan stock for California.

Table 7-5: California Stock

Fan Type	Estimated California Stock Stand-Alone Fans	Estimated California Stock Embedded Fans
Axial Cylindrical-Housed	140,533	9,692
Panel	624,164	398,772
Centrifugal-Housed	363,450	726,900
Centrifugal Unhoused	271,861	835,719
Inline and Mixed-Flow	96,921	
Radial	161,532	
Power Roof Ventilator	323,068	
Total	1,981,530	1,971,080

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary
Source: Energy Commission staff

This yields a total California stock of roughly 4.0 million fans.

First-Year and Stock Turnover Energy Savings

Energy Commission staff calculated an estimated statewide first year energy savings of 73.5 gigawatt-hours (GWh), based on multiplying the 2019 shipments by the energy savings at Efficiency Level 3. After full stock turnover, when all existing fans are replaced with minimally compliant fans, staff calculated a total energy savings of about 1,853 GWh per year. See Appendix A for sample calculations.

Energy Commission staff calculated statewide energy savings by multiplying the life-cycle net benefit per type of fan by the stock in California. The monetary net life-cycle benefit after stock turnover is $4.78 billion. First-year gross monetary savings are about $12.04 million.

Peak Demand Reduction

For simplicity, staff assumed a flat load profile for stand-alone and embedded fans and calculated peak demand reduction by dividing energy savings after stock turnover by 8,760 hours (1 year). By using the number of hours of operation for stand-alone and embedded fans, assumed by staff to be 5,760 hours[42] per year, the peak demand reduction after full stock turnover for stand-alone fans and embedded fans is 162.6 megawatts (MW) and 48.9 MW, respectively.

Table 7-6: Stand-Alone Fan Savings

Fan Type	Per-Unit Savings (kWh)	First-Year Savings (GWh)	Savings After Stock Turnover (GWh/yr)	First -ear Savings ($ in Millions)	Savings After Stock Turnover ($ in Millions per year)
Axial Cylindrical-Housed	1,155	5.6	162.3	0.82	23.71
Panel	500	11.2	312.4	1.89	53.04
Centrifugal-Housed	408	5.5	148.2	0.93	25.17
Centrifugal-Unhoused	130	1.3	35.3	0.22	5.99
Inline and Mixed-Flow	1,131	4.1	109.6	0.69	18.61
Radial	2,211	11.9	357.2	1.74	52.19
Power Roof Ventilator	927	10.0	299.4	1.69	50.84
Total		**49.5**	**1,424.4**	**7.99**	**229.54**

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary

Source: Energy Commission staff

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[42] AMCA and Efficiency Advocates Joint Proposal for Stand-Alone Fans, TN221217_20170918T163210_AMCA_ASAP_NEEA_NRDC_ACEEE_PGE_SDGE_SCE_SoCalGas_Comments_AMCA_a.pdf, p.31

Table 7-7: Embedded Fan Savings

Fan Type	Per-Unit Savings (kWh)	First-Year Savings (GWh)	Savings After Stock Turnover (GWh/yr)	First-Year Savings ($ in Millions)	Savings After Stock Turnover ($ in Millions per year)
Axial Cylindrical-Housed	361	0.2	3.5	0.03	0.59
Panel	102	1.9	40.7	0.33	6.90
Centrifugal-Housed	380	15.3	276.2	2.61	46.90
Centrifugal-Unhoused	130	6.4	108.4	1.08	18.41
Total		**24**	**429**	**4.05**	**299.73**

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary

Source: Energy Commission staff

CHAPTER 8: Technical Feasibility

The proposed efficiency standards for fans are technically feasible based on fans currently available in the market. As described below, the most significant opportunity for reducing the energy use of commercial and industrial fans is improved fan selection. Unlike other types of appliance efficiency standards, where the efficiency level means that less efficient products will need to be redesigned or cease to be sold once the standard takes effect, most fan models will not need to be redesigned to comply with the 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. Manufacturers and retailers would then be limited to selling a fan that operates efficiently within the consumer's desired range.

To the extent that manufacturers choose to redesign fans to meet the proposed FEI level, opportunities for efficiency improvement include improved fan design, equipment that results in lower pressure drops, and more efficient transmission, motors, and motor controllers.

Fan Selection

Every fan has an efficiency curve, which describes the efficiency of the fan at each potential operating point along the fan curve. The peak efficiency of a fan occurs at a single point, and efficiency drops off significantly at operating points away from the peak efficiency. In the example shown in **Figure 8-1**, the actual operating point of a fan (where the fan curve and system curve intersect) is very close to the peak efficiency of the fan.[43] However, if a given system curve instead intersects the fan curve at a point far from the peak efficiency point, the fan will operate significantly less efficiently than peak efficiency.

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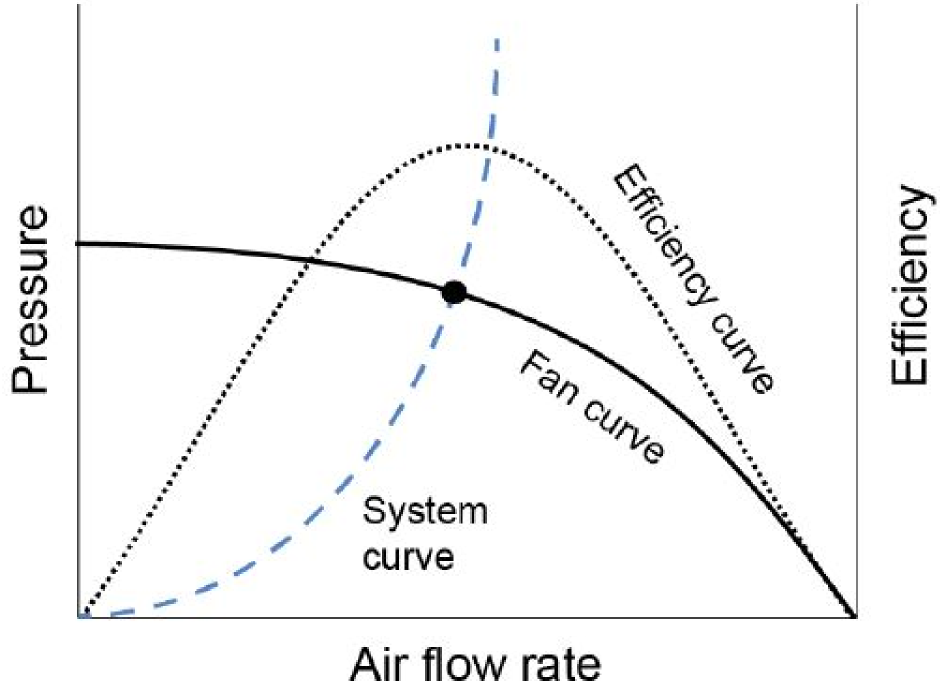
[43] The fan efficiency curve is independent and represents the efficiency of the fan operating at given pressures and flow rates.

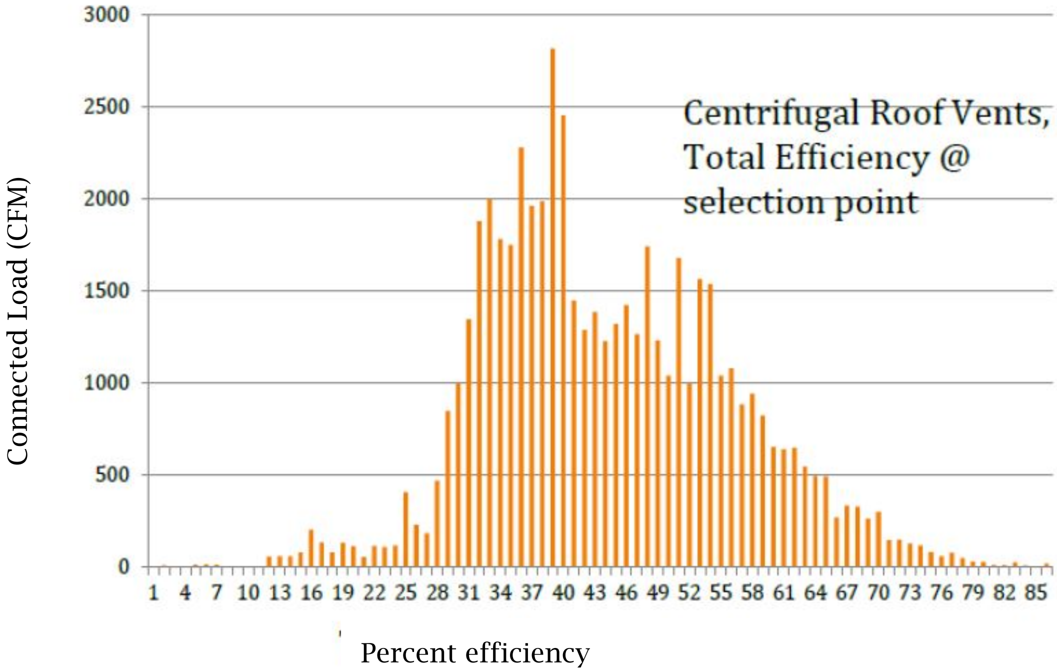
Figure 8-1: Fan Curve and Efficiency Curve Example Graph



Source: AMCA and Efficiency Advocates joint proposal

Actual fan selections vary widely in terms of efficiency at the specific design point. The following figures show how consumers are purchasing inefficient fans even though more efficient fans are currently available. **Figure 8-2** shows actual fan selection of centrifugal power roof ventilators in 2012. At the design point, total efficiency ranges from about 12 percent to 85 percent. The yellow line represents the number of fans selected for a specific design point in cubic feet per minute. Most of the fans selected are 40 percent or lower in efficiency, although more efficient fans are available.

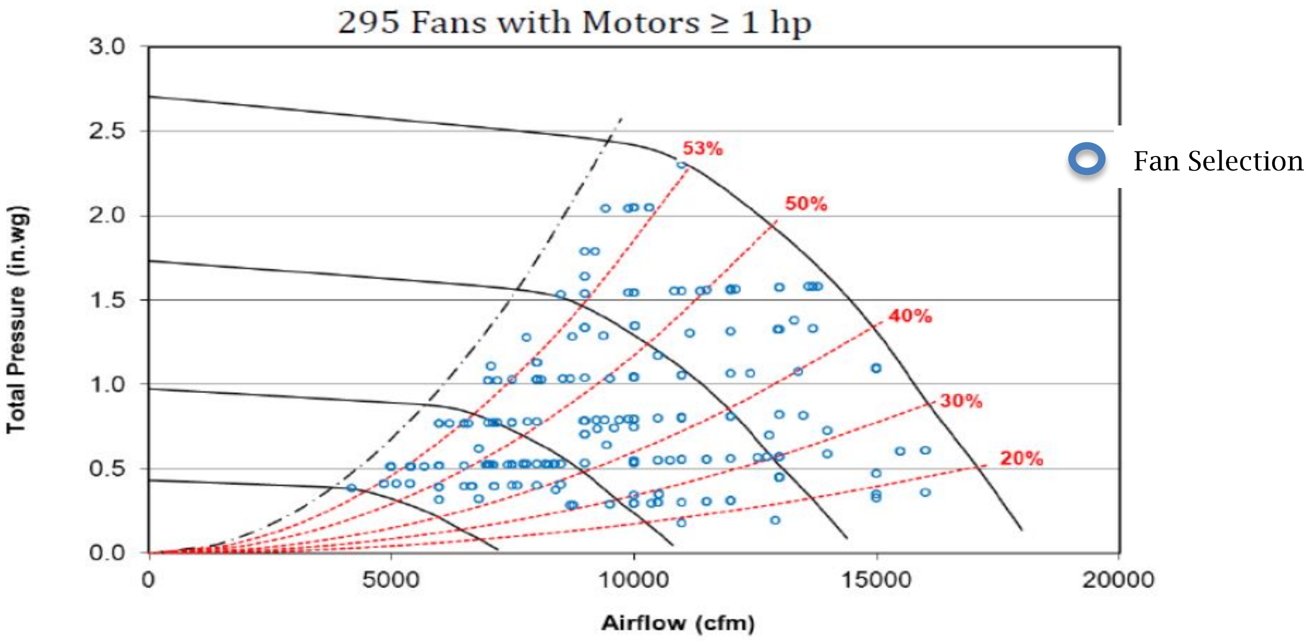
Figure 8-2: Centrifugal Power Roof Ventilator Fan Selection



Source: AMCA and Efficiency Advocates joint proposal

Similarly, **Figure 8-3** shows actual fan selections of 295 fans with motors greater or equal to 1 HP for one model of a centrifugal inline fan in 2012. While the peak efficiency of this fan is about 53 percent, a large number of fans were selected which operate under a 40 percent efficiency.

Figure 8-3: Fan Selection of Centrifugal Inline Fan Model



Source: AMCA and Efficiency Advocates joint proposal

Significant reductions in power consumption can be achieved by addressing fan efficiency at a customer's actual design point and by shifting the market to more efficient fan selections. The proposed standard would improve fan selection by applying standards to the entire certified operating range of each fan model.

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.

Multiple opportunities exist for improving aerodynamic efficiency, including blade shape, material selection, guide vanes, and housing optimization. Blade shape can significantly affect 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 due to the Bernoulli's principle in which faster moving are across the top of a blade creates less pressure than the slower moving air on the bottom of the blade creating airflow in an impeller.

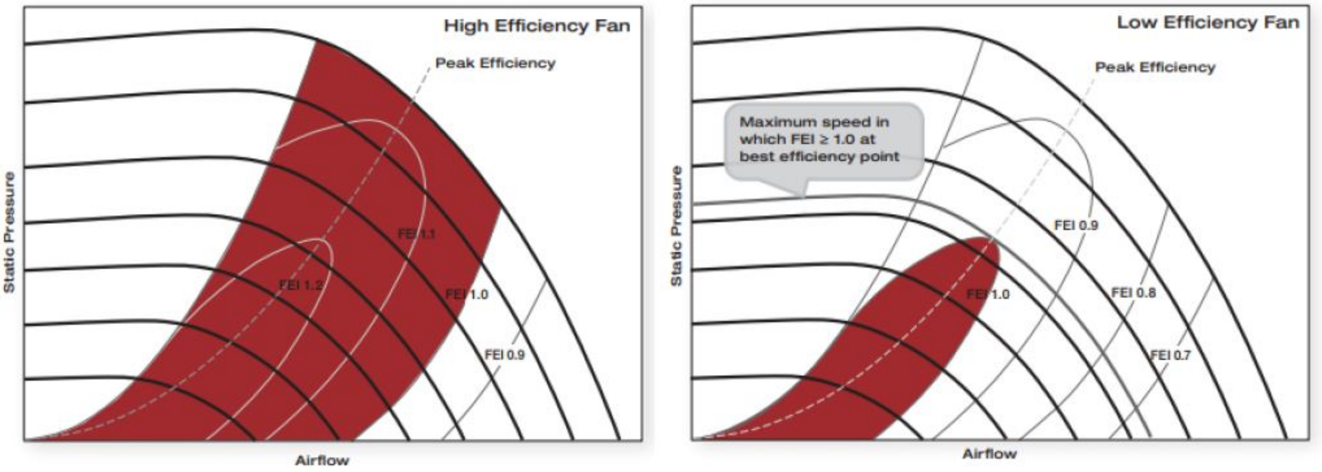
The choice of material can also affect fan efficiency. Impellers can be constructed using a variety of materials, including aluminum, steel, fiberglass, and plastic, which have different densities and other properties that can impact fan efficiency. A proper selection of material can result in aerodynamic improvements, and therefore better efficiency, for the fan.

Guide vanes direct and straighten the airflow, which results in lower pressure drop through the impeller, increasing fan efficiency. However, in some instances, guide vanes cannot be installed due to space constraints and/or fan utilization.

Finally, housing design can significantly affect efficiency as well. For example, housing that is too wide allows for recirculation of the air, while housing that is too narrow may interfere with the inlet, reducing the cross-sectional area and restricting the movement of air. The housing-fan tolerances can be improved to decrease the pressure the fan will experience due to air recirculation. Another solution is to improve the fitting of the fan housing to the inlet or outlet ducting.

The proposed approach for fan efficiency standards would encourage improved fan design. More efficient designs would allow manufacturers to advertise a larger compliant operating range for their fans. For example, **Figure 8-4** shows fan curves for two fans along with the compliant (red area) 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 has a larger compliant operating range, which means that it can meet the needs of numerous applications.

Figure 8-4: Compliant Operating Ranges of Two Fan Models



Source: AMCA and Efficiency Advocates joint proposal

Transmission

More efficient transmission can improve fan efficiency. As described earlier, fans can either be direct-drive or belt-driven. Direct-drive fans inherently have no transmission losses. Belt-driven transmissions do have some measure of transmission losses, the amount of which depends on the belt's design and other factors.

Transmission efficiency can be improved through 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 length of the belt, which reduce the bending resistance of the belt and improve efficiency. Cogged V-belts can improve efficiency about 2 percent relative to standard V-belts.[44] Improvements in belt efficiency can also 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 percent relative to standard V-belts.[45] (See **Figure 8-5.**)

Figure 8-5: Examples of V-Belts

Figure Credit: National Renewable Energy Laboratory

Motors

Similar to more efficient transmission, more efficient motors also improve the FEI result. Motor efficiency can be improved by using higher-efficiency 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 percent relative to "NEMA premium" motors.[46]

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 can improve fan efficiency by accurately adjusting the fan speed and lower the energy used by the motor driving the fan.

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[44] https://energy.gov/sites/prod/files/2014/04/f15/replace_vbelts_motor_systemts5.pdf.
[45] https://www.nrel.gov/docs/fy14osti/61448.pdf.
[46] http://www.novatorque.com/downloads/NovaTorque_FAQs.pdf.

Embedded Fans

Under the proposed testing method, embedded fans would be tested as stand-alone fans outside the equipment. However, the FEI at any given design airflow would be calculated based on the fan operating speed necessary to deliver that airflow, which depends in part on the internal pressure losses of the equipment within which the fan will be embedded.

As with stand-alone fans, the proposed standard for embedded fans is technically feasible due to the high number of available fans that are currently compliant with the proposed standard. Some stakeholders have submitted comments that the proposed test procedure, AMCA 208, is not representative of an embedded fan, but no engineering data have been received to support the argument. The Energy Commission has also received comments suggesting that the only avenue to increase fan efficiency is to increase the fan size. However, staff has found that new technologies are available that present a viable way to increase the efficiency of the embedded fan without increasing fan size. For example, assume a 27-inch embedded square inline fan; rather than increasing to a 30-inch square inline embedded fan to increase efficiency, a 27-inch mixed-flow fan could be used to provide a higher efficiency without an increase in fan diameter. Energy Commission staff is interested in data and information to assess any potential concerns about the feasibility of these standards for embedded fans.

CHAPTER 9: Environmental Impacts

Impacts

The proposed efficiency standards for commercial and industrial fans and blowers would apply only to fans newly manufactured on or after the effective date of the proposed standards and, therefore, would not cause additional waste as they do not require replacement earlier than the normal product life cycle of the fan. The standards do not require the use of any specific materials to improve the efficiency and, in fact, do not require any redesign of the fan at all, as the savings are in improving fan selection by consumers. Therefore, Energy Commission staff could not identify any adverse environmental impacts associated with the proposed efficiency standards.

Benefits

The proposed standards will improve consumer behavior to purchase fans that are compliant for their intended used and will reduce overall energy consumption statewide, providing important air and climate benefits and reducing energy costs.

The proposed standards will lead to improved environmental quality in California. Saved energy translates to fewer power plants built and less pressure on the limited energy resources, land, and water use associated with energy production. In addition, lower electricity consumption results in reduced greenhouse gas and criteria pollutant emissions, primarily from lower generation in hydrocarbon-burning power plants, such as natural gas power plants.

CHAPTER 10:
Proposed Regulatory Language

The proposed changes to the Title 20 standards are provided below. Changes to the standards are marked with underline for new language relevant to commercial and industrial fans and blowers and ~~strike-out~~ to delete existing language. Three dots or "…" represent the substance of the regulations that exists between the proposed language and current language.

The proposed regulations will:

1. Expand the scope of the regulations to include commercial and industrial fans and blowers.
2. Define the test methods to measure the efficiency of commercial and industrial fans and blowers.
3. Establish a minimum Fan Energy Index (FEI) of 1.0 for commercial and industrial fans and blowers.
4. Establish manufacturer data submittal requirements for the certification of commercial and industrial fans and blowers.
5. Establish marking requirements for commercial and industrial fans and blowers.

The efficiency standards for commercial and industrial fans and blowers would apply to fans manufactured on or after January 1, 2020, or at least one year from the adoption of this regulation.

Section 1601. Scope

…

(d) Spot air conditioners, evaporative coolers, residential furnaces, ceiling fans, ceiling fan light kits, whole house fans, residential exhaust fans, ~~and~~ dehumidifiers, and commercial and industrial fans and blowers.

1) Commercial and industrial fans and blowers do not include:
    a) Radial housed unshrouded fans with diameter less than 30 inches or a blade width of less than 3 inches;
    b) Circulating fans;
    c) Induced flow fans;
    d) Jet fans;
    e) Cross-flow fans;
    f) Fans embedded in central air conditioners and central air-conditioning heat pumps as defined at 10 CFR 430.2;

g) Small commercial packaged air-conditioning and heating equipment as defined at 10 CFR 431.92 with cooling capacity less than 65,000 Btu/h.

h) Furnaces as defined at 10 CFR 430.2;

i) Transport refrigeration and fans exclusively powered by internal combustion engines;

j) Vacuums;

k) Heat rejection equipment;

l) Air curtains;

m) Supply and condenser fans 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;

n) Fans in water-cooled and evaporative-cooled commercial package air conditioning and heating equipment as defined at 10 CFR 431.92 with cooling capacity less than 760,000 Btu/h;

o) Fans in water-source heat pumps as defined at 10 CFR 431.92 with cooling capacity less than 135,000 Btu/h;

p) Fans in 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;

q) Fans in packaged terminal air conditioners and packaged terminal heat pumps as defined at 10 CFR 431.92 with cooling capacity less than 760,000 Btu/h; or

r) Fans in variable refrigerant flow multisplit air conditioners and variable refrigerant flow multisplit heat pumps as defined at 10 CFR 431.92 with cooling capacity less than 760,000 Btu/h.

Section 1602. Definitions

…

(d) Spot Air Conditioners, Evaporative Coolers, Ceiling fans, Ceiling Fan Light Kits, Whole House Fans, Residential Exhaust Fans, ~~and~~ Dehumidifiers, and Commercial and Industrial Fans and Blowers.

…

“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.

“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 power roof ventilator (PRV) means a fan with an axial impeller and a cylindrical housing as well as a housing to prevent precipitation from entering the building with or without turning vanes used to exhaust air from a building. 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 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.

“Centrifugal power roof ventilator (PRV) exhaust” means a PRV with a centrifugal impeller that exhausts air from a building. Inlets are typically ducted, but outlets are not ducted.

“Centrifugal power roof ventilator (PRV) supply” means a PRV with a centrifugal impeller that supplies air to a building. Inlets are not ducted and outlets are typically 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.

“Circulating fan” means a fan used to move 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.

…

“Commercial and industrial fan and blower” means a rotary-bladed machine used to convert power to air power, with a brake horsepower greater than or equal to either 1 kW or 1 horsepower, and an air horsepower less than or equal to 150.

“Cross-flow fan” means a fan with a housing that creates an airflow path through the impeller in a direction at right angles to the axis of rotation and with airflow both entering and exiting the impeller at the 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 Table D-1 of Section 1604(d).

“Fan Energy Index or FEI” means the ratio of a reference fan electrical input power over actual fan electrical input power as calculated under the test method in Section 1604(d).

“Fan Electrical Power or FEP” means fan electrical power associated with a given fan duty point, in terms of airflow and pressure. It is calculated under the test method in Section 1604(d).

…

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

“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.

“Jet fan” means a fan used for producing a high-velocity flow of air in a space. The typical function is to add momentum to the air within a tunnel. Inlets and outlets are not 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.

…

“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.

…

“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 attachments included in the rated fan, excluding the impact of any surrounding equipment whose purpose exceeds or is different than that of the fan. Stand-alone 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.

…

Section 1604. Test Methods

…

(d) Spot Air Conditioners, Evaporative Coolers, Ceiling Fans, Ceiling Fan Light Kits, Whole House Fans, Residential Exhaust Fans, ~~and~~ Dehumidifiers, and Commercial and Industrial Fans and Blowers.

The test methods for spot air conditioners, evaporative coolers, ceiling fans, ceiling fan light kits, whole house fans, residential exhaust fans, ~~and~~ dehumidifiers, and commercial and industrial fans and blowers are shown in Table D-1.

Table D-1

Spot Air Conditioners, Ceiling Fan, Ceiling Fan Light Kit, Evaporative Cooler, Whole House Fan, Residential Exhaust Fan, Commercial and Industrial Fans and Blowers, and Dehumidifier Test Methods

Appliance	Test Method
Spot Air Conditioners	ANSI/ASHRAE 128-2001
Ceiling Fans, Except Low-Profile Ceiling Fans	10 C.F.R. section 430.23(w) (Appendix U to Subpart B of part 430)
Ceiling Fan Light Kits	10 C.F.R section 430.23(x) (Appendix V to Subpart B of part 430)
Evaporative Coolers	ANSI/ASHRAE 133-2008 for packaged direct evaporative coolers and packaged indirect/direct evaporative coolers; ANSI/ASHRAE 143-2007 for packaged indirect evaporative coolers
Whole House Fans	HVI-916, tested with manufacturer-provided louvers in place (2009)
Dehumidifiers	10 C.F.R. section 430.23(z) (Appendix X to Subpart B of part 430, active mode portion only)
Residential Exhaust Fans	HVI-916 (2009)
Residential Furnace Fans	10 C.F.R. section 430.23(cc) (Appendix AA to Subpart B of part 430)
Commercial and Industrial Fans and Blowers	ANSI/AMCA Standard 208-18 Calculation of the Fan Energy Index

Section 1605.1. Federal and State Standards for Federally Regulated Appliances

…

(d) Spot Air Conditioners, Evaporative Coolers, Ceiling Fans, Ceiling Fan Light Kits, Whole House Fans, Residential Exhaust Fans, ~~and~~ Dehumidifiers, and Commercial and Industrial Fans and Blowers.

…

(4) See Section 1605.3(d) for energy efficiency standards for commercial and industrial fans and blowers.

(5) There are no energy efficiency standards or energy design standards for spot air conditioners, evaporative coolers, whole house fans, or residential exhaust fans. There are no efficiency standards for ceiling fans and ceiling fan light kits.

…

Section 1605.2. State Standards for Federally Regulated Appliances.

…

(d) Spot Air Conditioners, Evaporative Coolers, Ceiling Fans, Ceiling Fan Light Kits, Whole House Fans, Residential Exhaust Fans, ~~and~~ Dehumidifiers, and Commercial and Industrial Fans and Blowers.

…

(3) See Section 1605.3(d) for energy efficiency standards for commercial and industrial fans and blowers.

(4) There are no energy efficiency standards or energy design standards for spot air conditioners, evaporative coolers, whole house fans, or residential exhaust fans. There are no efficiency standards for ceiling fans and ceiling fan light kits.

…

Section 1605.3. State Standards for Non-Federally-Regulated Appliances

…

(d) Spot Air Conditioners, Evaporative Coolers, Ceiling Fans, Ceiling Fan Light Kits, Whole House Fans, Residential Exhaust Fans, ~~and~~ Dehumidifiers, and Commercial and Industrial Fans and Blowers.

(1) See Section 1605.1(d) for energy design standards for ceiling fans and ceiling fan light kits.

(2) See Section 1605.1(d) for energy efficiency standards for dehumidifiers.

(3) Commercial and Industrial Fans and Blowers. The FEI of commercial and industrial fans and blowers manufactured on or after January 1, 2020, shall be at least 1.0 or higher.

(4) There are no energy efficiency standards or energy design standards for spot air conditioners, evaporative coolers, whole house fans, or residential exhaust fans. There are no efficiency standards for ceiling fans and ceiling fan light kits.

Section 1606. Filing by Manufacturers; Listing of Appliances in Database.

(a) Filing of Statements

{Skipping (a)(1)-(3) and sections A-C of Table X}

	Appliance	Required Information	Permissible Answers
…	…	…	…
D	Commercial and Industrial Fans and Blowers	Product Line	
		Fan type	Centrifugal Housed, Centrifugal Unhoused, Inline Mixed-Flow, Power Roof/Wall Ventilators, Panel, Embedded Fan
		Impeller type	
		Motor Manufacturer	
		Motor Efficiency	
		Transmission	Belt-Drive or Direct-Drive
		Transmission Efficiency	
		Controller Manufacturer	
		Controller Efficiency	
		Pressure 1 (P1) (in. wg)	
		Min Air flow at P1 (cfm)	
		Max Air flow at P1 (cfm)	
		Air Density at P1 (lbm/cf)	
		Min FEP actual at P1 (kW)	
		Max FEP actual at P1 (kW)	
		Min fan shaft power at P1 (HP)	
		Max fan shaft power atP1 (HP)	
		Min FEP ref at P1 (kW)	
		Max FEP ref at P1 (kW)	
		FEI at min air flow at P1	
		FEI at max air flow at P1	
		Pressure 2 (P2) (in.wg)	
		Min Air flow at P2 (ft^3 per min)	
		Max Air flow at P2 (ft^3 per min)	
		Air Density at P2 (lbm/ft^3)	
		Min FEP actual at P2 (kW)	

	Max FEP actual at P2 (kW)	
	Min fan shaft power at P2 (HP)	
	Max fan shaft power at P2 (HP)	
	Min FEP ref at P2 (kW)	
	Max FEP ref at P2 (kW)	
	FEI at min air flow at P2	
	FEI at max air flow at P2	
	Pressure 3 (P3) (in.wg)	
	Min Air flow at P3 (ft^3 per min)	
	Max Air flow at P3 (ft^3 per min)	
	Air Density at P3 (Lbm/ft^3)	
	Min FEP actual at P3 (kW)	
	Max FEP actual at P3 (kW)	
	Min fan shaft power at P3 (HP)	
	Max fan shaft power at P3 (HP)	
	Min FEP ref at P3 (kW)	
	Max FEP ref at P3 (kW)	
	FEI at min air flow at P3	
	FEI at max air flow at P3	
	Pressure 4 (P4) (in.wg)	
	Min Air flow at P4 (ft^3 per min)	
	Max Air flow at P4 (ft^3 per min)	
	Air Density at P4 (Lbm/ft^3)	
	Min FEP actual at P4 (kW)	
	Max FEP actual at P4 (kW)	
	Min fan shaft power at P4 (HP)	
	Max fan shaft power at P4 (HP)	
	Min FEP ref at P4 (kW)	
	Max FEP ref at P4 (kW)	
	FEI at min air flow at P4	
	FEI at max air flow at P4	
	Pressure 5 (P5) (in.wg)	
	Min Air flow at P5 (ft^3 per min)	

	Max Air flow at P5 (ft^3 per min)	
	Air Density at P5 (Lbm/ft^3)	
	Min FEP actual at P5 (kW)	
	Max FEP actual at P5 (kW)	
	Min fan shaft power at P5 (HP)	
	Max fan shaft power at P5 (HP)	
	Min FEP ref at P5 (kW)	
	Max FEP ref at P5 (kW)	
	FEI at min air flow at P5	
	FEI at max air flow at P5	
	Pressure 6 (P6) (in. wg)	
	Min Air flow at P6 (ft^3 per min)	
	Max Air flow at P6 (ft^3 per min)	
	Air Density at P6 (Lbm/ft^3)	
	Min FEP actual at P6 (kW)	
	Max FEP actual at P6 (kW)	
	Min fan shaft power at P6 (HP)	
	Max fan shaft power at P6 (HP)	
	Min FEP ref at P6 (kW)	
	Max FEP ref at P6 (kW)	
	FEI at min air flow at P6	
	FEI at max air flow at P6	
	Maximum rated speed (RPM)	

…

Section 1607. Marking of Appliances

…

(d) Energy Performance Information.

…

(14) Commercial and Industrial Fans and Blowers. Each commercial and industrial fan and blower shall be marked with a legible and permanently fixed label:

(A) For stand-alone fans designed to a specific operating point the fan shall be marked with the following information:

Manufacturer Name, Brand Name, or Brand Code
Model number
Serial number and date manufactured
Design flow
Design pressure
FEI
Designed RPM
Ducted or unducted

(B) For stand-alone fans designed with design point Unknown the marking shall include:

Manufacturer Name, Brand Name, or Brand Code
Model number
Serial number and date manufactured
List of pressures fan is compliant under (in. wg)
List of volumetric flowrate (ft^3/min)
Static or total pressure
Maximum RPM
Ducted or unducted

(C) For embedded, the marking shall be on the exterior of the unit the fan is embedded into and shall include the following information:

Model Number
Serial number and date manufactured
Design flow (CFM) and Operating speed (RPM)
FEI at design point
Total pressure at design point (in. wg)

APPENDIX A: Staff Assumptions and Calculation Methods

Appendix A discusses the information and calculations used to characterize commercial and industrial fans and blowers in California, the current energy use, and potential savings. Staff considered information from a variety of sources including information contained in the joint AMCA and energy efficiency advocates proposal and the AHRI proposal submitted to the Energy Commission. Staff presents the research and methods to illustrate staff's approach to energy consumption and savings. Staff has rounded the results of the calculations as presented in this appendix.

Assumptions

- National electricity prices for the commercial and industrial sectors of about 10.79 cents per kilowatt-hour ($0.1079/kWh) and $0.071/kWh in 2014, respectively. [47]
- California electricity prices for the commercial and industrial sectors of 16.98 cents per kilowatt-hour ($0.1698/kWh) and 14.61 cents per kilowatt-hour ($0.1461/kWh) for 2017.[48]
- The Energy Commission used data under the Department of Energy's NODA III, National Impact Analysis (NIA), and Life Cycle Cost (LCC) for this analysis, including the assumptions made under those analyses.
- Twelve percent of the total U.S shipments was used to calculate the shipments in California.[49]
- Average lifetimes for stand-alone and embedded fans were calculated under the LCC analysis.[50]
- LCC assumptions for calculating operating hours per fan were used.[51]
- EL 3 energy consumption per fan was calculated from the NIA.[52]

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[47] U.S. Energy Information Administration, *Electric Power Monthly With Data for October 2014* "Table ES1.B Total Electric Power Industry Summary Statistics, Year-to-Date 2014 and 2013 , https://www.eia.gov/electricity/monthly/archive/december2014.pdf.

[48] https://www.eia.gov/electricity/monthly/archive/december2017.pdf , Table 5.6.A

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

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

[51] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0190. "Lifetime" tab.

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

Calculations

Stock and Sales

Table A-1: Per Unit Annual Electricity Savings Stand-Alone Fans

Fan Type	Average National Electricity Rates in 2014 ($/kWh)	First-year U.S. Operating Cost at Baseline Level ($)	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	0.071	4,027	3,945	56,718	55,563	1,155
Panel	0.108	1,325	1,271	12,280	11,779	500
Centrifugal-housed	0.108	6,559	6,515	60,788	60,380	408
Centrifugal-unhoused	0.108	5,133	5,119	47,572	47,442	130
Inline and mixed-flow	0.108	2,209	2,087	20,479	19,342	1,131
Radial	0.071	5,660	5,503	79,718	77,507	2,211
Power roof ventilator	0.108	1,066	966	9,880	8,953	927

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary
Source: DOE third NODA[53]

Table A-2: Per-Unit Annual Electricity Savings Embedded Fans

Fan Type	Average National Electricity Rate in 2014 ($/kWh)	First-Year U.S. Operating Cost at Baseline Level ($)	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	0.108	2,965	2,926	27,479	27,118	361
Panel	0.108	335	324	3,105	3,003	102
Centrifugal housed	0.108	1,048	1,007	9,713	9,333	380
Centrifugal unhoused	0.108	2,618	2,604	24,263	24,133	130

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary
Source: DOE third NODA

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[53] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0194

Equation used for Table A-1 and Table A-2:

$$Per\ Unit\ Annual\ Electricity\ Savings = \left(\frac{Operating\ cost\ Baseline}{National\ average\ Electricity\ rate}\right) - \left(\frac{Operating\ cost\ at\ standard}{National\ average\ Electricity\ rate}\right)$$

Table A-3: Stand-Alone and Embedded Fan Shipments

Fan Type	**2012 U.S. Fan Shipments**			**Stand-Alone Fan Shipments as % of Total Fan Shipments**	**Embedded Fan Shipments as % of Total Fan Shipments**
	Stand-Alone	**Embedded**	**Total**		
Axial cylindrical-housed	33,500	3,717	37,217	90%	10%
Panel	148,000	125,786	273,786	54%	46%
Centrifugal-housed	88,000	266,066	354,067	25%	75%
Centrifugal-unhoused	65,000	319,064	384,064	17%	83%
Inline and mixed-flow	26,500		26,500	100%	
Radial	36,000		36,000	100%	
Power roof ventilator	67,500		67,500	100%	
Total	464,502	714,633	1,179,135	39%	61%

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary

Source: DOE third NODA

Table A-4: Stand-Alone Fan Sales in California

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%	40,383	4,846
Panel	344,006	54%	185,763	22,292
Centrifugal-housed	448,704	25%	112,176	13,461
Centrifugal-unhoused	493,574	17%	83,908	10,069
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				70,411

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary

Source: Energy Commission staff

Table A-5: Embedded Fan Sales in California

Fan Type	2019 Total U.S. Fan Shipments	Embedded Fan Shipments as % of Total Shipments	2019 U.S. Embedded Fan Shipments	2019 California Embedded Fan Sales
Axial cylindrical-housed	44,870	10%	4,487	538
Panel	344,006	46%	158,243	18,989
Centrifugal-housed	448,704	75%	336,528	40,383
Centrifugal-unhoused	493,574	83%	409,666	49,160
Total				109,070

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary

Source: Energy Commission staff

Equations used for Table A-4 and A-5:

$$2019\ California\ standalone\ fan\ sales = \big((2019\ total\ US\ shipments) * (standalone\ \%\ shipments)\big) * (0.12)$$

$$2019\ California\ embedded\ fan\ sales = \big((2019\ total\ US\ shipments) * (embedded\ \%\ shipments)\big) * (0.12)$$

Note: The percentage for stand-alone and embedded fans is from the last two columns of Table A-4.

Table A-6: California Stock for Stand-Alone Fans

Fan Type	2019 California Stand-Alone Fan Shipments	Average Lifetime (Years)	Estimated California Stock
Axial cylindrical-housed	4,846	29	140,533
Panel	22,292	28	624,176
Centrifugal-housed	13,461	27	363,447
Centrifugal-unhoused	10,069	27	271,863
Inline and mixed-flow	3,590	27	96,930
Radial	5,384	30	161,520
Power roof ventilator	10,769	30	323,070
Total	70,411		1,981,540

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary
Source: Energy Commission staff

Table A-7: California Stock for Embedded Fans

Fan Type	2019 California Embedded Fan Shipments	Average Lifetime	Estimated California Stock
Axial cylindrical-housed	538	18	9,684
Panel	18,989	21	398,769
Centrifugal-housed	40,383	18	726,894
Centrifugal-unhoused	49,160	17	835,720
Total	109,071		1,971,067

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary
Source: Energy Commission staff

Equations used for Table A-6 and A-7:

$$\begin{aligned}&Estimated\ California\ Stock\ standalone\ fan\\&\qquad = (2019\ California\ standalone\ fan\ shipment) * (Average\ lifetime)\end{aligned}$$

$$\begin{aligned}&Estimated\ Stock\ Embedded\ fan\\&\qquad = (2019\ California\ embedded\ fanshipment) * (Average\ lifetime)\end{aligned}$$

Table A-8: California Energy Savings for Stand-Alone Fans

Fan Type	Per-Unit Savings (kWh)	2019 Fan Sales	California Stock	First-Year Savings (GWh/yr)	Savings After Stock Turnover (GWh/yr)
Axial cylindrical-housed	1155	4,846	140,533	5.6	162.3
Panel	500	22,292	624,164	11.2	312.4
Centrifugal-housed	408	13,461	363,450	5.5	148.2
Centrifugal-unhoused	130	10,069	271,861	1.3	35.3
Inline and mixed-flow	1131	3,590	96,921	4.1	109.6
Radial	2211	5,384	161,532	11.9	357.2
Power roof ventilator	927	10,769	323,068	10.0	299.4
Total		70,410	1,981,529	49.6	1424.4

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary
Source: Energy Commission staff

Table A-9: California Energy Savings for Embedded Fans

Fan Type	Per-Unit Savings (kWh)	2019 Fan Sales	California Stock	First-Year Savings (GWh/yr)	Savings After Stock Turnover (GWh/yr)
Axial cylindrical housed	361	538	9,692	0.2	3.5
Panel	102	18,989	398,772	1.9	40.7
Centrifugal housed	380	40,383	726,900	15.3	276.2
Centrifugal unhoused	130	49,160	835,719	6.4	108.4
Total		109,071	1,971,084	24	429

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary
Source: Energy Commission staff

Equations used for Table A-8 and A-9:

$$First\ year\ Savings = (per\ unit\ savings) * (2019\ Fan\ Sales) * \left(\frac{1 * 10^3}{1 * 10^9}\right)$$

$$Savings\ after\ stock\ turnover = (per\ unit\ savings) * (California\ Stock) * \left(\frac{1 * 10^3}{1 * 10^9}\right)$$

Table A-10: Peak Demand Reduction Stand-Alone and Embedded Fans

Stand-Alone Fan type	**Peak Demand Reduction After Stock Turnover (MW)**
Axial cylindrical-housed	13.2
Panel	29.7
Centrifugal-housed	14.1
Centrifugal-unhoused	3.2
Inline and mixed-flow	10.4
Radial	28.8
Power roof ventilator	28.4
Total	127.8
Embedded Fan Type	
Axial cylindrical-housed	0.3
Panel	3.7
Centrifugal-housed	26.1
Centrifugal-unhoused	10.8
Total	40.9

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary

Source: Energy Commission staff

Equation used for Table A-10:

$$Peak\ demand\ reduction\ after\ stock\ turnover = \left(\frac{Savings\ after\ stock\ turnover^{*}}{8{,}760\ hours\ per\ year}\right) * \left(\frac{1 * 10^{9}}{1 * 10^{6}}\right)$$

* Savings after stock turnover from table A-9 and A-10 above

Table A-11: Net Benefit for Stand-Alone Fans

Fan Type	Per-unit Electricity Savings (kWh)	Per-unit Incremental Cost [54] ($/unit)	Average Lifetime (years)	Per-Unit Average Annual Savings ($/yr)	Lifecycle Net Benefits ($)	Benefit/cost Ratio
Axial cylindrical housed	1,155	399	29	168.74	2,838.77	7.1
Panel	500	53	28	84.98	1,541.55	29.1
Centrifugal housed	408	33	27	69.24	1,236.00	37.5
Centrifugal unhoused	130	39	27	22.03	364.77	9.4
Inline and mixed flow	1131	689	27	191.99	2,829.59	4.1
Radial	2211	221	30	323.07	6,111.24	27.7
Power roof ventilator	927	595	30	157.37	2,489.48	4.2
Total					17,411.40	

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary

Source: Energy Commission staff

Table A-12: Net Benefit for Embedded Fans

Fan Type	Per-Unit Electricity Savings (kWh)	Per-Unit Incremental Cost ($)	Average Lifetime (years)	Per-Unit Average Annual Savings ($/yr)	Life-Cycle Net Benefits ($)	Benefit/Cost Ratio
Axial cylindrical-housed	361	187	18	61.37	657.10	3.5
Panel	102	56	21	17.31	210.84	3.8
Centrifugal-housed	380	178	18	64.52	709.39	4.0
Centrifugal-unhoused	130	47	17	22.03	243.07	5.2

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary

Source: Energy Commission staff

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[54] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0194.

Table A-13: Net Present Worth Calculation at 3 Percent Discount Rate

Year	1	2	3	4	5	6	7
Stand-Alone Fan Savings							
Axial cylindrical-housed	163.82	159.05	154.42	149.92	145.55	141.31	137.20
Panel	82.50	80.10	77.77	75.50	73.30	71.17	69.10
Centrifugal-housed	67.23	65.27	63.37	61.52	59.73	57.99	56.30
Centrifugal-unhoused	21.39	20.77	20.16	19.57	19.00	18.45	17.91
Inline and mixed-flow	186.40	180.97	175.70	170.58	165.61	160.79	156.10
Radial	313.66	304.52	295.65	287.04	278.68	270.56	262.68
Power roof ventilator	152.78	148.33	144.01	139.82	135.75	131.79	127.95
Embedded Fan Savings							
Axial cylindrical housed	59.59	57.85	56.17	54.53	52.94	51.40	49.90
Panel	16.81	16.32	15.84	15.38	14.93	14.50	14.07
Centrifugal housed	62.64	60.82	59.05	57.33	55.66	54.04	52.46
Centrifugal unhoused	21.39	20.77	20.16	19.57	19.00	18.45	17.91
Year	8	9	10	11	12	13	14
Stand-Alone Fan Savings							
Axial cylindrical-housed	133.20	129.32	125.55	121.90	118.35	114.90	111.55
Panel	67.08	65.13	63.23	61.39	59.60	57.87	56.18
Centrifugal-housed	54.66	53.07	51.52	50.02	48.56	47.15	45.78
Centrifugal-unhoused	17.39	16.89	16.39	15.92	15.45	15.00	14.57
Inline and mixed-flow	151.56	147.14	142.86	138.70	134.66	130.74	126.93
Radial	255.03	247.60	240.39	233.39	226.59	219.99	213.58
Power roof ventilator	124.23	120.61	117.10	113.69	110.37	107.16	104.04
Embedded Fan Savings							
Axial cylindrical-housed	48.45	47.04	45.67	44.34	43.05	41.79	40.58
Panel	13.67	13.27	12.88	12.51	12.14	11.79	11.44
Centrifugal-housed	50.93	49.45	48.01	46.61	45.25	43.94	42.66
Centrifugal-unhoused	17.39	16.89	16.39	15.92	15.45	15.00	14.57

Year	15	16	17	18	19	20	21
Stand-Alone Fan Savings							
Axial cylindrical-housed	108.30	105.15	102.09	99.11	96.23	93.42	90.70
Panel	54.54	52.96	51.41	49.92	48.46	47.05	45.68
Centrifugal-housed	44.44	43.15	41.89	40.67	39.49	38.34	37.22
Centrifugal-unhoused	14.14	13.73	13.33	12.94	12.56	12.20	11.84
Inline and mixed-flow	123.23	119.64	116.16	112.77	109.49	106.30	103.20
Radial	207.36	201.32	195.46	189.77	184.24	178.87	173.66
Power roof ventilator	101.01	98.07	95.21	92.44	89.74	87.13	84.59
Embedded Fan Savings							
Axial cylindrical-housed	39.39	38.25	37.13	36.05	0	0	0
Panel	11.11	10.79	10.47	10.17	9.87	9.58	9.31
Centrifugal-housed	41.41	40.21	39.04	37.90	0	0	0
Centrifugal-unhoused	14.14	13.73	13.33	0	0	0	0

Year	22	23	24	25	26	27	28
Stand-Alone Fan Savings							
Axial cylindrical-housed	88.06	85.50	83.01	80.59	78.24	75.96	73.75
Panel	44.35	43.06	41.80	40.59	39.40	38.26	37.14
Centrifugal-housed	36.14	35.08	34.06	33.07	32.11	31.17	0
Centrifugal-unhoused	11.50	11.16	10.84	10.52	10.22	9.92	0
Inline and mixed-flow	100.20	97.28	94.45	91.69	89.02	86.43	0
Radial	168.61	163.69	158.93	154.30	149.80	145.44	141.20
Power roof ventilator	82.13	79.74	77.41	75.16	72.97	70.85	68.78
Embedded Fan Savings							
Axial cylindrical-housed	0	0	0	0	0	0	0
Panel	0	0	0	0	0	0	0
Centrifugal-housed	0	0	0	0	0	0	0
Centrifugal-unhoused	0	0	0	0	0	0	0

Year	29	30	Total
Stand-Alone Fan Savings			
Axial cylindrical-housed	71.60		3,237.77
Panel			1,594.55
Centrifugal-housed			1,269.00
Centrifugal unhoused			403.77
Inline and mixed-flow			3,518.59
Radial	137.09	133.10	6,332.24
Power roof ventilator	66.78	64.83	3,084.48
Embedded Fan Savings			
Axial cylindrical-housed	0	0	844.10
Panel	0	0	266.84
Centrifugal-housed	0	0	887.39
Centrifugal-unhoused	0	0	290.07

Note: Fan type correlation to defined fan is on page 1 under the Executive Summary
Source: Energy Commission staff

Equation used for Table A-11, Table A-12, and Table 13:

$$Net\ Present\ Worth(NPW) = \sum\left(\frac{Annual\ savnigs}{(1 + discount\ rate)^{year}}\right)$$

$$Lyfecycle\ Net\ benefit = (Net\ present\ worth - Incremental\ Cost)$$

$$Average\ annual\ Savings = \big(Electricity\ Savings(kWh)\big) * \left(\frac{\$0.1698^{*}}{1\ kWh}\right)$$

$$Average\ annual\ Savings = \big(Electricity\ Savings(kWh)\big) * \left(\frac{\$0.1461^{*}}{1\ kWh}\right)$$

$$Benefit\ to\ cost\ ratio = \left(\frac{lifecycle\ savings\ (\$)}{per\ unit\ incremental\ cost\ (\$)}\right)$$

*note: $0.1461 for Industrial rate and $0.1698 for Commercial rate[55]

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[55] https://www.eia.gov/electricity/monthly/archive/december2017.pdf, U.S. Energy Information Administration Electric Power Monthly with DATA for October 2017, Table 5.6.A. Average Price of electricity to Ultimate Customer by End-Use Sector, by State, October 2017 and October 2016.