



SUPPORTING INFORMATION ANNEX

MODEL REGULATION GUIDELINES FOR ENERGY-EFFICIENT CEILING FANS

Model Regulation Guidelines for Energy- Efficient Ceiling Fans

Supporting Information Annex

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For more information, contact:

United Nations Environment Programme –

United for Efficiency initiative

Industry and Economy Division

Energy, Climate, and Technology Branch

1 Rue Miollis, Building VII,

75015, Paris FRANCE

Tel: +33 (0)1 44 37 14 50

Fax: +33 (0)1 44 37 14 74

E-mail: unep-u4e@un.org

<http://united4efficiency.org>

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Pramod Singh	Alliance for an Energy Efficient Economy
Jie Yang	China National Institute for Standardization (CNIS)
Yujuan Xia	CNIS
PK Mukherjee	CLASP
Sneha Sachar	Clean Cooling Collaborative
Mirka della Cava	Clean Cooling Collaborative
Bassam Elassaad	Elassaad & Associates
Wei Han	Energy Foundation China
Philippe Riviere	European Commission - DG Energy
Antoine Durand	Fraunhofer ISI
Clara Camarasa	International Energy Agency
Didier Coulomb	International Institute of Refrigeration (IIR)
Jean-Luc Dupont	IIR
Bruno Lafitte	Independent Expert
Ashish Jindal	Natural Resources Defense Council
Aditya Chunekar	Prayas (Energy Group)
Tarun Garg	Rocky Mountain Institute (RMI)
Akhil Singhal	RMI
Stephen Gill	The Carbon Trust
Prosanto Pal	The Energy Research Institute
Maarten van Werkhoven	TPA Advisors
David Wellington	UNEP U4E
Saikiran Kasamsetty	UNEP U4E
Patrick Blake	UNEP U4E
Bettina Schreck	UNIDO
Qicai Chen	Weikai Testing Technology Co., Ltd.

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Editing: Lisa Mastny and Moira Mathers (U4E)

Cover design: Fabrice Belaire



ACRONYMS AND ABBREVIATIONS

AC	Alternating Current
BEE	Bureau of Energy Efficiency (India)
BLDC	Brushless Direct Current Motor
cm	Centimetre
DC	Direct Current
EL	Efficiency Level
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
kPa	Kilopascal
m ²	Square Metre
m ³ /(min-W)	Cubic Metres of Air per Minute per Watt
mm	Millimetre
MEPS	Minimum Energy Performance Standard
MW	Megawatt
TWh	Terawatt-hour

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ABOUT UNITED FOR EFFICIENCY

U4E (united4efficiency.org) is a global initiative led by UNEP, supported by leading companies and organizations with a shared interest in transforming markets for lighting, appliances and equipment, by encouraging countries to implement an integrated policy approach to energy-efficient products so as to bring about a lasting, sustainable and cost-effective market transformation.

The approach focuses on the end-user market and targets the five main components of the value chain for an energy-efficient market:

- Standards and regulations.
- Supporting policies, including education, information and training.
- Market monitoring, verification and enforcement.
- Finance and financial delivery mechanisms, including incentives and public procurement.
- Environmentally sound management and health.

U4E provides countries with tailored technical support through its in-house international experts and specialized partners, to get the most out of countries' electricity by accelerating the widespread adoption of energy-efficient products, allowing monetary savings on consumer electricity bills, helping businesses thrive through greater productivity, enabling power utilities to meet growing demands for electricity and assisting governments in reaching their economic and environmental ambitions. The initiative is present in more than 30 countries worldwide.

Based on each country's circumstances, U4E works with any of the following products: Lighting, Refrigerators, Room Air Conditioners, Electric Motors and Distribution Power Transformers – the five products that together consume more than half of the world's electricity. Such support is available at three levels: global, regional and national; providing tools and resources and supporting multiple stakeholders on international best practices, regional policy roadmaps and harmonization process recommendations through guidelines and publications, such as energy efficiency Policy Guides, Global Model Regulations Guidelines, Model Public Procurement Specifications and Financing Guidelines.

In addition, the initiative provides capacity-building and education, policy tools and technical resources which include Country Savings Assessments completed for more than 155 countries showing the significant available financial, environmental, energy, and societal benefits that are possible with a full transition to more energy-efficient electrical products. This growing suite of tools and resources equips policymakers to understand the significant opportunities and the steps needed to start transforming their markets to eco-efficient appliances and equipment.

1 INTRODUCTION

This Annex provides context on the rationale underpinning the [Model Regulation Guidelines for Energy-Efficient Ceiling Fans](#)¹. It includes a brief explanation of sample markets, product scope, energy efficiency considerations and testing protocols. The Guidelines refer to International Electrotechnical Commission (IEC) 60879: 2019 for testing and measuring energy efficiency.

In many warm and hot climates, ceiling fans are common and they consume a considerable amount of electricity. There is a significant opportunity to cost-effectively improve energy efficiency with existing technologies. For example, ceiling fans with brushless direct current (DC) motors use around 50 per cent less electricity, with a longer lifetime, than conventional alternating current (AC) induction motors.

The United Nations Environment Programme's (UNEP) United for Efficiency initiative (U4E) has produced Country Savings Assessments for 156 developing and emerging economies, which project annual electricity savings, utility bill savings and other benefits if countries adopt the Model Regulation Guidelines². These are currently being updated to include information on the savings potential of ceiling fans.

¹ Available at: <https://united4efficiency.org/resources/model-regulation-guidelines-for-energy-efficient-ceiling-fans/>

² Country Savings Assessments are available at <https://united4efficiency.org/countries/country-assessments>.

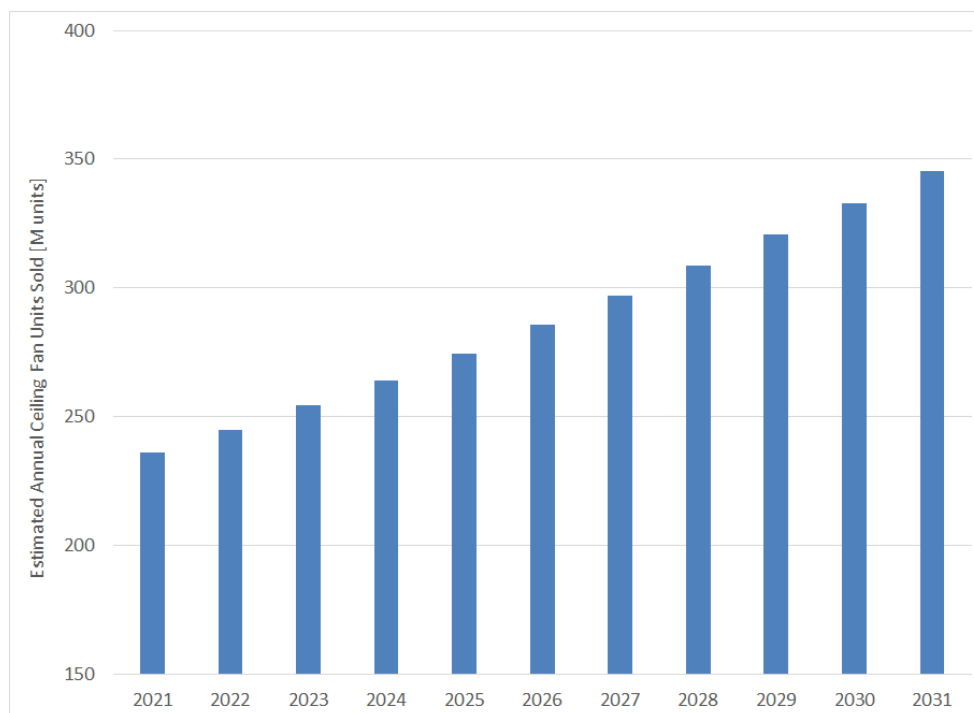
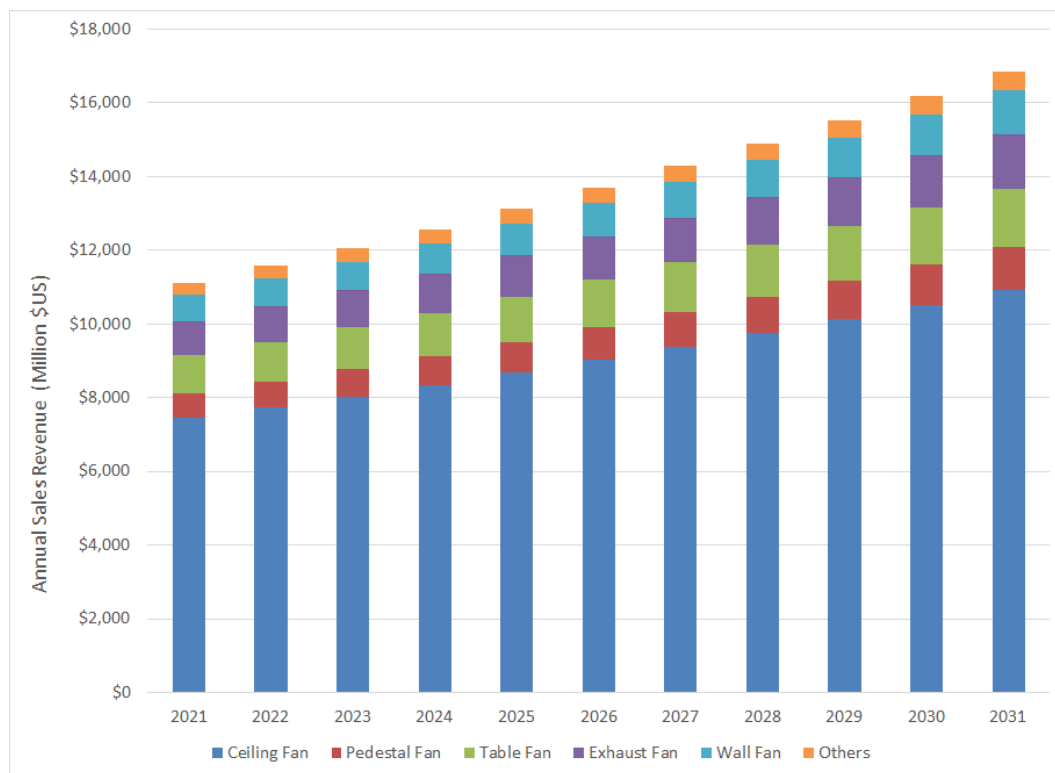
2 MARKET DATA SUMMARY

Fans come in a variety of types including ceiling fans, portable table fans and pedestal fans that are typically mounted on pole that is secured to a base on the floor.

Ceiling fan global revenues make up an estimated 45 per cent of the electric fan market (Allied Market Research 2023; Bonafide Research 2022; 360researchreports 2022). The overall electric fan market was valued at around US\$8 billion in 2023 and is projected to grow 3.9 per cent annually to reach \$10.9 billion in 2031 (Allied Market Research 2023). This corresponds to sales of around 250 million units in 2023, increasing to around 350 million units in 2031 (at an average selling price of \$32). Annual sales revenue by fan type is shown in Figure 1.

The growth in ceiling fans is driven by several factors including overall population growth, increased affordability from rising living standards and technological advancements, increased urbanization, as well as a warming climate. Ceiling fan adoption rates can also be dependent on consumer preferences and on the availability of other fan product offerings in the local market.

Figure 1: (a) Electric fan market global revenue by fan market segment and (b) estimated annual ceiling fan units sold from 2021 to 2031



Source: Allied Market Research (2023).

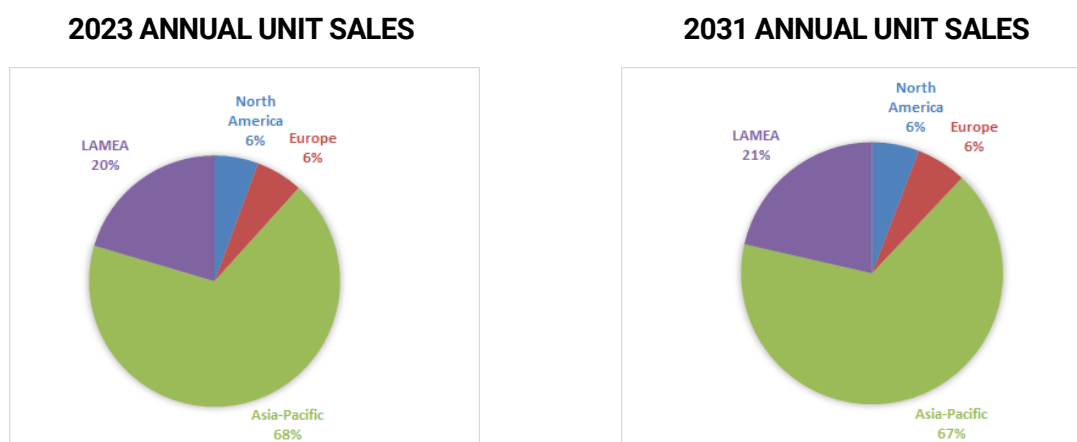
Table 1 shows the global ceiling fan market in number of units sold by region from 2021 to 2031. Figure 2 shows the regional shares in 2023 and 2031, with Asia-Pacific holding a 67 per cent market share in the number of total units sold annually during the next decade.

Table 1: Number of ceiling fans sold annually by region, 2021-2031 (million units)

Region	2021	2023	2025	2027	2029	2031	Compound Annual Growth Rate (2022-2031)
Asia-Pacific	161.0	172.0	184.4	197.9	212.0	226.5	3.5%
Europe	14.2	15.4	16.7	18.1	19.6	21.2	4.1%
Latin America, the Middle East and Africa	47.7	51.8	56.4	61.6	67.1	73.0	4.4%
North America	13.2	14.3	15.5	16.8	18.3	19.8	4.1%
Total	236.0	253.4	273.0	294.5	317.0	340.5	3.9%

Source: Allied Market Research (2023).

Figure 2: Share of ceiling fan units sold annually by region, 2023 and projections for 2031



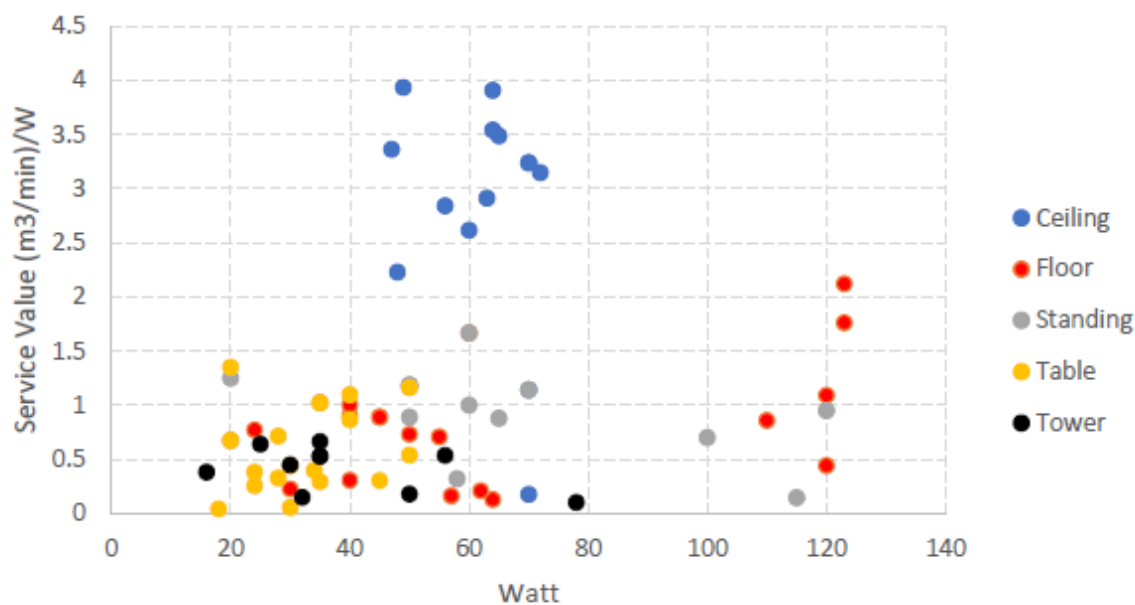
Source: Allied Market Research (2023).

3 PRODUCT SCOPE

Figures 3 and 4 show that ceiling fans have three to six times higher service value (or energy efficiency) for the same power level compared to other fan types. Separate standards are thus recommended for ceiling fans and non-ceiling fans, since ceiling fans are a large, distinct electric fan market segment with different energy efficiency, usage and technology capability considerations.

Ceiling fans include the standard “small-diameter” fan sizes of less than 2,000 millimetres most commonly found in residential and small commercial buildings, and the “large-diameter” fans more commonly found in commercial buildings. The focus of these Guidelines is on the residential and small commercial market segments, since these are the bulk of unit sales, and larger diameter fans may have different safety, testing and durability requirements. For this market segment of fans, sizes are less than or equal to 1,800 millimetres, with around 95 per cent or more of fan sizes being less than 1,500 millimetres. Higher sizes of fans fall under the category of industrial cooling fans, which are dealt with in ISO TC 117.

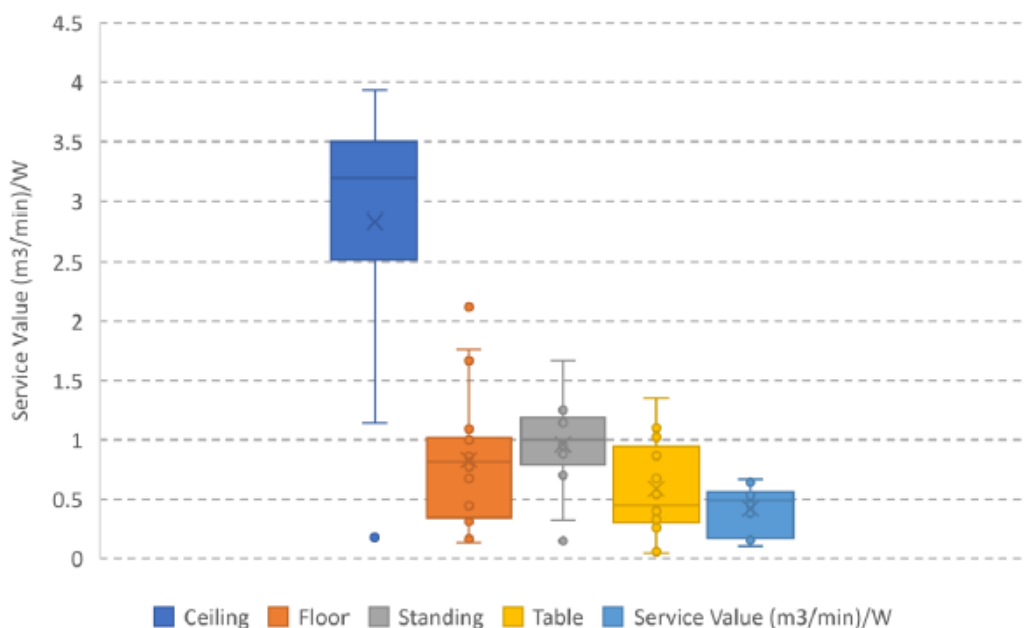
Figure 3: Spread in wattage and service value of the different type of comfort fans for a representative sample of 75 comfort fans in the European market



Note: The product types listed here are not identical to Figure 1, and in some cases, there is a lack of definitive nomenclature – for example, standing fans and pedestal fans may refer to the same product.

Source: European Commission (2018).

Figure 4: Spread in service value of the different types of comfort fans

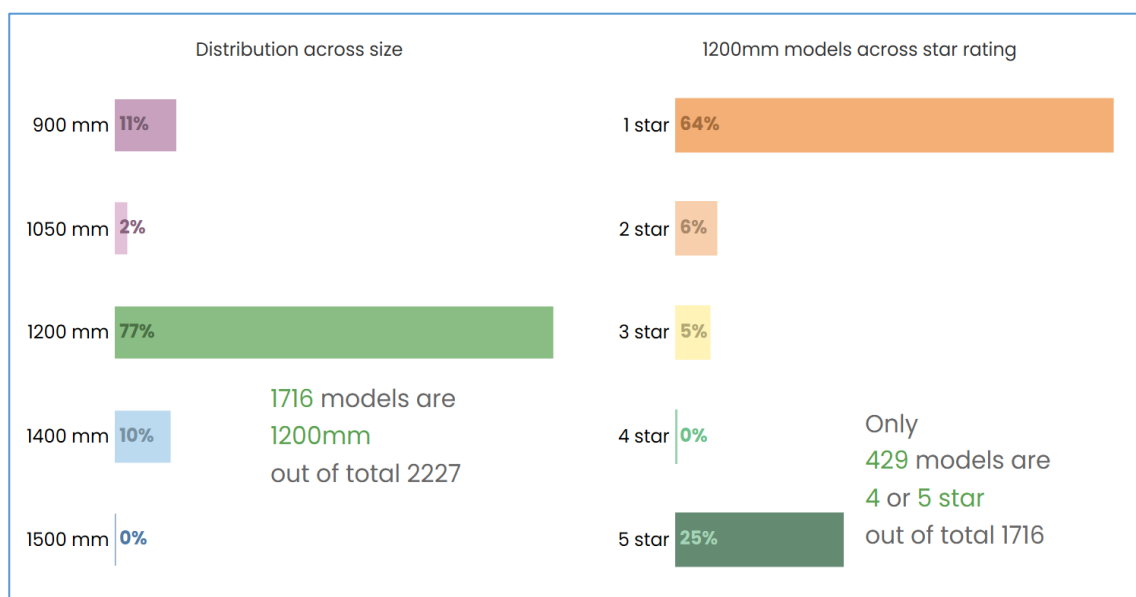


Source: European Commission (2018).

Some of the available market data for India are illustrated in Figure 5. Figure 5a shows that the majority of ceiling fans in India are 1,200 millimetres in diameter and have a one-star energy efficiency level. Figure 5b shows that the power reduction from one-star fans can be greater than 50 per cent for fans of 1,200 millimetres or larger.

Figure 5: (a) Distribution across ceiling fan size and star rating in India and (b) average power for five-star ceiling fans and improvement from minimum efficiency (one-star energy efficiency level)

(a)



Source: Chunekar and Sahasrabudhe (2023).

(b)

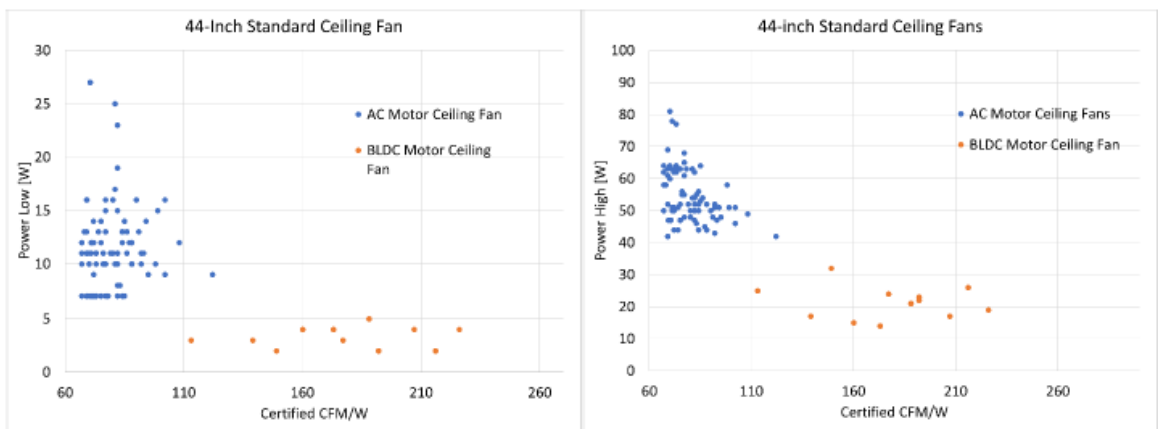
Diameter (millimetres)	Power at India One-star Energy Efficiency Level (minimum efficiency)	Average Power, Five-star Ceiling Fan Power [BEE]	Per cent reduction
900	42	29	31%
1 200	68	32	53%
1 400	79	35	56%
1 500	87	40	54%

Source: BEE database (n.d.).

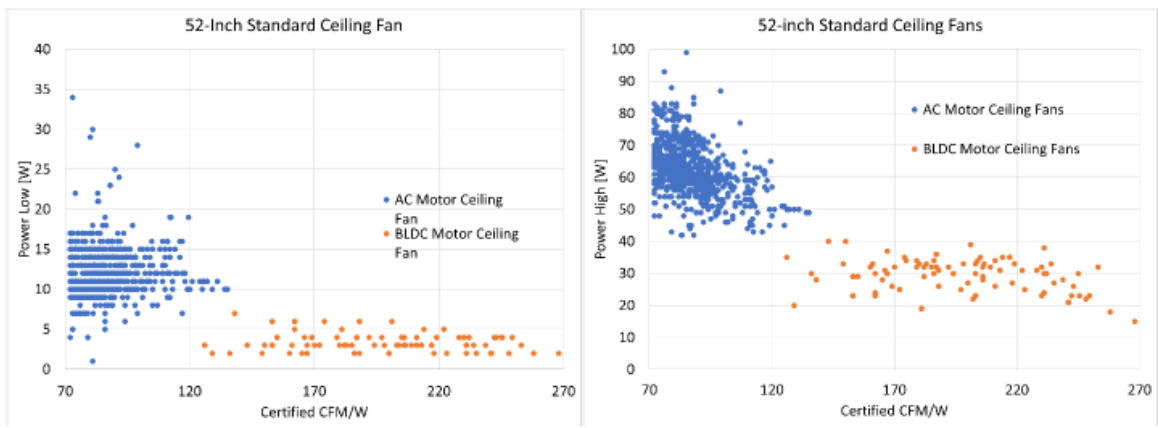
Figure 6 shows the power and air flow in cubic feet per minute per watt (multiply by 0.0283 for cubic metres/min/watt) for typical ceiling fans of 44 inches (1,118 millimetres) and 52 inches (1,321 millimetres) in the United States. It can be seen from these plots that brushless DC motor ceiling fans can be more than 50 percent lower in power than alternating current (AC) motor ceiling fans, and that typical high-speed powers for 44-inch ceiling fans are 45-70 watts and for 52-inch ceiling fans are around 50-80 watts.

Figure 6: High- and low-speed power versus cubic feet per minute per watt for (a) 44-inch standard fans and (b) 52-inch standard fans

(a)



(b)



Source: U.S. Department of Energy (2022).

4 INTERNATIONAL MINIMUM ENERGY PERFORMANCE STANDARDS AND TEST STANDARDS FOR CEILING FANS

Table 2 shows examples of international minimum energy performance standards (MEPS) and test standards (or test protocols) for ceiling fans. A limited number of countries have MEPS, and thus there is an opportunity for wider MEPS first-time adoption and/or MEPS tightening. For example, there is a huge opportunity for “super-efficient” ceiling fans in India, with 50-60 per cent electricity savings from brushless direct current motors and improved fan blade design, with an estimated 90 per cent adoption rate at the household level, but with only 3 per cent of ceiling fans achieving high efficiency (Aggarwal & Agrawal 2022).

In terms of the test standard for ceiling fan energy efficiency ratings, most countries outside of the United States use the IEC 60879-based test protocol, whereas the United States of America (USA) has its own test protocol, as summarized in Table 3.

Table 2: Examples of international minimum energy performance standards (MEPS) and test standards for ceiling fans

Country	Minimum Energy Performance Standards (MEPS)	Test Standards	Reference Test Standards
Bangladesh	BDS 1860:2012	BDS 818:1998 Amend 1: 2006	IEC 60879
Brazil	PI n° 02/2017		
Canada	Energy Efficiency Regulations, 2016 PART 2 DIVISION 1 SUBDIVISION L Ceiling Fans	Same as USA	Same as USA
China	GB 12021.9-2021	GB 13380-2018, QB/T 5262-2018, GB/T 35758-2017	IEC 60879, IEC 62301 (Standby power)
European Union	Commission Regulation (EU) No 206/2012	IEC 60879	
India	IS 374-2019_Notification number S.O. 2210(E) dated May 12, 2022	IS 374:2019	IEC 60879
Malaysia	MS 2574:2014	MS 1220:2010	IEC 60879
Mexico	PROY-NOM-034-ENER / SE-2020	PROY-NOM-034-ENER / SE-2020	IEC 60879
Pakistan	PS:1/2010	PS:1/2010	IEC 60879
Sri Lanka	SLS 1600:2011	SLS 1600:2011, SLS 814:1988	
United States of America	10 CFR 430–Energy Conservation Program: Test Procedure for Ceiling Fans	Appendix U to Subpart B of Part 430 – Uniform Test Method for Measuring the Energy Consumption of Ceiling Fans	AMCA 208-18, AMCA 230-15, AMCA 230-15 TE, IEC 62301
Viet Nam	TCVN 7826:2015	TCVN 7827:2015	IEC 60879

Note: For India, fan testing air velocity measurements below 0.25 metres per second (15 metres/minute) are discarded, while for IEC 60879, air velocity measurements below 0.15 metres per second (9 metres/minute) are discarded. For the United States of America, the test protocol is from U.S. Department of Energy (2022a).

4.1 Testing protocol differences

The unit for ceiling fan service value (or energy efficiency rating) is given in air flow per watt, or cubic metres of air per minute per watt: m³/(min-W). The resultant service value is thus dependent on how exactly the test protocol specifies how air flow is measured.

Table 3 provides some test specifications for IEC 60879 and the USA test standard. In particular, the airflow measurement specification in IEC 60879 picks up air flows from larger radii than the IEC tests, and thus the numerator in the service value metric and the overall service value metric is higher for the IEC than for the United States for the same fan.

Table 3: Some test protocol differences between IEC 60879 and the U.S. test protocol

Test Standard	Room Temperature, Humidity	Pressure	Fan Speed	Distance from Fan Blades to Sensors	Air Velocity Sensor Locations
IEC 60879	20 C ± 5°C; 50% ± 30% relative humidity	86 kPa to 106 kPa (1 atm = 101.325 kPa)	Highest fan speed	150 cm	Radially placed sensors with air velocity measurements below 0.15 metres per second discarded.
United States of America test protocol	21°C; 50% ± 5% relative humidity	Turn off all forced-air environmental conditioning equipment entering the chamber (e.g., air-conditioning), close all doors and vents	Weighted average of lowest and highest speed	109 cm	Radially placed sensors extending 20.32 cm beyond the outermost edge of the fan blade. (This radius is typically smaller than the outermost sensor radius captured in IEC 60879.)

Sources: IEC (2019); U.S. Department of Energy (2022a).

4.2 Testing protocol details for IEC 60879

Ceiling fan service value (or energy efficiency rating) is defined as the total air flow at a specified horizontal plane below the ceiling fan divided by the fan power at full speed (highest speed setting at the rated voltage and frequency).

$$Ceiling\ Fan\ Service\ Value\ \left(\frac{m^3}{min-watt}\right) = \frac{Air\ flow_T}{P_{full\ speed}} \tag{1}$$

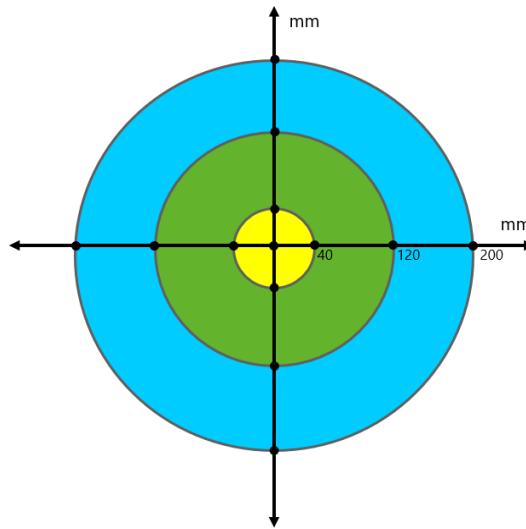
where

Air flow_T is the total air flow below the ceiling fan in m³/min and

P_{full speed} is the fan power at full speed (or the highest setting) in watts.

The total air flow is calculated by adding the airflows in annular areas below the ceiling fan. Per the IEC 60879 test standard, the first three annular regions are shown in Figure 7, with sensor locations corresponding to the black dots (40 millimetre radius for first region and 80 millimetre increments in radius for each successive annular region). The horizontal plane of air flow measurements is set at 150 centimetres below the plane of the ceiling fan blades.

Figure 7: Configuration to measure airflow for ceiling fan



The airflow in annulus i (m^3/min) is given by the product of the average airflow, $V_{avg,i}$ (m/min) and the annular area, $Area_i$ (m^2) where

$$V_{avg,i} = \frac{\sum_{j=1}^8 V_j}{8} \quad [2]$$

and

$$Area_i = \pi (r_{outer,i}^2 - r_{inner,i}^2) \quad [3]$$

where

V_j is the air velocity at each sensor location

$V_{avg,i}$ is the average air velocity in annulus i , taken by eight sensor locations in each annulus

$r_{outer,i}$ is the outer radius of annulus i , and

$r_{inner,i}$ is the inner radius of annulus i , and

The total air flow as defined by test standard IEC 60879 is computed as follows:

$$Air\ flow_T = \sum_{i=1}^n Area_i * V_{avg,i} \text{ for } V_{avg,i} \geq 9 \frac{m}{min} \quad [4]$$

Note that only the first n annular areas for which $V_{avg,i}$ is equal or above the threshold value of 9 metres/minute are included.

5 CURRENT ENERGY EFFICIENCY STANDARDS AND BEST AVAILABLE ENERGY EFFICIENCY CEILING FANS

Current ceiling fan service value standards are shown for China (Figure 8) and India (Figure 9). China has three service value levels, while India has five. The service value levels are plotted on different charts since the service value level is dependent on the test protocol, and India has a slightly different test protocol than IEC 60879, as noted in Table 3 above. Larger fan blades move more air and have higher energy efficiency. Note also that India has minimum air delivery or air flow requirements (e.g., 210 m³/min for fan sizes from 1,200 to 1,400 millimetres), since higher service value is biased to lower fan speed and lower airflow.

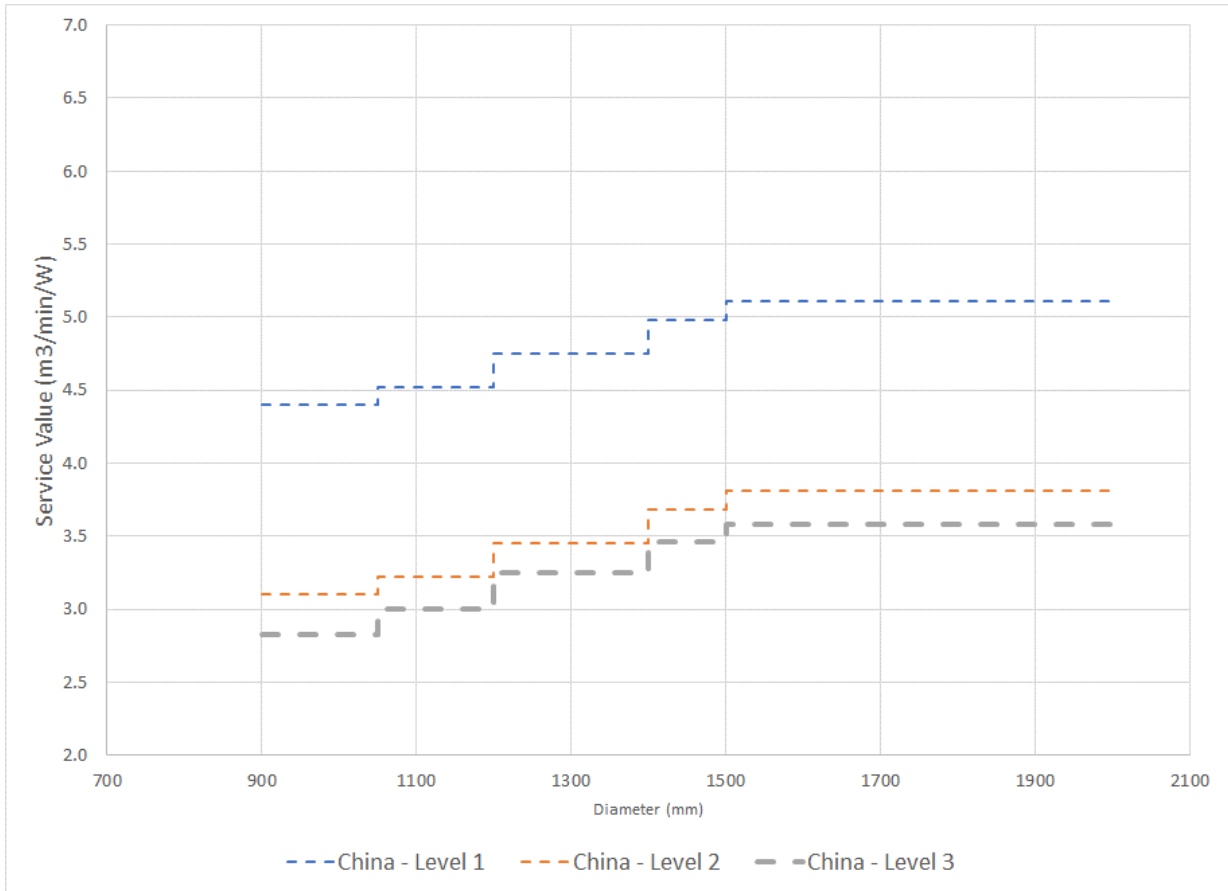
A representative sample of other countries' service value standards are shown in Figure 10. India has the highest or near-highest service values for 1,500 millimetre diameter ceiling fans. As noted above, most fans are at or below this size. Strictly speaking, service value standards from different countries cannot be compared on equal footing unless they have the same testing standards. In this case, assuming that the only testing difference between India and the other countries is as shown in Table 3 (higher threshold for air velocity sensor measurements in India), then the service value levels for other countries would be lower than that shown in Figure 7, since less air flow would be captured in the service value metric's numerator.

Figure 11 shows the U.S. 2022 proposed service value standards compared to IEC-based service value levels. This baseline level is lower than the minimum standard in India due to the testing differences described in Table 3 above. Accounting for this, a U.S.-baseline fan with a service value of 2 for U.S. testing would be rated as having a service value of around 4 with IEC testing³. Thus, a fan with a given service value with U.S. standard rating should be corrected to a higher service value for the IEC standard to account for this test difference.

Residential and small commercial ceiling fan types here do not include fans with light kits since these are less common outside of the United States of America and since test protocols and rated service value levels do not include energy consumption for any lighting integrated into the product. (IEC 60879 test procedure specifies that for air flow and power consumption, luminaires and any other additional features are disconnected or turned off.)

³ The correction factor of 2 units was derived by comparing baseline U.S. and India power levels and energy efficiencies for 1,200 millimetre and 1,400 millimetre and similar comparisons for brushless DC ceiling fan introduction at 1,200 millimetre and 1,400 millimetre, assuming that brushless DC ceiling fan introduction in the United States is at efficiency level EL3 and in India is at an efficiency level halfway between four- and five-star levels. For example, the baseline U.S. power value at 1,200 millimetres is around 64 watts with a service value of 1.9, and India's one-star power is 68 watts at a service value of 4.0, or quite comparable in power levels. We do not have airflow patterns from fan testing, but we assume that virtually all of the difference in energy efficiency rating is due to testing differences. With these assumptions, the increase in energy efficiency is at least 2 in numerical units from the U.S. to the IEC (India) test protocol.

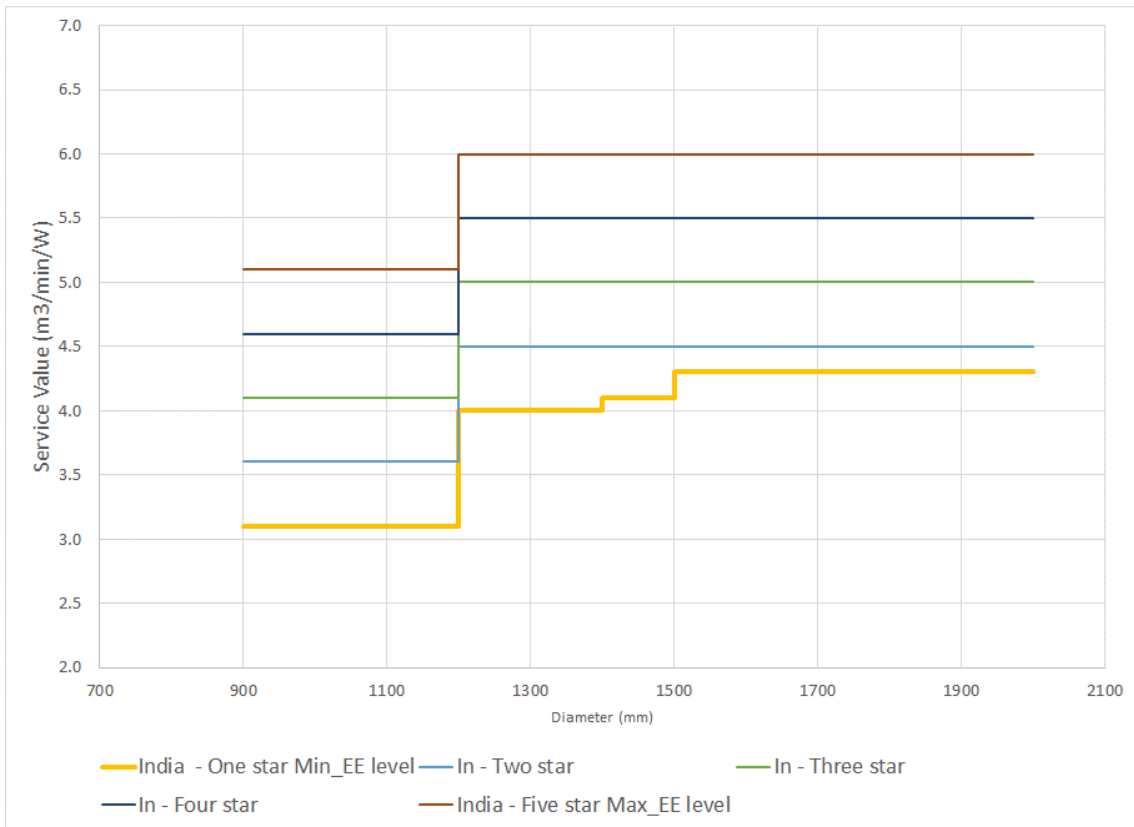
Figure 8: China service value standards for ceiling fans, 2021



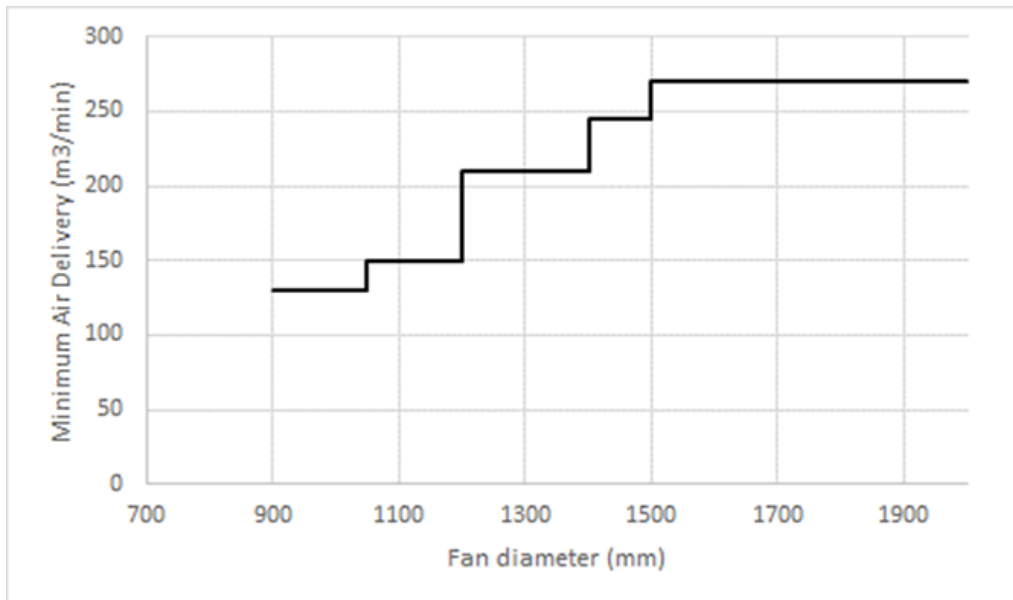
Source: China National Institute of Standardization (2021).

Figure 9: (a) India service value standards for ceiling fans, 2022, and (b) minimum air delivery or air flow in cubic metres per minute

(a)

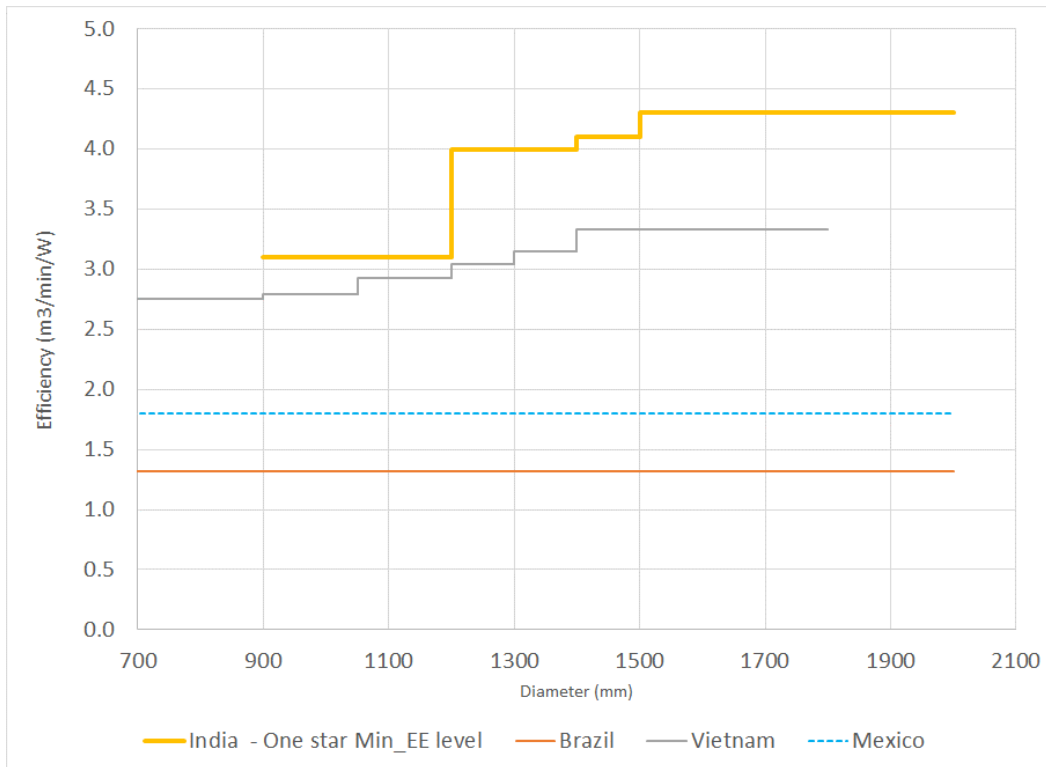


(b)



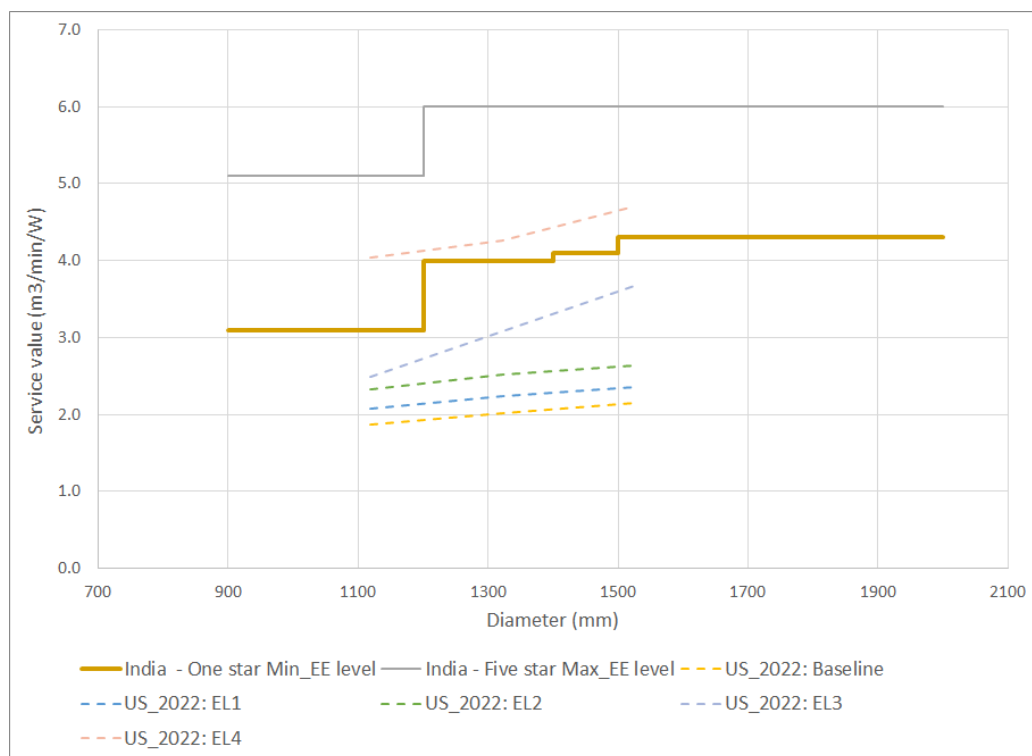
Source: BEE (2022).

Figure 10: Minimum service value standards for ceiling fans in Brazil, India, Mexico, the Republic of Korea and Viet Nam



Sources: Brazil: INMETRO (2023); India: BEE (2022); Mexico: SEGOB Mexico (2021); Viet Nam: Lane and Ellis (2014).

Figure 11: United States of America service value standards are lower compared to standards in India due to testing differences between the U.S. test protocol and the IEC-based testing protocol



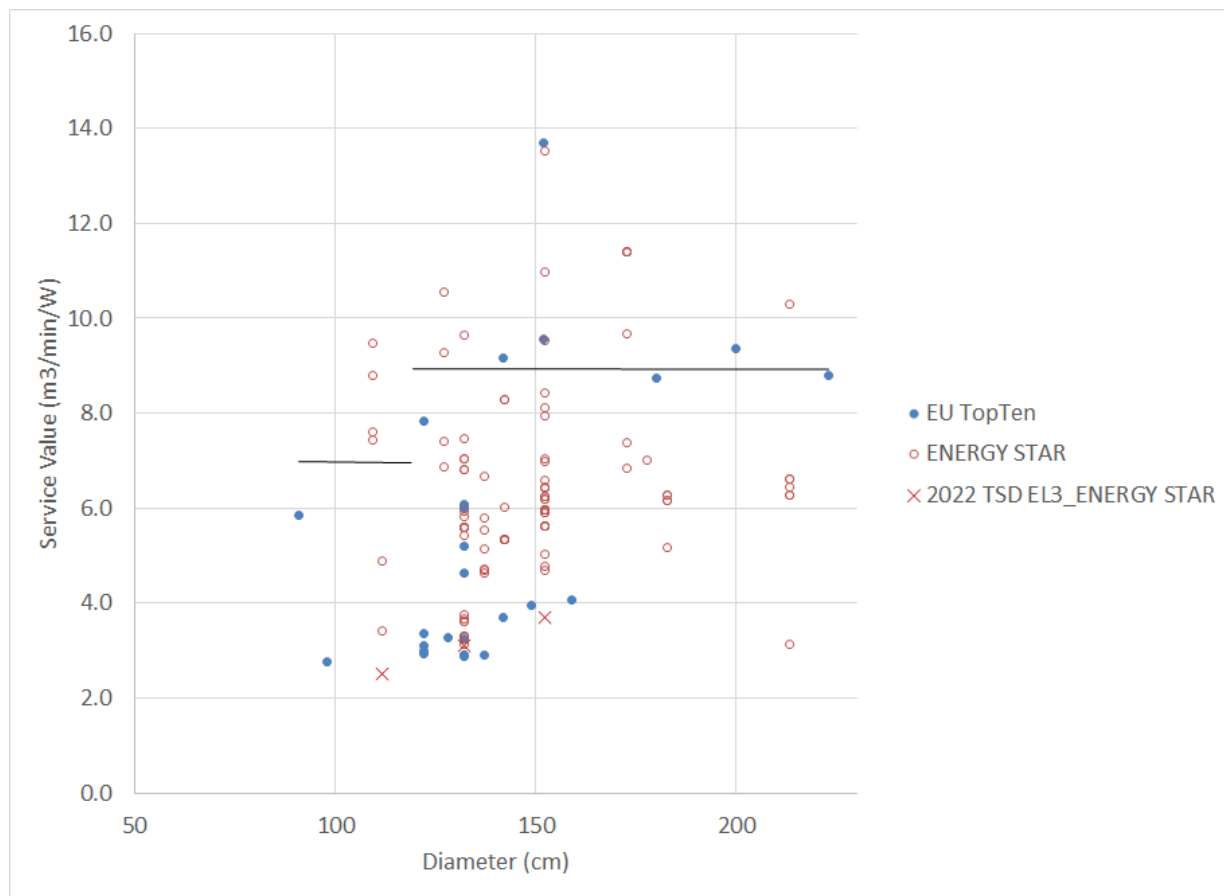
Sources: BEE (2022); U.S. Department of Energy (2023).

5.1 High service value or “best available” technology ceiling fans

Best available service value ceiling fan units from the European Union TopTen and United States of America Energy Star databases (standard fan only) are shown in Figure 12. The two horizontal lines show the approximate 75th percentile of the high and low service value envelopes for fan sizes below 1,200 millimetre size (service value of 7 in units of m³/min-watt) and above 1,200 millimetres (service value of 9), and more than one manufacturer’s models are available above these levels. The fans in the European Union are rated at 220 volts and those in the United States at 120 volts, and the European Union uses IEC 60879 testing.

As noted earlier, the service value rating for the United States of America test standard needs to be adjusted for the IEC 60879 testing. This is estimated to add a nominal correction of 2 units (m³/min-watt) due to IEC (India) testing differences. The resultant 75th percentile service value levels for fan sizes below 1,200 millimetre size and above 1,200 millimetre size would be at 9 and 11, respectively (see Figure 13).

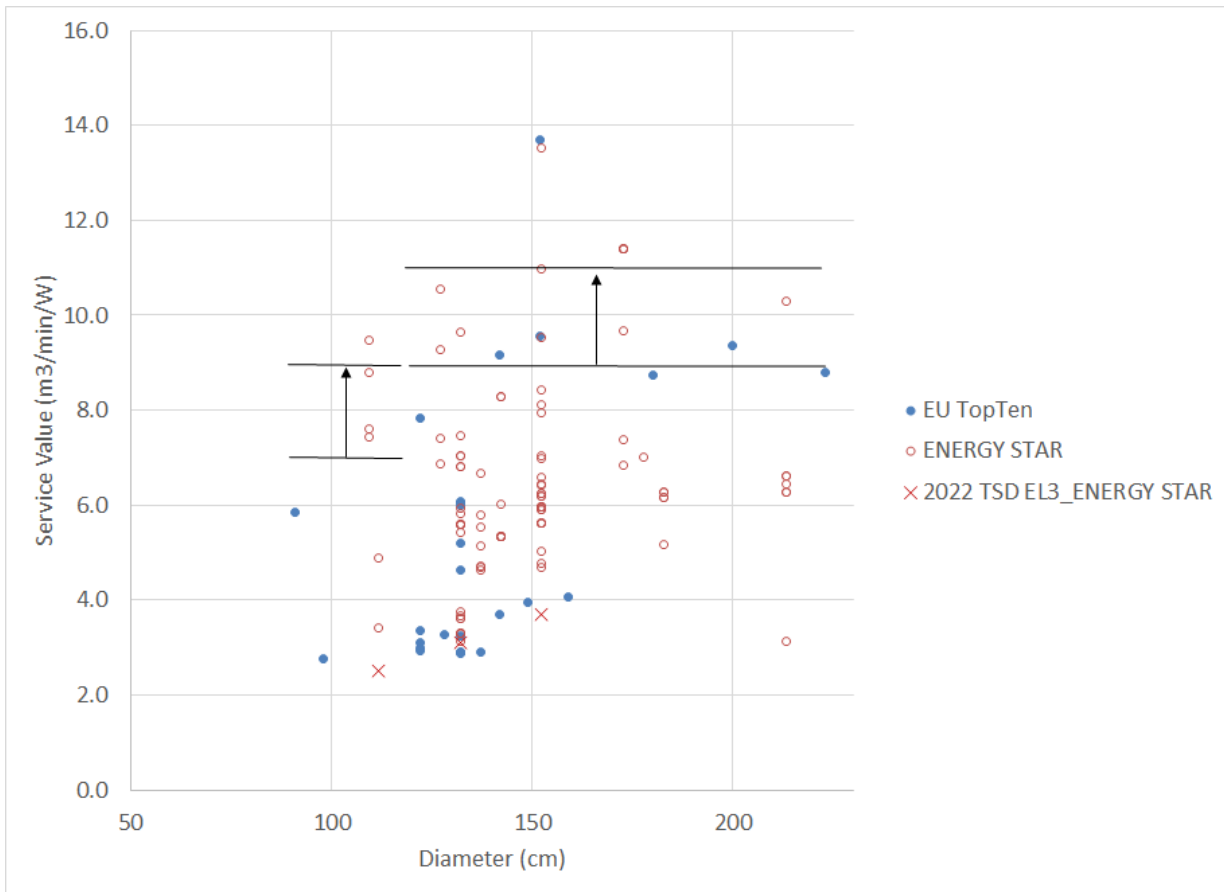
Figure 12: High-efficiency ceiling fan service values versus fan diameter



Note: The two horizontal lines show the approximate 75th percentile of the high and low service value envelopes for fan sizes below 1,200-millimetre size and above 1,200-millimetre size.

Sources: European Union (2023); Energy Star (2022).

Figure 13: Approximate 75th percentile levels of Energy Star ceiling fans service value with correction for IEC (India) testing for fan sizes above and below 1,200 millimetres



Sources: European Union (2023); Energy Star (2022); author calculations.

6 PROPOSED MINIMUM, MEDIUM AND MAXIMUM SERVICE VALUE STANDARDS FOR CEILING FANS

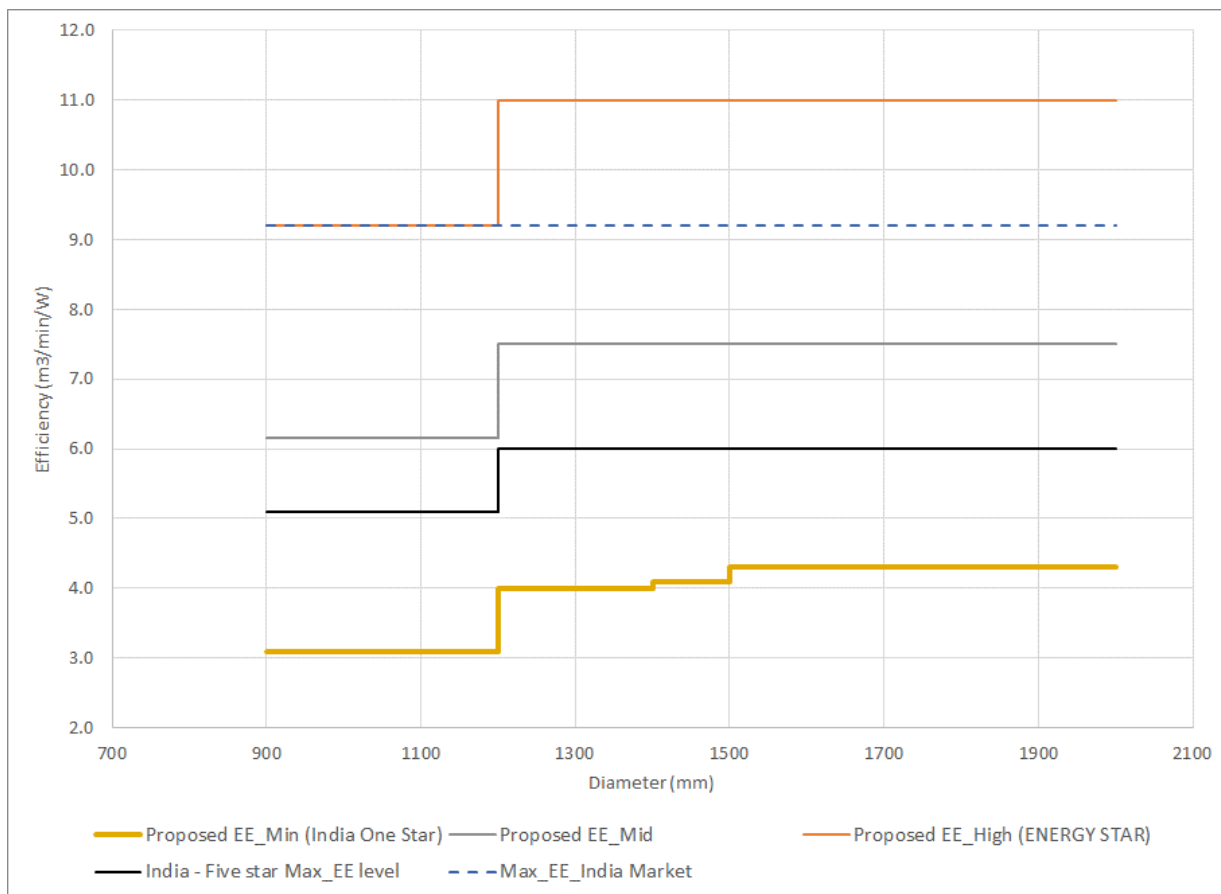
The minimum service value standard adopts the minimum (or one-star) service value standard in India, since this would raise the level of efficiency for most countries and since countries near India such as Pakistan and Bangladesh and other countries in southeast Asia are probably similar to India in usage patterns. India's standards were enacted in 2022 and are not likely to be revised in the next few years.

The Guidelines also propose that the IEC 60879 test standard be adopted, since many countries' standards are based on that protocol. This implies some adjustment to the proposed minimum standards based on India's minimum standard, since, as noted above in Table 3, India's fan testing air velocity measurements below 15 m/min (0.25 m/s) are not included, while for IEC 60879, air velocity measurements below 9 m/min (0.15 m/s) are not included, as in Equation 4 above. This would imply an upward correction to the minimum service value levels to account for more air flow capture under the IEC protocol.

However, the team did not have sufficient data to make a high-confidence correction to the India service value levels adjusting for the different air velocity test threshold. Gao *et al.* (2017) and Raftery *et al.* (2019) have test data with air flow patterns for a range of ceiling fan sizes, but both references used larger rooms than the IEC test standard, had lower mount distances (the distance between ceiling height and fan blades), and did not use the two-chamber configuration as specified in the IEC. For example, using the data from Raftery's supporting data for fans between 1.3 and 1.5 metre diameter sizes, there does not appear to be a difference in estimated efficiency between the India and IEC testing (i.e., the air velocities at the sensor plane to a radius of 3 metres from the fan's central axis – corresponding to the IEC test chamber size – are above the threshold velocity for both India and the IEC).

The maximum service value standard is set at the approximate 75th percentile Energy Star level as described in the preceding section (service value of 9 for less than 1,200 millimetre fan sizes and service value of 11 for fan sizes greater than or equal to 1,200 millimetres, adjusted for the IEC 60879 test standard). The medium level is set between the minimum and maximum levels (see Figure 14 and Table 4).

Figure 14: Proposed minimum, medium and maximum service value standards for ceiling fans



Sources: BEE (2022); Author calculations

Table 4: Medium service value and maximum service value standards for procurement programmes

Blade Dimension (millimetres)	Medium Service Value Level (m³/(min-W))	Maximum Service Value Level (m³/(min-W))
Less than 900	6.2	9
900 – 1 050	6.2	9
1 050 – 1 200	6.2	9
1 200 – 1 400	7.5	11
1 400 – 1 500	7.5	11
Greater than 1 500	7.5	11

Sources: European Union (2023); Energy Star (2022).

7 IMPROVING CEILING FAN SERVICE VALUES

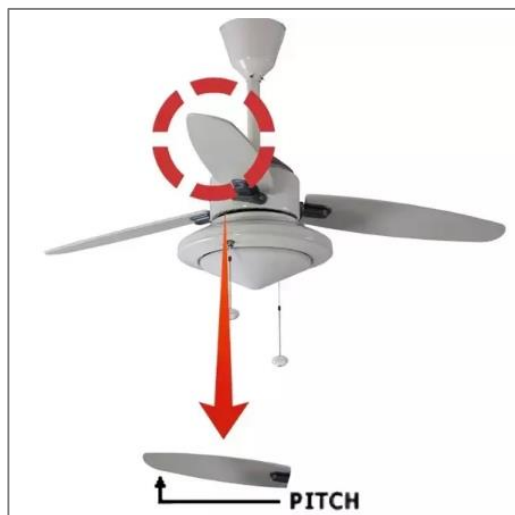
There are two key approaches to improve the service value or energy efficiency rating (in $\text{m}^3/\text{min-watt}$) for a ceiling fan: 1) increasing the airflow; and 2) increasing the fan motor efficiency.

7.1 Increase the airflow by improving the blade design

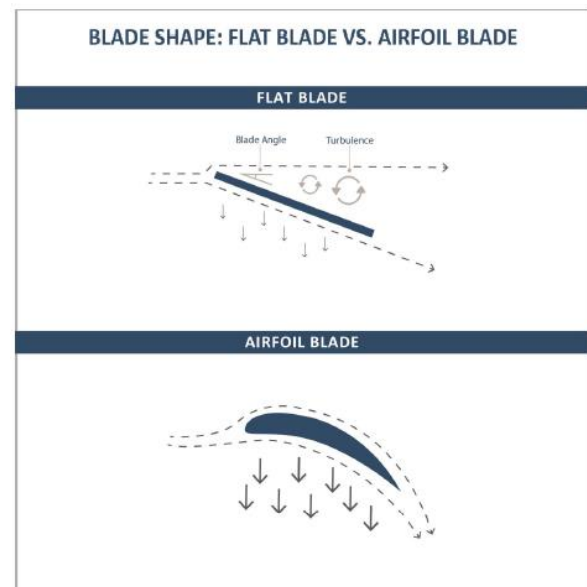
The blade shape, number of blades and blade pitch (angle of blade from horizontal plane) determine the airflow of a ceiling fan (see Figure 15). Three blade design approaches can improve air flow:

- 1) Blade aerodynamics: Switching to an air-foil shape from flat blades decreases air resistance but can also increase manufacturing cost.
- 2) Blade length: Increasing the blade size and the number of blades improves airflow. But this in turn increases the weight and drag, making the ceiling fan less energy efficient.
- 3) Blade pitch: Increasing the blade angle also increases airflow. The optimal blade pitch for residential fans is 12-15 degrees or less based on the design. Similarly, for airfoil-style blades, varying the blade angle over the length of the fan blade can maximize airflow. For example, providing a steeper angle towards the centre of the fan can give better airflow as fan speed is low here, while towards the outer tip of the fan blade, fan speed is high, and shallower fan blade angles can limit the drag and maximize energy efficiency.

Figure 15: (a) Ceiling fan blade pitch or blade angle and (b) flat blade versus airfoil blade



(a) Blade pitch or blade angle



(b) Flat blade versus airfoil blade

7.2 Reduce power consumption with more energy-efficient fan motor

The motor is at the heart of a ceiling fan, and optimizing motor type and motor performance has a large impact on overall energy efficiency. The type of motor determines its energy efficiency. The energy efficiency of brushless DC motors is higher than that of AC induction motors.

Brushless DC motors are typically smaller, quieter and much more efficient than AC induction motors. Brushless DC motors are electronically commutated, synchronous motors with permanent magnets embedded in or on their rotors. Their stators, which house the windings through which the electric current flows, are external to the rotor. No electric current flows through the rotor itself, which reduces rotor losses compared to induction motors and improves efficiency (U.S. Department of Energy, 2022b). AC induction motors are less efficient because their rotors do not rotate synchronously with the magnetic field that induces rotor motion, which results in slip, which is the difference between the speed of the rotor and the magnetic field in an AC induction motor (Shah *et al* 2014).

Coil winding is one key component of a fan motor, with copper and aluminium as two widely used winding materials. Using pure copper and aluminium instead of recycled metal can help lower power consumption and improve fan energy efficiency. Copper has higher electrical conductivity than aluminium (around 70 per cent higher) and better long-term durability, but it has a higher cost, as in the examples by (GEEKAY 2026; Benadum 2020; and The Piping Mart 2023). Other than coil winding material, emphasis should also be on the stamping material. Low-loss lamination steel and the use of thin lamination can also reduce the iron losses.

Past reliability issues with brushless DC motors that have been largely resolved included instances where demagnetization of the rotor magnet occurred, and printed circuit board chip damage due to high humidity in open spaces.

The ceiling fan motor's cover should keep most dust out, but some may still get in. To clean the motor and avoid any adverse effect of dust accumulation, the top of the motor cover should be periodically vacuumed. This should help remove the excess dust from your fan's motor.

7.3 Blade materials

Blade materials include metal, wood, composite materials such as composite wood material, plastic-based materials and paints. One common plastic blade material is ABS (acrylonitrile butadiene styrene) blades, a thermoplastic material that is easily formed into various shapes and can be manufactured to look like timber (JD Lighting 2021), although thermoplastic material may not be suitable for hot climates and fans installed in semi-outdoor installations. Plastic materials may lend themselves to more flexibility in blade designs to the manufacturability of thermoplastics materials. Metal blades such as aluminium are among the most durable options and often come with a protective coating such as zinc and silicon (Martec 2022).

Porous blade materials such as natural palm materials allow air to pass through the fan blade, and that air does not contribute towards the total air movement of the ceiling fan. These blade materials are less common. Note that the U.S. Department of Energy (2023) efficiency levels EL3 and EL4 in Figure 10 both use the same brushless DC motors, but EL3 is assumed to use blade materials of the natural palm material type, and EL4 corresponds to "BLDC motor – Flat Blades" because flat wood composite blades are usually used.

The type of bearings also plays an important role in improving motor performance and efficiency.

Ceiling fan blades should also be kept clean to avoid dust and dirt build-up and ensure optimal fan performance.

8 INCREMENTAL COST OF MORE EFFICIENT MOTORS

Incremental cost data for more energy-efficient motors are shown in Figures 16 and 17 (U.S. Department of Energy 2022b). Table 5 first describes the four service value levels above the baseline level. The first two levels rely on larger motor sizes. EL3 introduces brushless DC motors first with natural blade materials (palm-like) and then EL4 with flat blades (typically wood composite or plastic). Flat blades are less porous to air than the natural blade material and have high efficiency.

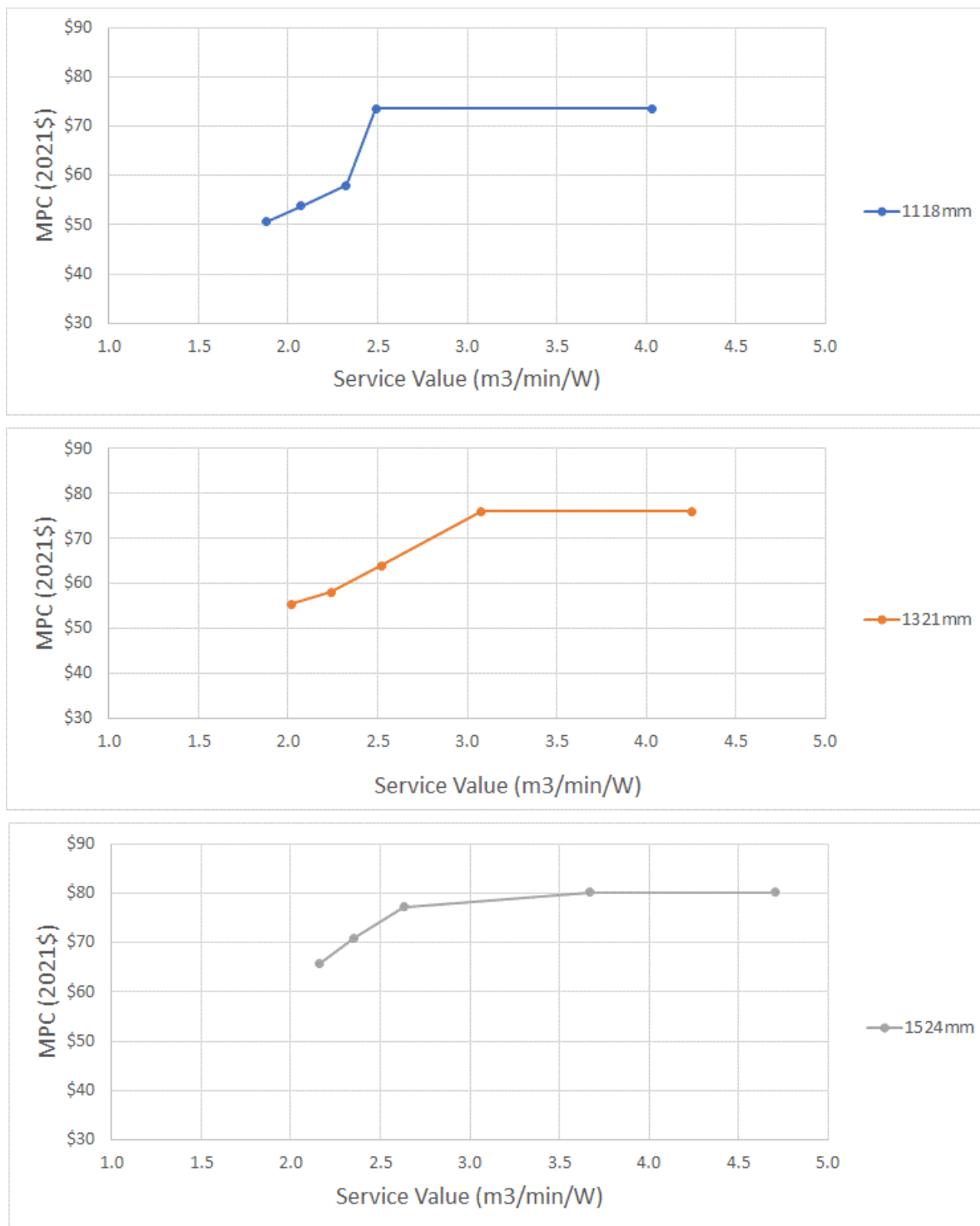
Each cost curve plot in Figure 16 shows five points (Baseline, EL1, EL2, EL3, EL4), and MPC (manufacturer production cost) refers to the direct manufacturing cost before distributor or retail markup. Figure 17 re-plots these data in percentages and shows that for 1,321 millimetre fan size, a 53 per cent gain in energy efficiency can be achieved with a 37 per cent increase in the manufacturer production cost.

Table 5: Efficiency levels for ceiling fans from U.S. 2022 preliminary rule-making

Service Value Level	Service Value Measures for Standard Ceiling Fans
EL 0	Baseline
EL 1	10% reduction in power usage; 11% higher service value [larger motor] vs. baseline
EL 2	20% reduction in power usage; 25% higher service value [larger motor] vs. baseline
EL 3	Energy Star® level – BLDC with natural blade materials
EL 4	Max-tech: BLDC – Flat Blades

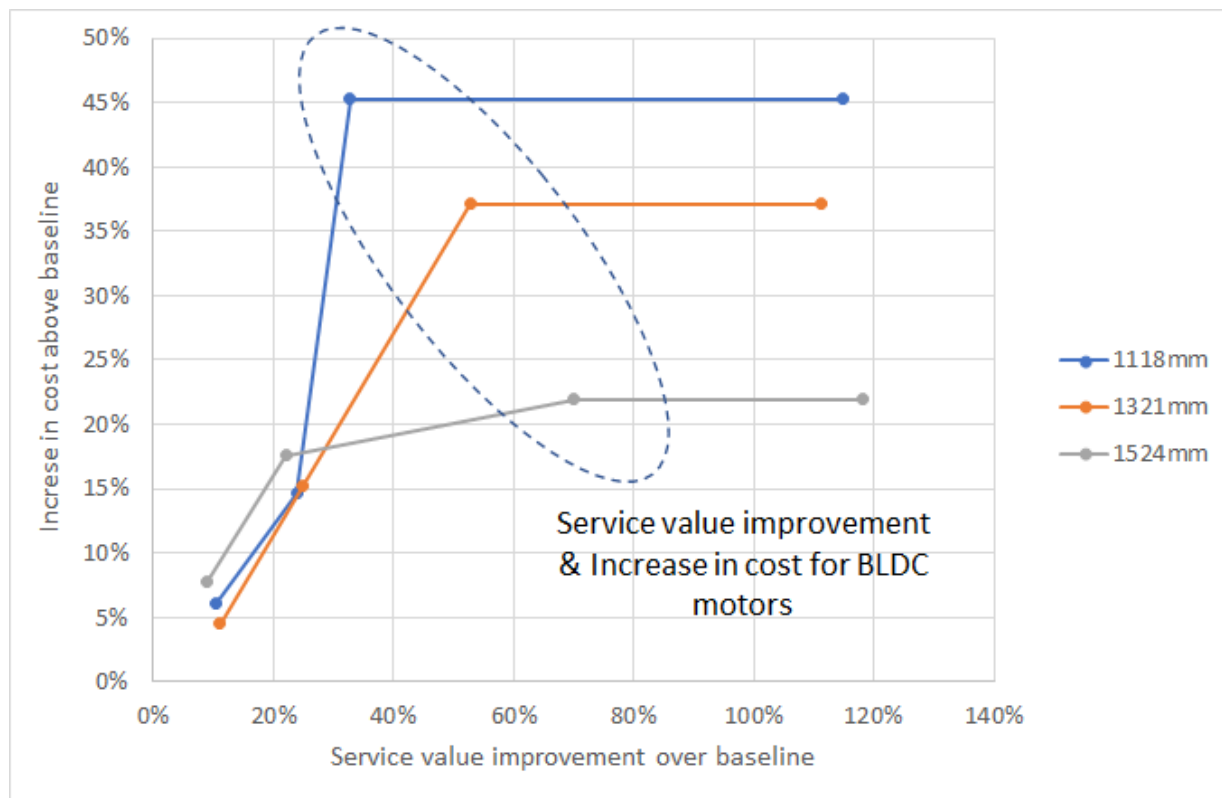
Source: U.S. Department of Energy (2022).

Figure 16: Cost-service value curves for three fan sizes



Source: U.S. Department of Energy (2022b).

Figure 17: The data in Figure 16 re-plotted as percentages



Note: When the data in Figure 16 are re-plotted as percentages, this shows the dependence of manufacturing cost above baseline and percentage improvement in service value as a function of fan blade diameter. The dashed line shows the three fans’ improvement and cost increase with the introduction of brushless DC motors.

Source: U.S. Department of Energy (2022b).

9 INCENTIVE PROGRAMMES – AN EXAMPLE DESIGN

Programmes to support increased energy efficiency include tightened energy efficiency standards, more extensive labelling requirements and greater accessibility of product information, and incentive programmes, to name a few. We consider an incentive programme as an example here.

A possible design for a bulk purchase incentive programme for highly energy-efficient (or super-efficient) ceiling fans is provided below for the case of India, but this general approach can be adapted to other countries.

First, retail price data are compiled for baseline and super-efficient models (Table 6). Here, super-efficient corresponds to models at or above the level of the proposed medium service value level. The average of two references give 1,250 Indian rupees (2022) for the baseline retail prices for ceiling fans and 2,850 Indian rupees for a super-efficient model.

Table 6: Retail price data for baseline and super-efficient ceiling fans in India

Reference	Baseline (2022 Indian rupees)	Super-efficient (2022 Indian rupees)	Incremental Cost (2022 Indian rupees)
CEEW 2022	1,000	3,000	2,000
Chunekar & Sahasrabudhe (Prayas) 2023	1,500	2,700	1,200
Average	1,250	2,850	1,600

Sources: CEEW (2022); Chunekar & Sahasrabudhe (2023).

Assuming a bulk purchase discount of 15-25 per cent (CEEW 2022), the consumer rebate for retail price parity is shown in Table 7 below. The consumer rebate in this case draws from the average price data in Table 8 and is calculated as follows:

$$Rebate = Retail\ price_{SE\ fan} * (1 - Bulk\ Procurement\ Discount\ [\%]) - Retail\ price_{baseline\ fan}$$

A more detailed analysis can consider local utility rates, annual energy savings and payback time for different consumer rebate amounts. There are also different methods for deploying the incentive. For example, distributing the incentive at the distributor level has certain advantages and has seen several successful regional examples for other consumer products in the United States with two to ten times higher adoption rates (Energy Star n.d.)

Table 7: Bulk purchase programme discount and consumer rebate for baseline price parity in India

Bulk procurement discount	Consumer rebate (Indian rupees)
0%	1,600
15%	1,200
20%	1,050
25%	900

Sources: CEEW (2022); Chunekar & Sahasrabudhe (2023).

Table 8: Retail price data for baseline and super-efficient ceiling fans in India

Reference	Baseline (2022 Indian rupees)	Super-efficient (2022 Indian rupees)	Incremental Cost (2022 Indian rupees)
CEEW 2022	1,000	3,000	2,000
Chunekar & Sahasrabudhe (Prayas) 2023	1,500	2,700	1,200
Average	1,250	2,850	1,600

Sources: CEEW (2022); Chunekar & Sahasrabudhe (2023).

These types of incentive programmes can accelerate the market transition to highly efficient products. As manufacturing volumes increase for more energy-efficient components, the direct manufacturing costs are lowered, and over time, the consumer rebate amounts can be reduced.

10 FUNCTIONAL PERFORMANCE, SAFETY AND OTHER CONSIDERATIONS

Some functional performance, safety and/or considerations are described below.

Installation:

- Installation should adhere to any manufacturing instructions and specifications such as electrical grounding, appropriate electrical outlet box and sufficient structural mounting for heavy fan units.
- Generally, a ceiling fan should be installed at least 2.2 meters (seven feet) above the ground and “industry standards recommend fan blades be at least 21 cm (eight inches) below the ceiling, though clearances of 31 cm (12 inches) or more are more optimal at providing air circulation into the swept area of the blades and avoiding ‘starving’ the fan.”

Operating conditions:

- Ceiling fans unless otherwise specified are rated for indoor use only.
- Temperature: The cooling effectiveness of fans at elevated temperatures primarily depends on convective heat transfer from the air and evaporative cooling from sweat on the skin. Guidance from health and environmental organizations may be conservative: i.e., that fans do not help when temperatures are above around 36°C (World Health Organization 2015; U.S. Centers for Disease Control and Prevention 2012), or when the heat index – a combination of the temperature and humidity – rises above 37.2°C (99°F) (U.S. Environmental Protection Agency 2006). More recent data suggest that these limits could be higher (e.g., to 40°C with moderate humidity) depending on demographic and other underlying health factors (Baker 2019).

Other important ceiling fan placement considerations from the United States including fire alarms and water sprinkler systems are included here for reference:

- Minimum three-feet (0.914 metres) horizontal distance from smoke alarm – Because a ceiling fan can disturb the natural upward flow of air to a smoke detector alarm and potentially delay the alarm’s response to a fire, a smoke alarm should not be installed within three feet horizontally of the maximum radius of the tip of a ceiling fan blades, according to the National Fire Protection Association (n.d.).
- A fan too close to a fire sprinkler requires an additional sprinkler – A pendant-type sprinkler within three feet (0.914 metres) of the centre of a ceiling fan is considered obstructed and requires installation of an additional sprinkler. Sidewall sprinklers within five feet of the centre of a ceiling fan also require an additional sprinkler, per International Residential Code (2018).

10.1 Component requirements and considerations

10.1.1 Motor

Certain factors impair performance or shorten lifetime. For example, excess room humidity can lead to corrosion of the motor and electronic components and shorter motor lifetime. Similarly, fan blades made of composite wood products in very humid environments may droop due to moisture absorption (How to look at a house 2022).

10.1.2 Weak grid considerations

Voltage sags and power dips from the electrical grid can be caused when there is a weak grid or a fault interruption caused, for example, by a large incoming load or grid failure nearby. These types of events can lead to overloading or overheating equipment as current demand goes up to compensate for incoming voltage drops. In areas with a weak grid, additional equipment such as surge protectors for ceiling fans may be needed and would add additional cost (Pumps and Systems n.d.).

10.1.3 Safety/other considerations

Ceiling fans need to follow the requirements for any relevant national electrical codes (such as grounding requirements to avoid electric shock hazard) and any manufacturer product requirements (such as manufacturer installation instructions), the most important one being that fan blades are a minimum of seven feet (2.13 metres) above the floor for personal safety. Fans also must be installed with an electrical outlet box rated for ceiling fan and weight and any appropriate outlet box and ceiling fan support braces as needed.

Additional safety considerations include maintaining a minimum distance of three feet (0.914 metres) from smoke alarms horizontally from the path of the tip of the ceiling fan (e.g., U.S. National Fire Protection Association NFPA 72, 29.11.3.4(9) and additional sprinklers are required if a fan is too close to a fire sprinkler per International Residential Code (IRC 2904.2.4.1,2).

UL (Underwriters Laboratories) also has fan ratings for “Damp” and “Wet” locations to prevent premature corrosion, product failure and/or droopy blades that may result from composite wood blades.

The U.S. Occupational Safety and Health Administration’s permissible noise exposure limit for ceiling fans is 90 dBA based on a time-weighted average over an eight-hour day, while the U.S. National Institute for Occupational Safety and Health recommends limiting the eight-hour exposure to less than 85 dBA.

Dirty blades have more weight and drag and dirty housing hampers air flow around the motor.

Other related information can be found in the following references:

- For safety, IEC 60335-2-80 is followed in most countries.
- Electromagnetic compatibility of fans (CISPR 14-1 and CISPR 14-2, IEC 61000-3-2, IEC 61000-3-3).

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For more information:
communication@unep.org
United Nations Avenue, Gigiri
PO Box 30552, 00100
Nairobi, Kenya

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