Potential Global Benefits of Improved Ceiling Fan Energy Efficiency

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Executive Summary

This report presents the results of an analysis, commissioned by the United States Department of Energy (US DOE), of ceiling fan efficiency. This analysis was prepared in support of the Super-efficient Equipment and Appliance Deployment (SEAD) initiative.[1] The International Energy Studies group at Lawrence Berkeley National Laboratory (LBNL) performed the analysis. The objective of this analysis is to provide the background technical information necessary to improve the efficiency of ceiling fans, and to provide a foundation for the voluntary activities of SEAD participating countries.

SEAD aims to transform the global market by increasing the penetration of highly efficient equipment and appliances. SEAD partners work together in voluntary activities to: (1) "raise the efficiency ceiling" by pulling super-efficient appliances and equipment into the market through cooperation on measures like incentives, procurement, and awards; (2) "raise the efficiency floor" by working together to bolster national or regional minimum efficiency standards and labels; and (3) "strengthen the efficiency foundations" of programs by coordinating cross-cutting technical analysis to support these activities.[2]

Motivation for this Study

Ceiling fans make up a significant amount of residential electricity consumption in many countries around the world. For example, previous research shows that ceiling fans accounted for about 6% of residential primary energy use in India in 2000, and this figure is expected to grow to 9% in 2020 (de la Rue du Can et al. 2009). Fan use in the commercial sector is also likely to be significant, a recent study on appliance load in residential and commercial sectors in the western state of Gujarat in India found that ceiling fans accounted for 5.7% of the load from commercial establishments (Garg 2010). Fans are also well known to be a cost-effective option for reducing air conditioner electricity demand; air conditioners account for about 16% of residential electricity consumption in the U.S. (U.S. DOE & U.S. EPA 2010).Thus, the energy efficiency of ceiling fans is an important area to address in reducing overall energy consumption in many countries.

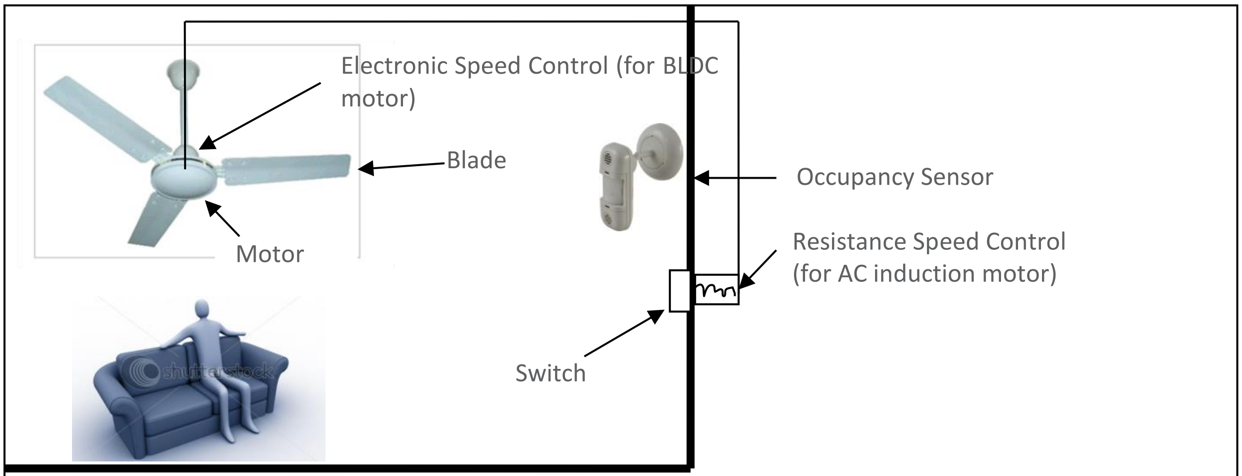
However, the economic and engineering literature and data on ceiling fan energy consumption and efficiency improvement options are sparse. This study analyzes the cost-effectiveness of several efficiency improvement options in ceiling fans and estimates the global potential for energy and carbon dioxide (CO_2) emissions savings. We utilize the Bottom-Up Energy Analysis System (BUENAS) to make these global potential estimates. This paper also offers some insights into design of policies to support ceiling fan energy efficiency improvement.

[1] An initiative of the Clean Energy Ministerial (CEM) and a task within the International Partnership for Energy Efficiency Cooperation (IPEEC), SEAD seeks to engage governments and the private sector to transform the global market for energy-efficient equipment and appliances. As of October 2012, the governments participating in SEAD are: Australia, Brazil, Canada, the European Commission, France, Germany, India, Japan, Korea, Mexico, Russia, South Africa, Sweden, the United Arab Emirates, the United Kingdom, and the United States. More information on SEAD is available from its website at http://www.superefficient.org/.

Objective and Scope

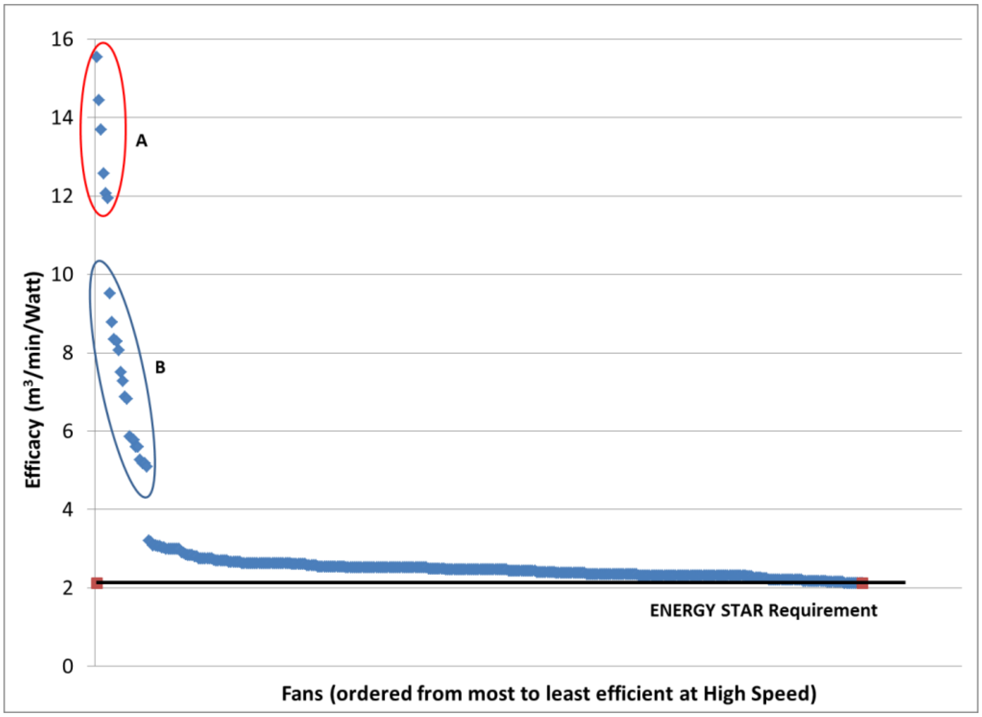
The objective of this analysis is to identify potential ceiling fan efficiency improvements and their incremental costs to assess the cost effectiveness of these options and to provide approximate global and country-specific estimates of the total energy savings potential of these improvements. The overarching goal is to provide relevant and appropriate information to support the design of policies and programs that will accelerate the market penetration of efficient ceiling fans.

Although ceiling fan systems are made up of multiple components that affect energy consumption; this report focuses on two of the most important components from energy consumption perspective that could be improved: *motors and blades* (see Figure 1). Figure 2 shows data on energy efficiency of U.S. ENERGY STAR qualified ceiling fans. The far left data points represent fans that have brushless direct current (BLDC) motors which are almost twice as efficient as induction motors typically used in ceiling fans and also have more efficient blades. As a result these ceiling fans are between *two to four fold* more efficient as the US Energy Star requirement. These results are indicative of the large potential for ceiling fan energy-efficiency improvements using commercially available technology.



Fan source: Aavaas 2011
Sofa source: shutterstock images 2011
Sensor source: Schneider Electric 2011

Figure 1 Ceiling Fan Components



Source: ENERGY STAR 2012a, 2012b

Figure 2 Efficacy of ENERGY STAR ceiling fans (combination of fan-only products and fan with light kit) at high speed.[3]

Data Sources and Analysis Method

The literature and available data on ceiling fan energy consumption are sparse. Our team obtained the data for this report from a review of the literature, including technical reports; U.S. ENERGY STAR databases; participation in international conferences; and interviews with experts in the field.

We begin by clarifying ceiling fan performance measures, with attention to the fluid mechanics of turbomachinery. We derive relationships among: ceiling fan power consumption, rotation speed, downward air velocity, volumetric airflow, and efficacy (measured in airflow per unit power consumed). This allows us to understand the engineering basis of current ceiling fan standards in various countries.

We then consider efficiency improvement options focusing on the introduction of efficient fan blades, efficient alternating current (AC) induction motors, and the substitution of brushless direct current (BLDC) motors for AC induction motors. We show that the most efficient fans on the market are already using some of these technologies, such as BLDC motors and efficient blades. We estimate the cost of implementing these efficiency improvement options and the corresponding gains in efficiency from a review of the literature and interviews with experts in the field and estimate their cost effectiveness.

We utilize our estimates for the efficiency improvement potential for a typical ceiling fan in the Bottom-Up Energy Analysis System[4] (BUENAS) to assess the global potential energy consumption and CO_2 emissions benefits of increased ceiling fan efficiency. Our analysis compares future ceiling fan energy consumption for two scenarios: a base or business-as-usual (BAU) case, which assumes current usage and efficiency trends, and an efficiency scenario, which considered

[3] Group A are confirmed to employ BLDC motors, while all but one of group B employs DC motors.

[4] http://www.superefficient.org/en/Products/BUENAS.aspx

adoption of cost effective efficiency measures in new ceiling fans sold. The electricity consumption reduction seen in this efficiency scenario represent an approximate estimate of the total cost effective techno-economic saving potential, a part of which can be captured by promoting policies and programs to accelerate the adoption of efficient fans.

Analysis Results

Results for individual ceiling fans are used to inform results of potential global energy savings from fan efficiency improvements.

A. Benefits for Individual Ceiling Fans

We estimate the cost of conserved electricity (CCE) for various efficiency improvement options to assess their cost effectiveness; improvements for which CCE is lower than the cost of electricity are cost effective.[5] CCE is estimated by dividing the electricity savings due to an efficiency improvement option by the annualized incremental cost of that efficiency improvement option. Table 1 shows estimates of the cost of conserved electricity (CCE) and corresponding annual energy savings from using the various energy efficiency improvement options in fans in India. These results show the significant potential for cost effective savings because CCE for these options is less than 3 cents/kWh whereas the cost of electricity is typically greater than 7 cents/kWh. We note that although Table 1 is focused on India, these improvements are feasible currently, so the technology also has potential for being utilized internationally. Cost effectiveness analysis of efficiency improvement options in other economies are presented in Appendix D. Since our analysis is primarily based on data on costs of efficiency improvements in India and US, the cost effectiveness analysis is more robust for these countries. Given the globally traded nature, maturity and high contribution of materials costs to the total costs of the efficiency technologies considered, we argue that cost estimates based on the data in India and US are likely to be a reasonable approximation of the costs in other regions. The cost effectiveness analysis for other regions takes into account region specific estimates of usage and discount rates.

Table 1 Incremental manufacturing costs, annual energy savings and CCE for various efficiency improvement options in ceiling fans in India[6]

Efficiency Improvement Option	% reduction from baseline power	Average incremental manufacturing cost($)	Annual energy saved per fan (kWh)	CCE ($/kWh)
Improved AC Induction Motor (A)	36%	$1.5	80	$0.005
BLDC Motor (B)	50%	$10.5	112	$0.027
Efficient Blades (C)	15%	$3.5	33	$0.031
A+C	45%	$5.0	101	$0.014
B+C	57%	$14.0	129	$0.032

B. Global Potential Energy Savings

As seen in Table 1, achieving 50% reduction in power consumption using BLDC motors is cost effective. A combination of BLDC motors and efficient blades can reduce the consumption further. As a conservative estimate, based on the discussion in section 2.2.3, the global energy savings analysis using BUENAS assumes that ceiling fan energy consumption can be reduced by 50%. The results of our analysis, depicted in Figure 3, indicate that a phase-in from 2012 to 2016 of

[5] Cost of electricity(CCE) for consumers is the electricity tariff; hence if CCE is lower than the tariff, then the corresponding efficiency improvement options are cost effective from a consumer perspective.

[6] Efficiency improvement options from single components are presented first followed by efficiency improvement options from combining two options. The options are subsequently ordered by increasing cost of conserved energy. Also option C, efficient blades can be used with both BLDC and AC motors. While BLDC motors and AC motors are widely available, efficient blades may be proprietary designs, and also carry associated aesthetic tradeoffs.

efficient ceiling fans with equivalent improvements could significantly reduce global residential energy consumption. Residential energy consumption could be reduced by approximately 70 TWh/year by 2020 versus the business as usual (BAU) scenario.

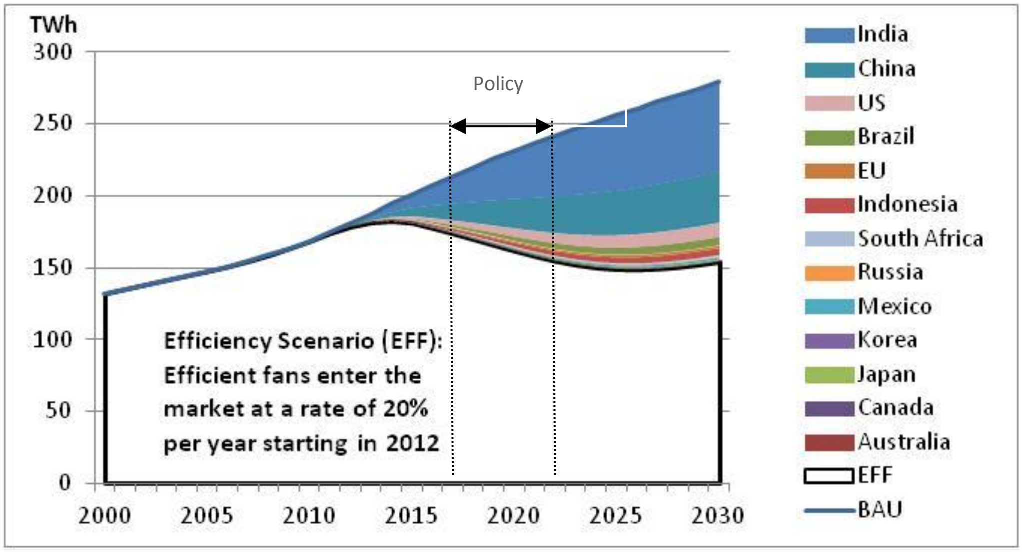


Figure 3 Potential electricity savings resulting from introduction of efficient fans, 2000-2030

C. Insights for Market Transformation Programs

This paper shows that there are several cost-effective options to improve ceiling-fan efficiency that could reduce fan energy consumption by more than 50%. Several barriers, including high first cost and lack of information (e.g., lack of labels that recognize highly efficient performance, lack of technical capacity), have been identified as contributing to the limited adoption of highly efficient fans (Singh et al. 2010). Out of the several types of policies typically used to accelerate adoption of efficient products (e.g., awards, incentives, and standards and labeling programs), standards and labeling programs are the most commonly used to accelerate the market penetration of efficient fans.

The standards and labels levels for Bureau of Energy Efficiency (BEE)'s star rating program in India are presented in Figure 4. These efficacy levels are tested under different conditions (notably airflow requirements/speeds) than standards and labels in the US, Europe and China so they cannot be directly compared against each other without accounting for this fact.[7] However, the improvements in efficacy discussed in this report are applicable across the range of commonly encountered airflows, i.e. these improvements will offer significant energy savings of a similar order of magnitude regardless of airflow, and test procedure alignment. For comparison, the US ENERGY STAR label has an efficacy requirement of 4.2 (m^3/min/W) at low speeds and 2.1 (m^3/min/W) at -high speeds while the lowest standard for efficacy in China varies by fan size from 3.47 (m^3/min/W) for 1800 mm fans to 2.75 (m^3/min/W) for 900 mm fans (U.S. DOE & U.S. EPA, 2010, and AQSIQ, 2010).

[7] See Appendix C for a discussion of the effect of fan speed on efficacy. Increasing airflow from 5000 CFM (the US high speed) to 7415 CFM (i.e.210 m^3/min, the minimum airflow for star rated fans in India), i.e. A 48% increase will yield a decrease in efficacy of at most 35%.

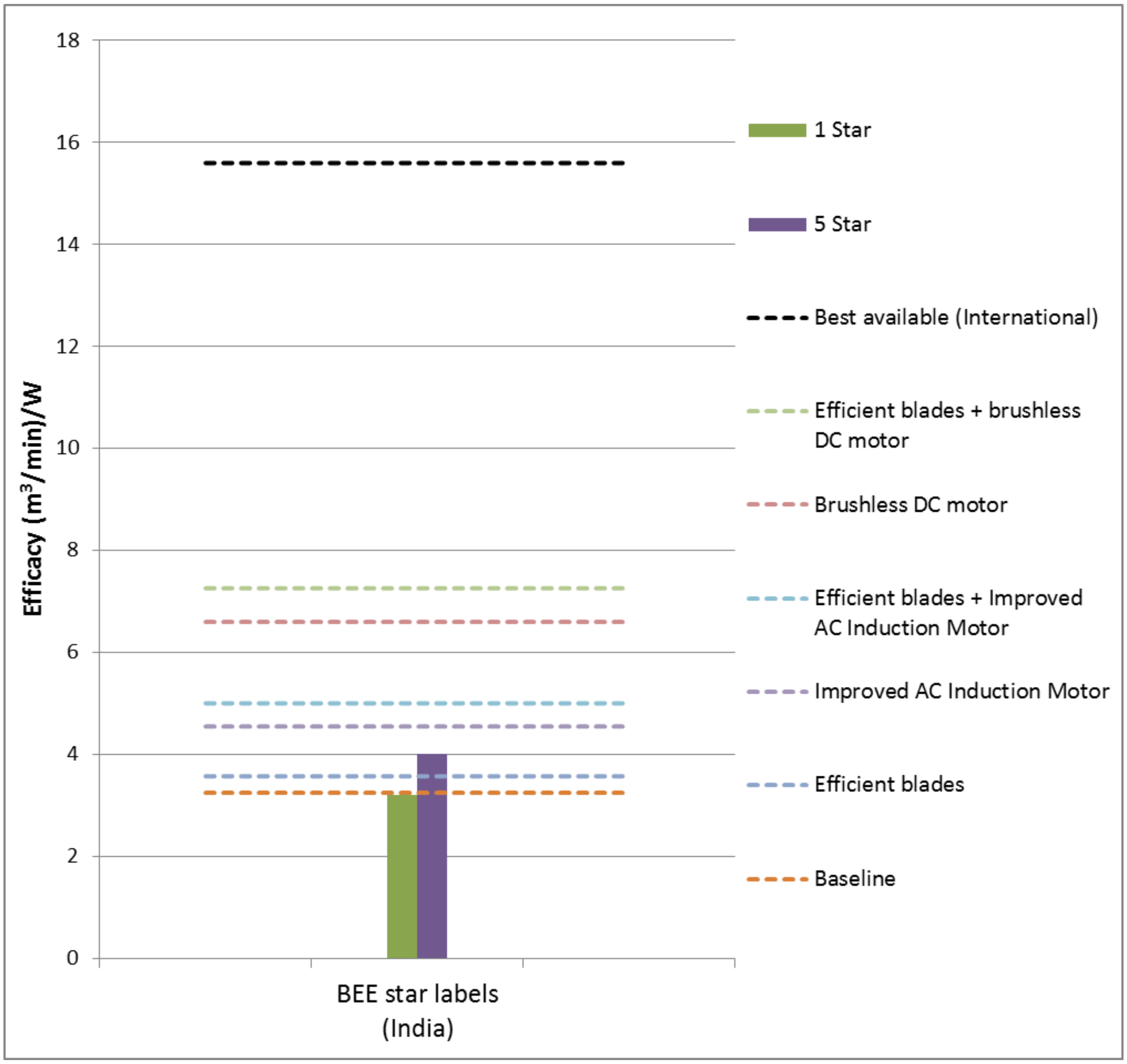


Figure 4 BEE (India) star labels compared to estimates of potential ceiling fan efficacy[8]

Thus as is evident from Figure 4, the highest efficacy level recognized by labels in several countries is significantly lower than what can be achieved by adopting cost effective efficiency options. Hence current efficacy label levels need to be revised significantly to encourage deeper penetration of efficient ceiling fans at the top of the market with efficacies achievable using BLDC motors and efficient blades that are already on the market in the US, and that are cost-effective.

The low penetration levels of efficient ceiling fans in both India and the US even with labeling programs in place[9] seems to indicate the presence of barriers to efficiency in addition to information, such as first cost, (e.g. as discussed in Reddy, 1991) that may not be able to be addressed fully within a standards and labeling framework. In emerging economies, consumers are highly sensitive to high first costs (Singh et al. 2010). However, despite the large saving potential, financial incentive programs to promote the adoption of highly efficient fans by removing this first cost barrier are not common.

One notable example under development is the Super-Efficient Equipment Program (SEEP) in India where financial incentives will be provided to fan manufacturers to produce and sell highly efficient fans that consume less than half of

[8] Note: The baseline efficacy value is based on the average values reported as 'National Player's Models' presented in (Garg & Jose 2009). Incremental improvements correspond to those presented in section 2.2. The efficacy level of the best available fan corresponds to the fan with the highest efficacy in Figure 4.

[9] BEE's voluntary star rating program for fans only covered 2% of the Indian market, while only 18% of the fans(without a light kit) on the US ceiling fan market were compliant with ENERGY STAR (PWC, 2012, and EPA 2011) indicating significant room for efficiency improvement.

the energy consumed by fans typically sold on the Indian market (Singh et al. 2010). Even if the entire incremental cost of the highly efficient fans is covered by the financial incentives, the cost of the conserved electricity for efficiency improvements over 50% is just Rs. 0.7 per kWh ($0.014/kWh) which is about one sixth of the cost of supplying electricity in India (J. Sathaye & Gupta 2010). SEEP or a similar upstream incentive program for ceiling fans would be cost-effective even assuming higher costs and lower hours of use as discussed in section 2.3.

It is quite likely that a financial incentive program accelerating the penetration of highly efficient fans has a large cost effective saving potential in several other countries and should be considered as one of the key options for reducing electricity demand and emissions.