Codes and Standards Enhancement Initiative
For PY2004: Title 20 Standards Development

Analysis of Standards Options For Ceiling Fans

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1 Introduction

The Pacific Gas and Electric Company (PG&E) Codes and Standards Enhancement (CASE) Initiative Project seeks to address energy efficiency opportunities through development of new and updated Title 20 standards. Individual reports document information and data helpful to the California Energy Commission (CEC) and other stakeholders in the development of these new and updated standards. The objective of this project is to develop CASE Reports that provide comprehensive technical, economic, market, and infrastructure information on each of the potential appliance standards. This CASE report covers standards and options for ceiling fans.

2 Product Description

A ceiling fan is defined as a hard-wired, non-oscillating fan that is suspended from the ceiling for circulating air via the rotation of horizontal fan blades. Electric motor powered ceiling fans have been used for cooling building occupants since the 1880's with little change in the basic configuration of the fan. They consist of four or five flat blades attached to an electric motor, which is usually suspended from the ceiling by a downrod (see Figures1-3). Most ceiling fans have at least three speeds and also may have a reversing switch for operation in the winter. Often ceiling fans ship with attached lighting fixtures or can be retrofitted with lighting kits. Before the advent of mechanical air conditioning, ceiling fans were ubiquitous in residential, commercial, and industrial buildings, but they lost popularity with the increased penetration of central air conditioning. Recently residential ceiling fans have experienced a resurgence, with many new California homes often being equipped with multiple fans.

Figure 1: Traditional ceiling fan –no light kit.

Figure 2: Traditional ceiling fan –with light kit.

Figure 3: Ornamental ceiling fan with decorative blades.

The air motion generated by ceiling fans results in improved comfort, which has been documented in numerous studies (ASHRAE, 1997). The Institute for Environmental Research at Kansas State University has performed extensive testing of human physiological response to varying levels of air movement. Data indicate that ceiling fans provide equivalent environmental comfort at temperatures 3ºF higher than under still air conditioners. Conservatively assuming a 3-6% reduction in air conditioner energy use for each degree set point increase, ceiling fans could reduce typical residential cooling energy use by 10-20%, depending upon climate and how they are used. However, field studies conducted by the Florida Solar Energy Center (FSEC) have not demonstrated statistically significant cooling energy savings due to ceiling fan use (James et al, 1996). This can be attributed either to the "take back" effect or possibly that ceiling fans provide less air conditioner savings in humid climates than in dry climates, such as California. A 2001 study of monitored California ceiling fan operation found that 8 out of 36 homes with programmable thermostats raised their cooling setpoint to reflect the benefit of ceiling fan operation (RLW 2002).

3 Market Status

3.1 Market Penetration

Major manufacturers ceiling fans include Hunter, Emerson, and King of Fans, although exact market share of the major manufacturers is difficult to determine. Three sources of data were evaluated to assess California market penetration: The Energy Information Administration 2001 Residential Energy Consumption Survey (EIA 2001), a 2001 RLW Analytics study (RLW 2002), and the 1994 PG&E Residential Energy Survey (PG&E 1994). The RECS data compiled in Table 1 shows a lower saturation of ceiling fans in California relative to the national average, primarily due to fewer houses with multiple fans. The RLW Analytics study estimates there are 9 million ceiling fans within the PG&E/SCE/SDG&E service territories. Based on available population data[1], this extrapolates to 10.8 million ceiling fans statewide. 95% of California ceiling fans have an integral or attached lighting kit (RLW 2002).

Table 1: Ceiling Fan Saturation

# of fans	RECS		RLW	PG&E
	US	California		
1 fan	20.6%	20.7%	23.4%	
2 fans	14.1%	12.7%	8.7%	
3 or more fans	30.4%	11.8%	16.0%	
Total	65.1%	45.2%	48.1%	37.5%
Stock (millions)	150	10.3	10.8	N/A

3.2 Sales Volume

A total of 16.5 million ceiling fans were shipped in 2000 for the North American market (Appliance 2001). Apportioned by population, annual California sales are estimated at 1.8 million units for the year 2000. Based on the upward trend in ceiling fan shipments over the past decade, we project that California sales are increasing by about 42 thousand units per year.

3.3 Market Penetration of High Efficiency Options

In 2001, the US EPA initiated a voluntary Energy Star certification program for ceiling fans. The program included two efficiency tiers with Tier I having an effective date of January 2002 and Tier II an effective date of October 2003. Airflow efficiency requirements are shown in Table 2. In addition to airflow, the specification requires that all integral and attachable light kits must meet the requirements of the Energy Star Residential Light Fixture specification.

[1] See Table II-9 in "California Energy Demand 1991-2011. Vol. I – Revised Electricity Demand Forecasts", Dec 1991. California Energy Commission. P300-91-023.

Table 2: Tier I Energy Star Specifications for Air Flow Efficiency

Fan Speed	Minimum Airflow	Efficiency Requirement*
Tier I		
Low	1,250 cfm	155 cfm/Watt
Medium	2,500 cfm	110 cfm/Watt
High	5,000 cfm	75 cfm/Watt
Tier II		
Low	1,250 cfm	155 cfm/Watt
Medium	3,000 cfm	100 cfm/Watt
High	5,000 cfm	75 cfm/Watt

*Individual models' measured performance may vary by +/- 5%. As of October 1, 2004 the tested model must meet the efficiency requirement.

As of March 2004 there were 544 ceiling fans listed that comply with Energy Star requirements (521 of these fans did not feature lights and 23 did).

4 Savings Potential

4.1 Baseline Energy Use

National estimates of ceiling fan energy use were done for the Energy Star certification program using RECS for saturations and interpolating between two studies of ceiling fan use to estimate energy use (Calwell & Horowitz 2001). In 2001, RLW Analytics monitored 62 homes with 150 ceiling fans within PG&E, SCE, and SDG&E service territories (RLW 2002). They measured fan motor and lighting power levels, and monitored fan and light operation for one year. Table 3 compares energy use estimates of the two studies. Although the average California and national demand estimates are almost the same, California fan motor and lighting usage are 39% and 27% respectively of the national numbers. The lower fan usage in California is understandable as the national data are dominated by the South, which has a combination of high saturation and high usage, but the very low California lighting intensity is surprising. Because the survey was conducted during the summer of 2001, in the middle of the California power crises when many people were acutely aware of energy use, there is some question as to whether the results are indicative of typical lighting operation during more normal conditions.

Table 3: Ceiling Fan Energy Usage

End Use	Average Demand (Watts)	Hours per day	Annual Use (kWh)
California			
Fan motor	38	2.5	35
Lighting	132	0.9	43
National			
Fan motor	35	6.3	80
Lighting	120	3.3	145

Total annual California usage is estimated at 76 kWh per fan, with 43% of the annual energy attributed to the fan motor. Based on this estimate, statewide annual ceiling fan energy usage is projected to be 799 GWh, of which 354 GWh are attributable to the fan motor. Based on average diversified summer day demand profiles (RLW 2002), projected peak motor demand is estimated at 92 MW (assuming average fan demand of 8.5 Watts), and the projected peak lighting demand is estimated at 144 MW (assuming average lighting demand of 14 Watts).

4.2 Proposed Test Method

The NEMA Standard Publication No. FM1-1951 outlines two methods of air delivery measurement (IEC Standard 879 and Canadian Standard CSA C814), both of which are more than 30 years old. These methods rely on manual readings of air velocities at various points in a standard room using a mechanical anemometer, and are labor intensive, less than accurate, and not generally repeatable.

Another measurement approach is outlined in the AMCA 230-99 standard, which uses a load cell to measure the thrust of the fan. The fans airflow capability is then calculated using the measured thrust value. According to the Hunter Fan Company, this test method is not ideal for ceiling fan applications.

In 2000 the Hunter Fan Company developed a test method to increase the efficiency and improve the accuracy of the airflow measurement procedure. The Energy Star program subsequently adopted this test method. This new technique greatly reduces the testing time compared to the NEMA or IEC standards. The fan is hung in a humidity and temperature controlled test chamber above a large cylinder. The air moved by the fan passes through the cylinder and over a row of hot-wire anemometer velocity sensors. A computer reads the anemometers simultaneously, allowing the whole test to be completed in a few minutes once the fan is set up.

We propose using this Energy Star Solid State Test Method, which is outlined in the Energy Star Testing Facility Guidance Manual, version 1.0, Chapter 4, dated September 20, 2002, as the methodology for measuring fan efficacy at low, medium and high fan speeds.

4.3 Efficiency Measures

4.3.1 Fan Motor

A sample of 26 fans from 9 manufacturers was used to assess baseline fan motor efficacy in terms of "Watts per cfm". The data was from the Hunter Fan Company's test results used for development of the Energy Star program and published in April 2001. Figure 4 plots fan performance at each of the three operating speeds. Most of the fans have similarly shaped performance curves despite some being more efficient than others, but four fans had significantly poorer performance and a distinctly different curve. Data are plotted for the average of all fans in the sample, the average of fans meeting Energy Star specifications, the Energy Star lower limit, and for the four individual poor performing fans.

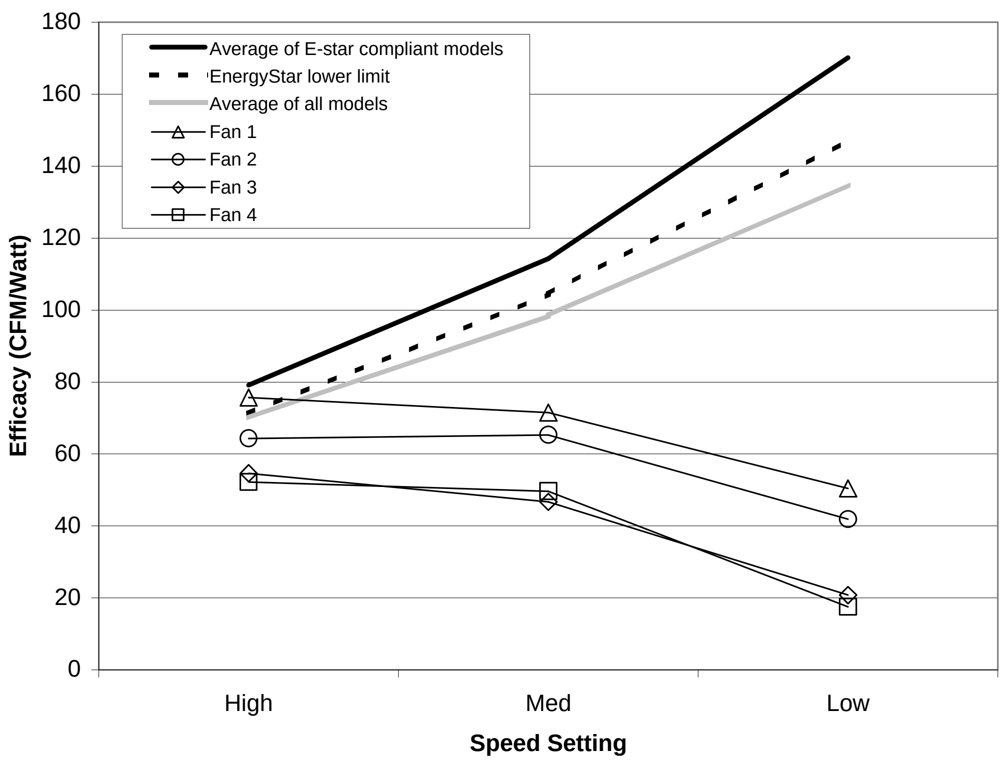
The efficacy curves for the poor performing fans are the ones with the negative slopes. One characteristic of these fans, which are often ornamental, is that the fan blades are designed for aesthetic value, not efficiency. The three principal factors affecting ceiling fan efficacy are motor size, motor quality and blade design. The relationships between these factors and ceiling fan efficiency are:

- Motor Size – Fan motors are typically sized for quiet operation and long life, not for high efficiency. Motor efficiency generally increases with increasing motor load relative to motor size. If the motor is oversized, the fan operates less efficiently.

- Motor Quality – There is considerable variation between the performance of standard and energy-efficient motors. Improved design, materials, and manufacturing techniques enable energy-efficient motors to accomplish more work per unit of electricity consumed[2]. Most ceiling fans motors are shaded pole induction motors less than 1/8 hp, the least efficient motor type used in household appliances. But even within this motor class there are many design decisions that can significantly affect motor efficiency.

- Fan Blade Design – The weight and aerodynamic drag of the fan blades affect the load on the fan motor. Most fans use flat (angled) fan blades, and simply setting the angle of the blades correctly can result in higher operating efficiencies.

Figure 4: Comparison of Ceiling Fan Efficacy



[2] Motor Challenge (a Program of the US Department of Energy): Buying an Energy-Efficient Electric Motor

A new fan design that has recently been brought to market is the Gossamer Wind, manufactured by King of Fans. The Florida Solar Energy Center (FSEC) and AeroVironment designed the Gossamer Wind to maximize the efficiency and airflow of the fan at maximum fan speed. The Gossamer Wind generates similar performance to other high efficiency fans at medium and low fan speed settings, but out-performs all other fans in the high speed setting by at least 20 cfm/Watt. The cost of this fan is roughly $35 more than comparable fans. Figure 5 shows the blade design of the Gossamer Wind fan.

Figure 5. Gossamer Wind Fan with Aerodynamic Blade Design

4.3.2 Lighting

A typical ceiling fan has 3 to 5 light sockets, each of which can accept a 40 or 60W incandescent lamp, or a central globe designed for a 100-150W incandescent lamp. Two efficient lighting options are 1) replace each incandescent lamp with a 15W CFL, and 2) use a central light source consisting of a 40 to 60W circuline or 2D lamp. Energy savings from these measures range from 70 to 75 percent. Other non-energy benefits include longer life, better lighting quality, and improved comfort from the reduced heat output.

4.4 Standards options

Three options for ceiling fans could be considered:

1. Require testing, listing, and labeling of fan performance data and fan and lighting configuration. This data will: 1) provide consumers with information for purchasing efficient products, 2) provide utilities with data to formulate incentive programs, and 3) provide a basis for determining a future standard.
2. Require that fans meet a minimum energy efficient air movement performance standard based on the Energy Star specification or a more stringent level.
3. Require that fan light kits sold with fans or sold separately must (a) use pin-based compact fluorescent lamps or (b) be sold with an initial supply of screw based CFLs to fill all of the sockets.

4.5 Energy Savings

The EPA claims Tier 1 Energy Star ceiling fans reduce motor energy use by 10%. Currently the EPA-listed fans exceed Energy Star minimum efficiency levels by 7%, on average. Our analysis of the 26 fan Hunter sample indicates that bringing non-compliant fans up to the Energy Star level would reduce average fan demand by 13% - an annual fan motor savings of 4.3 kWh per year. Switching fan lighting from incandescent to fluorescent would save 70% of the lighting energy or 30 kWh per year. Potential statewide energy savings are summarized in Table 4.

Table 4: Potential Energy Savings

Measure	*Baseline usage (kWh/yr)*	*Per unit Savings (kWh/year)*	*First Year Savings (GWh/year)*	*Statewide Potential Savings (GWh/year)*
Fan	35	4.3	9	46
Lighting	43	30	60	324

5 Economic Analysis

5.1 Incremental Cost

Costs for fluorescent lamps vary from $24 for direct CFL replacement to $20 for a central 2D lamp. Figure 6 plots the retail cost of the 26 fans (used to develop Energy Star efficiency levels), as a function of efficiency at each of the three fan speeds. As the cost of CFLs continues to decrease in the marketplace, the $24 cited may prove to be very conservative. Three vertical lines shown in Figure 6 delineate the minimum airflow efficiency at each fan speed. Although there is not a clear relationship between cost and efficiency, the cheapest fans generally have the lowest efficiency.

Figure 7 plots efficiency vs. retail price for 133 Energy Star listed fans for which retail pricing was obtained. For many ceiling fans, cost is primarily dictated by style, aesthetics, and by features not directly impacting fan efficacy (such as a remote control). For the vast majority of non-compliant fans, the cost implications of improving efficiency are not significant since motor specification and blade redesign or optimization are not costly options. For fans with standard or high efficiency motors, all that will be required is optimization of the blade angle. Those fans that have low efficiency motors will need a higher efficiency motor, an option we estimate to have an incremental manufacturer cost of $2 and an incremental retail cost of $4. Assuming one half of current fans have low efficiency motors, the average incremental cost would be $2.

Figure 6: Fan Performance as a Function of Retail Cost (26 fan sample)

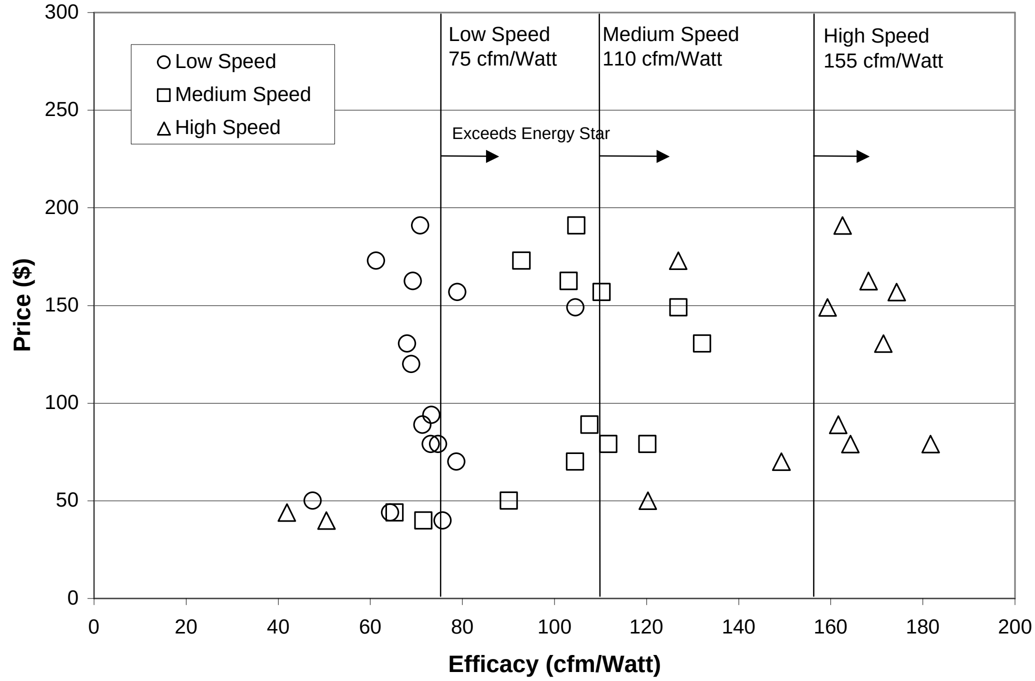
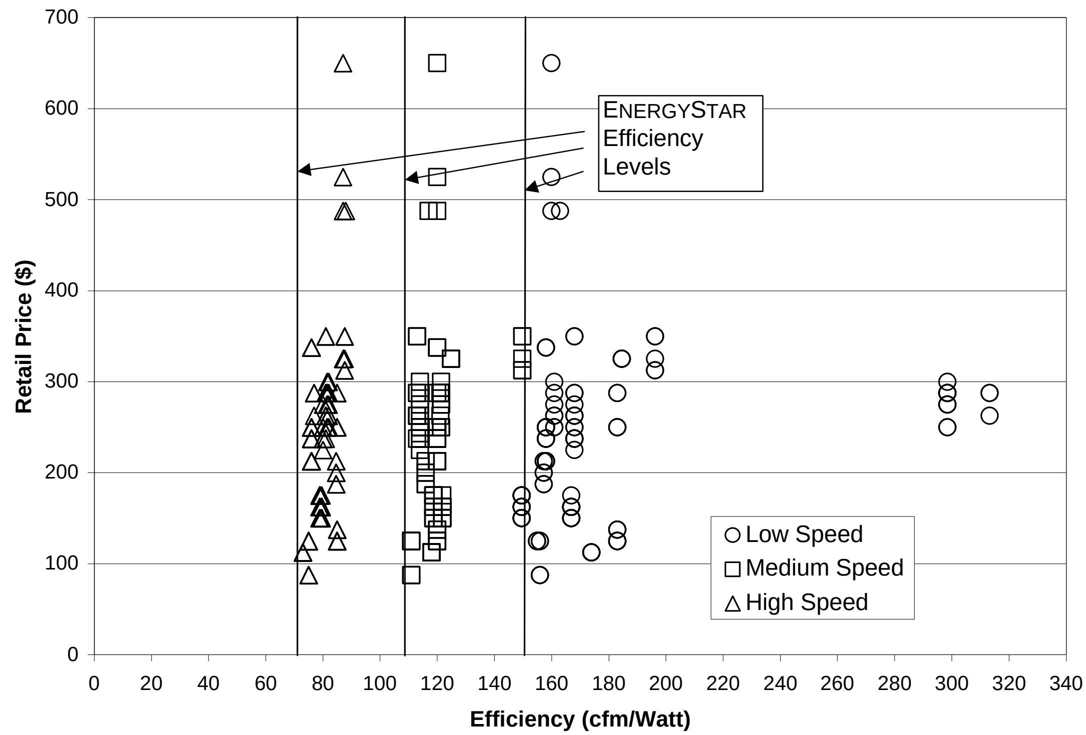


Figure 7: Fan Performance as a Function of Retail Cost (Energy Star listed fans)



5.2 Design Life

The range of life expectancy for a ceiling fan is 7 to 18 years (Appliance 2001). An average 13-year life expectancy was assumed based on the average of these values. CFL lifetimes average over 6,000 hours and with lights used less than one hour per day, the CFLs will outlast the ceiling fan.

5.3 Life Cycle cost

The life cycle cost for ceiling fan efficiency measures is provided in Table 5, and was calculated using the standard California Energy Commission methodology.

Table 5: Analysis of Customer Net Benefit

Measure	*Design Life (years)*	*Annual Energy Savings (kWh)*	*Present Value of Energy Savings**	*Incremental Cost*	*Net Customer Present Value***
Fan	13	4.3	$4	$2	$2
Lighting	13	30	$28	$22	$6

*Present value of energy savings calculated using a Life Cycle Cost of $0.931/kWh (CEC 2001).
**Positive value indicates a reduced total cost of ownership over the life of the appliance

6 Acceptance Issues

6.1 Infrastructure Issues

Ornamental fans may have difficulty meeting the standard as they have very poor air flow efficiency, so manufacturers will likely have to change the blade design to be more functional. For non-ornamental fans, the major change will be the motor specification, since many of the qualifying fans have a similar blade design to those not meeting the standard. Upgrading motor efficiency and tuning the blades should not affect the manufacturing process since small, efficient motors are widely available. Moving to efficient lighting may not be as easy for manufacturers. They have been slow to ramp up new models with dedicated ballasts and pin based lamps, in part because the technology is unfamiliar to them and often requires partnering with Energy Star fixture manufacturers. Manufacturers are also uncertain about the degree of customer acceptance of CFLs in lieu of decorative incandescent lamps.

6.2 Existing Standards

The Maryland Energy Efficiency Standards Act was passed by the Maryland legislature in 2003 but vetoed by the governor and then subsequently overridden in January, 2004. It requires that all ceiling fans must meet Energy Star Tier I criteria. The lighting criteria will not go into effect until January 1, 2008. Similar legislation came close in several other states in 2003 and will be on the docket in many states in 2004. The motors used in ceiling fans are too small to be covered by the Energy Policy Act of 1992 (EPACT).

7 Recommendations

7.1 Recommended Standards Options

The number of Energy Star compliant ceiling fans has been steadily increasing since the initiation of the program. Given this increasing interest among manufacturers, it would be prudent for California to accelerate this trend by adopting a test and list requirement. The data gathered from testing and listing can provide the basis for a future air movement performance standard.

In addition to the test, list, and label approach, California could establish a standard equivalent to the Tier I Energy Star level. Such a performance standard would impact the widely available, low quality ornamental fans currently on the market and, for non-ornamental fans that do not comply with the Tier I levels, there may be a small incremental cost involved to achieve compliance. California could also establish a standard requiring the use of energy efficient compact fluorescent lighting in ceiling fan lighting. However, due to the very limited hours of operation shown for the fan and lights in California, the net customer present value is marginal and we do not recommend a standard at this time. In the future, the rapidly declining cost of CFLs relative to the $24 incremental cost assumed in this analysis, may allow this recommendation to be revisited, despite the estimated relatively low hours of use. Further work should be done to determine if the RLW monitoring data generated during the energy crisis of 2001 is anomalous. If California annual operating hours are closer to national averages, a standard for the fan and the light could very well be justified.

7.2 Proposed Changes to the Title 20 Code Language

The following data is recommended for section Table U in section 1606:

- Airflow at high, medium, and low speed.
- Power use at high, medium, and low speed.
- Airflow efficiency in cfm/Watt at high, medium, and low speed.
- Type of lighting (incandescent, fluorescent, other, none).

The following standards language is recommended for section 1607:

Section 1607. Marking of Appliances.
(c) **Exceptions to Subsection (b)**.

(4) For ceiling fans, the following information shall be permanently, legibly, and conspicuously displayed on an accessible place on the unit's packaging:

- Airflow at high, medium, and low speed.
- Airflow efficiency in cfm/Watt at high, medium, and low speed.

8 References

Appliance, 2002: *Appliance*, September 2002, 25th Annual Portrait of the U. S. Appliance Industry.

Ashley J., 1984. Hangar Destratification Investigation, N-1692, Naval Civil Engineering Laboratory, Port Hueneme, California 93043.

ASHRAE, 1997. Chapter 8 of ASHRAE Fundamentals. Atlanta, GA.

California Energy Commission, 1991. California Energy Demand 1991-2011: Vol I.: Revised Electricity Demand Forecasts. P300-91-023.

California Energy Commission (CEC), 2001. *2001 Update, Assembly Bill 970 Appliance Efficiency Standards Life Cycle Cost Analysis*. P400-01-028, Table 12A. Sacramento, CA. California Energy Resources Conservation and Development Commission.

Calwell, C. and N. Horowitz, 2001. "Ceiling Fans: Fulfilling the Energy Efficiency Promise". Home Energy Magazine. Jan/Feb 2001. pp 24.

EIA 2001. Residential Energy Consumption Survey. Energy Information Administration.

James, P., J. Sonne, R. Vieira, D. Parker, and M. Anello (1996). Are Energy Savings Due to Ceiling Fans Just Hot Air? FSEC-PF-306-96, Florida Solar Energy Center, Cocoa, Florida.

Pacific Gas and Electric Company, 1994. Residential Energy Survey.

RLW Analytics, 2002. Statewide Investor Owner Utility Ceiling Fan Study: Final Report. Prepared for San Diego Gas and Electric Company.

Rohles, F.H. 1980. The preferred indoor comfort temperatures. Report #80-02. Institute for Environmental Research, Kansas State University, Manhattan, KS.