Measured Ceiling Fan Performance and Usage Patterns: Implications for Efficiency and Comfort Improvement

Authors

Jeff Sonne and Danny Parker

Original Publication

Sonne, J. and Parker, D., 1998, "Measured Ceiling Fan Performance and Usage Patterns: Implications for Efficiency and Comfort Improvement," Presented at the 1998 ACEEE Summer Study on Energy Efficiency in Buildings, Vol. 1, pp. 335-341.

Publication Number

FSEC-CR-1770-98

Measured Ceiling Fan Performance and Usage Patterns: Implications for Efficiency and Comfort Improvement

J.K. Sonne, and D.S. Parker, FSEC, Cocoa, FL

ABSTRACT

Simulations suggest residential cooling energy use can be reduced up to 15% through the use of ceiling fans with thermostat set-up. However, monitoring data from a large scale study of Florida homes found that air conditioning consumption was not lower because thermostats settings were not raised in response to fan use, and many fans were apparently left on for long periods in unoccupied zones. To further study these findings, we collected field data on actual ceiling fan usage patterns and how they might be affected by education. We also studied power characteristics and air moving efficiency of current generation ceiling fans and a prototype improved fan.

Field tests were performed in two occupied Miami homes. Time-of-use loggers were installed on the five ceiling fans in each home and left in place for a year. In one household, no specific information was given on recommended fan operation; in the other, members were informed about the best operation strategy. Monitoring revealed large differences in fan energy use; the informed household used approximately 175 kWh per year to operate fans (average 2.7 hours on per day per fan) as opposed to 810 kWh in the uninformed home (12.6 hours per day per fan).

Secondly, a test room was set-up where ceiling fan power use, rpm and airflow underneath the fan could be measured. Three ceiling fans of various types were evaluated. Results revealed a) power use of the fans varied from 7 - 93 W depending on model and motor speed and b) measured air velocity profile dropped off sharply beyond the fan blade diameter. Using measured performance, we estimated the combined motor and fan efficiencies at less than 5%.
However, the prototype improved fan showed a significant air velocity to power use ratio improvement.

Our results indicate significant potential benefits from consumer education as well as a large potential for improvement of ceiling fan efficiency.

Introduction

Simulations have shown that energy savings from using ceiling fans efficiently can be significant. Raising thermostats 2°F while using ceiling fans can save approximately 15% of cooling energy use while still allowing occupants to maintain the same level of comfort (James et. al. 1996). However, monitoring data from a large scale study of Florida homes found that air conditioning consumption was not lower because thermostats settings were not raised in response to fan use, and many fans were apparently left on for long periods in unoccupied zones (Florida Power and Light 1995). To further investigate these findings, for this study we collected field data on actual ceiling fan usage patterns and how they might be affected by education. We also studied power use and air moving efficiency of current generation ceiling fans as well as an aerodynamically optimized prototype design for more efficient operation.

Methodology

Field Monitoring

Field ceiling fan tests were performed in two occupied Miami homes. The first home is a typical 1,500 square foot existing home with two adults and a ten-year old boy (*uninformed* house). Generally, the family is indifferent to most issues affecting energy use. The second is a 1,600 square foot home occupied by two adults, with at least one being very knowledgeable in issues affecting energy use (a former utility employee) and also very familiar with how ceiling fans should be operated to provide maximum benefit (*informed* house). Time-of-use loggers were installed on the five ceiling fans in each home and left in place for a year, from August 1996 to August 1997, before data were collected.

Test Laboratory

A test lab was set-up with which ceiling fan power use, rpm and airflow could be measured. A digital hot wire anemometer (with an accuracy of 0.05% of full scale reading) was mounted on a tripod to take air velocity measurements. A precision digital watt meter (with a resolution of 0.1 W) was used to measure power consumption, and a hand-held infrared tachometer was used to measure ceiling fan speed (rpm). Finally, a small motor dynamometer was used to measure motor efficiency. The ceiling fans were each mounted in turn at the same location in a large open room with approximately nine foot ceilings (106.5").

Three commercially available ceiling fans were acquired for comparative testing; efforts were made to use commonly available fans for the tests. One of the fans (Fan 3), marketed as a high quality unit, was recently rated as one of the best ceiling fans in terms of air moving ability in a recent issue of a consumer guide magazine (Consumer Reports 1997). The two other commercially available fans consisted of a lower cost model (Fan 1) and a more expensive 5-bladed fan (Fan 2) which uses a larger motor (similar in size to Fan 3) designed to move more air. Fan 1, at $70, represents a very large part of the current ceiling fan market. It uses four blades and an inexpensive 50 watt shaded pole induction motor. Fan 4 is a prototype improved blade design developed by FSEC and Aerovironment, Inc. Aerodynamically optimized by numerical simulation, the propeller blade includes a true airfoil, taper and twist to maximize airflow and air moving efficiency.[1]

The fan blades were identical for all 3 commercially available fans and represent the standard design within the industry. The blades are flat, generally rectangular and rounded at the corners with a width of 5" at the blade root up to 5 1/2" at the tip and length of 20 inches. The blade area is approximately 103 square inches each. They are made of a painted wood composite and each had a measured weight of 329 grams, with mounting hardware. The blades have a nominal tilt of 12.5 degrees although we measured only an 8 degree pitch on our test bench. The twisted blade of the prototype varies in pitch over its chord length from 26° at its root to 7° at the tip.

The fans were mounted using existing hardware as it came out of the box. Each fan came with a 3" down rod which connects the fan motor to the mounting bracket, giving a ceiling to blade tip distance of about 9 1/4". The air flow measurements were made underneath the blades at vertical distances of 43" from the floor to conform with ANSI/ASHRAE Standard 55-1992, and 54 1/4" from fan blades (American Society of Heating Refrigeration and Air-Conditioning Engineers Inc. 1992). Air flow measurement

---

[1] At the time of writing, the advanced design has two patents pending and is scheduled for commercial production in 1999.

stations were established by marking off 12 stations starting directly below the centerline of the fan and going out at six inch increments from the centerline. Since the fan blade has a diameter of approximately 52", the first six stations comprise the locations which cover the blade sweep; the remaining six stations (3 to 5 1/2 ft. from the fan centerline) represent the fan air entrainment zone. Figure 1 shows the experimental set-up.

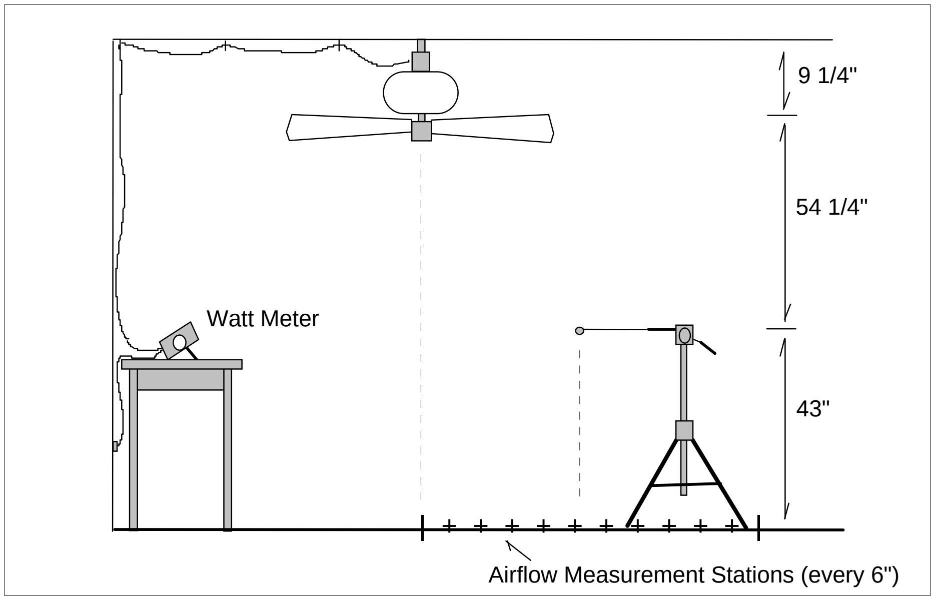

Figure 1. Test lab experiment set-up.

Testing was done by mounting each fan in turn and evaluating:

- Air velocity (m/s)
- Power (W)
- Speed (rpm)

Air velocity was measured at each of the air flow stations with the fan on low, medium and high speed. Two repetitions of each measurement were made. The measured velocities between each measurement station were multiplied by the corresponding area (m^2) to yield a volumetric flow (m^3/s). The flows were then summed to include contributions from all flow stations extending out to three feet from the fan center (beyond this point, air velocities below all fans dropped to background values of <0.1 m/s) to give total cubic feet per minute (cfm). An efficiency index was produced by dividing the total airflow of each fan by the measured motor wattage (cfm/W).

Results

Field Monitoring

Field monitoring revealed large differences in fan use. The average ceiling fan was on for 12.6 hours per day in the *uninformed* household and 2.7 hours per day in the *informed* home. Even though only a case study, the 12.6 average hours measured in the *uninformed* home matches well with the reported mean hours of ceiling fan operation of 13.4 hours per day from the previously noted large scale Florida study. Table 1 compares fan use in the two houses.

Table 1. Measured Ceiling Fan Use

Fan Location	Uninformed (hrs/day)	Informed (hrs/day)
Dining Room	16.7 hrs.	0.3 hrs.
Living Room	4.4 hrs.	2.1 hrs.
FL Room/Den	3.1 hrs.	1.1 hrs.
Master Bedroom	15.7 hrs.	8.6 hrs.
Bedroom #2	13.2 hrs.	1.2 hrs.
Average/hrs/day	12.6 hrs.	2.7 hrs.
Average/day/person	4.2 hrs.	1.3 hrs.

Even when normalizing for the fact that another person lives in the *uninformed* house, the number of hours per occupant that the ceiling fans are operated is more than three times as great as in the *informed* house. This indicates that diligent operation of ceiling fans can make a large difference in the number of hours fans operate.

It is informative to examine the usage pattern of the ceiling fans in the master bedroom in particular. Figures 2 and 3 show the master bedroom ceiling fan use profile of the *uninformed* and *informed* residences respectively over the one year study span. The ceiling fan in the *informed* household is very regularly operated during evening and nighttime hours to provide sleeping comfort and switched off during daytime hours. The data shows the fan was only off during evenings and nighttime when the occupants were obviously away from home (all fans were off) or during winter months. On the other hand, the ceiling fan in the master bedroom of the *uninformed* home is on nearly as much during the daytime hours as during the evening and nighttime. Much of the ceiling fan "off-time" in the *uninformed* household is during the winter months.

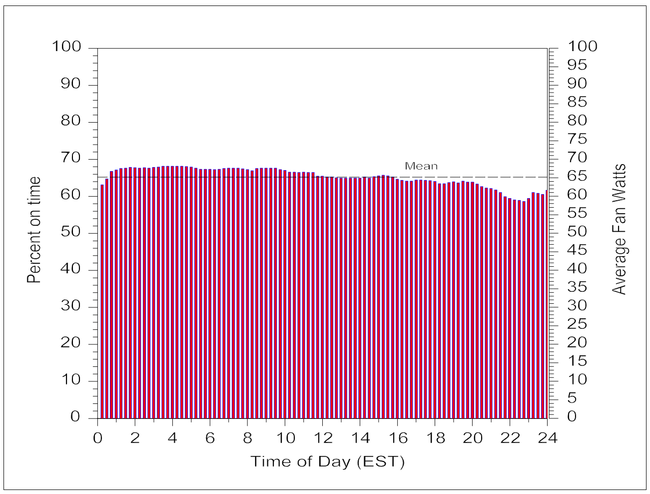

Figure 2. Master bedroom ceiling fan on-time in uninformed house.

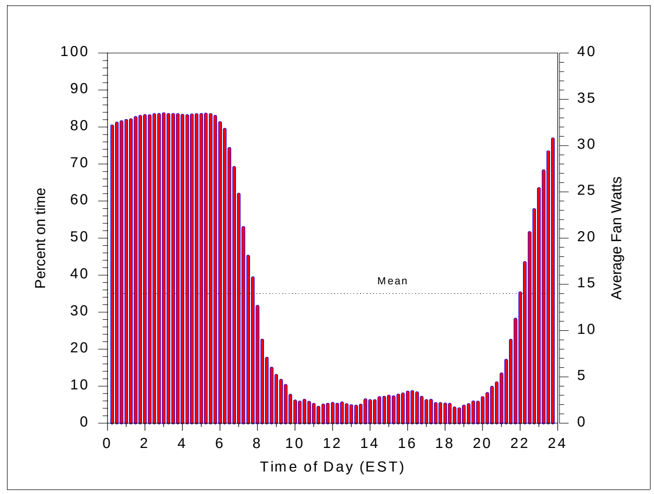

Figure 3. Master bedroom ceiling fan on-time in informed house.

We did not measure the power use of each fan. When audited however, we found that all of the fans in the *uninformed* household were set to the medium speed with all of them operating. Only one fan was found operating in the *informed* household during the audit; it was also set to medium speed. Based on a number of ceiling fan tests, we know that medium fan speed typically results in a power draw of 25 - 50 W. Using 35 W as the average, this would indicate that ceiling fans in the *uninformed* household use 809 kWh/year verses 175 kWh/year in the *informed* home. There are also large differences in air conditioning energy use in the two households, but there are many other factors contributing to the differences to the extent that attribution to ceiling fan use patterns would be misleading. Total annual electricity use for the study period in the *uninformed* household was 18,538 kWh with ceiling fans making up 4.4% of the total use. Annual electricity consumption in the *informed* house for the same period was 13,259 kWh with ceiling fans representing only 1.3% of the total.

Laboratory Test Results

Table 2 shows laboratory tested fan performance at low, medium and high speeds. The index is an efficiency measure derived by dividing airflow by power use.

Table 2. Comparative Fan Performance and Efficiency

	Fan 1	Fan 2	Fan 3	Fan 4
Low Speed				
Airflow (cfm)	1087	1001	1866	1907
Power (Watts)	9.6	7.7	8.7	9.1
Index (cfm/W)	113	130	214	210
Medium Speed				
Airflow (cfm)	2476	2649	3664	4702
Power (Watts)	24.3	32.1	26.6	24.5
Index (cfm/W)	102	83	138	192
High Speed				
Airflow (cfm)	3110	6057	5339	6471
Power (Watts)	50.2	93.1	74.8	49.6
Index (cfm/W)	62	65	71	131

Power use of the fans for all speeds varied from 7.7 - 93.1 Watts. At low and medium speed, all four fans have fairly similar power use, averaging 8.7 W at low speed and 27.7 W at medium speed. At high speed, average power use is 72.7 W, but use is much more varied, ranging from 49.6 W (Fan 4) to 93.1 W (Fan 2). Each fan has the highest efficiency index at low speed and lowest index at high speed. Fan 3 consistently has the highest index of the 3 commercially available fans. However, except when compared to Fan 3 at low speed, our advanced design (Fan 4) consistently had the highest indexes – from 1.4 to 2.3 times those of the other fans, indicating that it was approximately twice as efficient as the conventional designs in moving air. Figure 4 graphically summarizes the performance of the four fans at high speed.

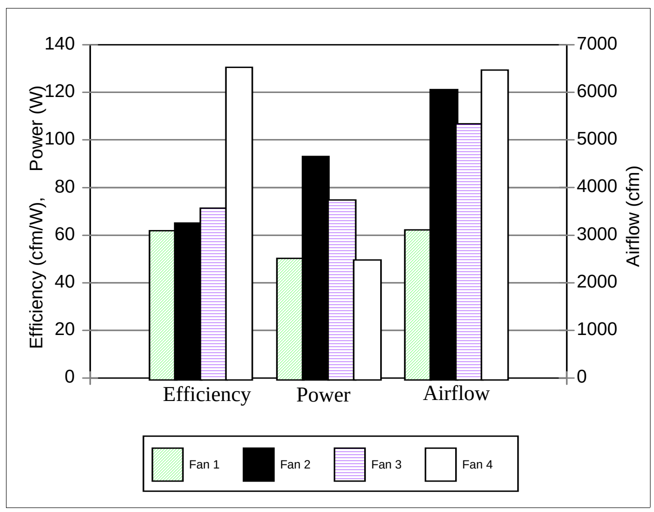

Figure 4. Fan performance at high speed.

The motor dynamometer gave motor-only efficiencies of 3.5% at low speed and 12% at high speed (watts input to shaft power). Using measured performance, we estimate the combined motor and fan efficiencies at less than 5% for the conventional fans and roughly twice this efficiency for the improved prototype.

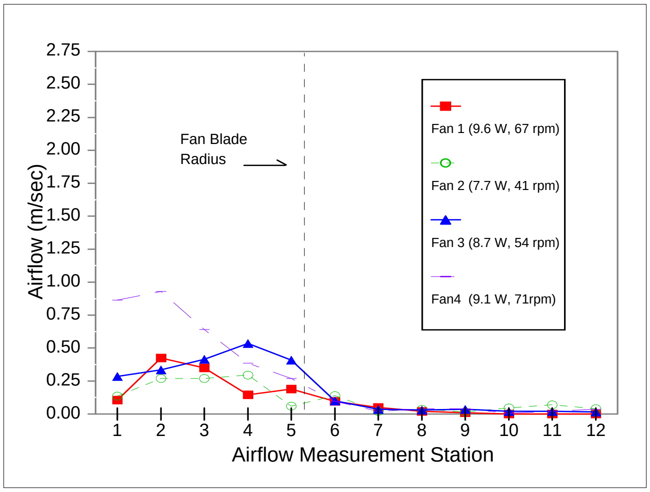

Figure 5. Airflow performance of fans at low speed.

Figures 5, 6 and 7 show the measured air velocities over the measurement area for the four fans at low, medium and high speed respectively. The legend provides motor power consumption and fan rpm. The plots show that all the fans only provided good air flow (>0.50 m/s) over the radius of the fan blades (the blades extend to between stations 5 and 6) and velocities are essentially negligible as measurement station seven is reached.

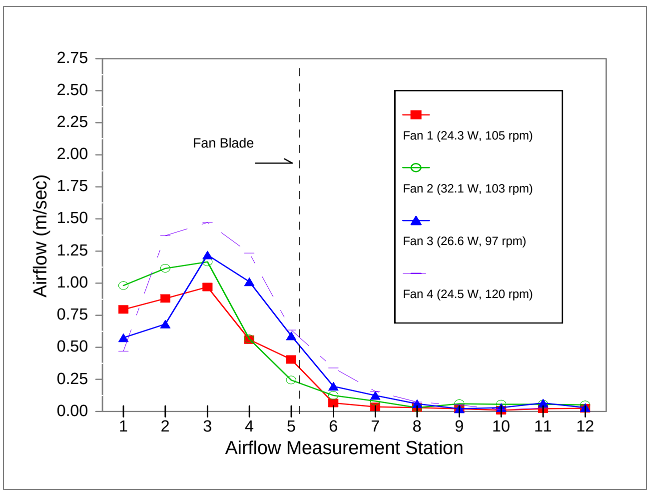

Figure 6. Airflow performance of fans at medium speed.

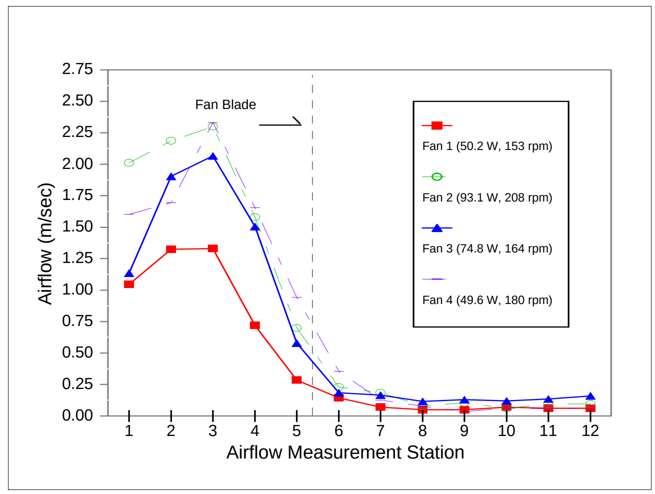

Figure 7. Airflow performance of fans at high speed.

Conclusions

The field monitoring work indicates significant potential benefits from consumer education on ceiling fan use. We are looking to expand the study next year with possibly as many as ten homes being monitored to further verify these results and develop fan use education methods.

The lab tests indicate a large potential for improvement of fan efficiency, as evidenced by the significantly improved performance achieved by FSEC's prototype. Also, considering the significant drop in air velocities past the ends of the fan blades, larger fan blades are recommended to increase airflow coverage (especially since furniture is often located near walls away from the center of rooms). This recommendation is supported by a previous study assessing ceiling fan impact on comfort (Rohles et. al. 1983).

References

ASHRAE. 1992. *ASHRAE Standard 55-1992: Thermal Environmental Conditions for Human Occupancy*. Atlanta, Georgia: American Society of Heating, Refrigeration and Air-Conditioning Engineers, INC.

"Stirring Up a Breeze." *Consumer Reports*. 1997. July.

Florida Power and Light. 1995, Present *New Home Construction Research Project Findings, Results and Recommendations: Final Report* ed to the Florida Public Service Commission. Miami, Florida: Florida Power and Light Company.

James, P., J. Sonne, R. Vieira, D. Parker, and M. Anello. 1996. "Are Energy Savings Due to Ceiling Fans Just Hot Air?" In Proceedings of the ACEEE Summer Study on Energy Efficiency in Buildings, 8:89-93 Washington D.C.: American Counsel for an Energy-Efficient Economy.

Rohles, F., S. Konz and B. Jones. 1983. *Ceiling Fan as Extenders of the Summer Comfort Envelope*, ASHRAE Transactions. 89: Pt. 1A. Atlanta, GA.: American Society of Heating, Refrigeration and Air Conditioning Engineers.