PERFORMANCE AND APPLICATIONS OF GOSSAMER WIND™ SOLAR POWERED CEILING FANS

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ABSTRACT

Research has shown that highly efficient solar powered ceiling fans improve thermal comfort and potentially provide health benefits when air conditioning or conventional ceiling fans are not available, such as during the 2003 summer heat waves in Europe, and in many undeveloped areas of the world. Ceiling fans can improve the spatial effectiveness of heating, ventilation and air conditioning (HVAC) systems. They can reduce air conditioning energy use if occupants increase thermostat set-points and reduce frequency of operation, and if waste heat from the fan motor is minimized.

This paper introduces a solar powered ceiling fan that utilizes Gossamer Wind™ improved blade technology and an efficient direct current (DC) motor. The Florida Solar Energy Center compared airflow and air velocity of Gossamer Wind Solar Powered (GWSP) fans. Three- and four-blade configurations were tested. GSWP fans were also connected to solar panels and tested. The potential uses of GWSP fans in dwellings, schools, warehouses, agricultural and livestock applications are discussed.

KEYWORDS

ceiling fans, air velocity, energy efficiency, thermal comfort

INTRODUCTION

Ceiling fans provide a cooling breeze, reduce temperature stratification and improve thermal comfort. Ceiling fans save energy in homes by improving thermal comfort, which results in changes to the thermostat set-point or reduced use of air conditioning.

Thermal Comfort

Since ceiling fans increase air velocity they can provide improved comfort to occupants. If the air is too hot and dry, however, such as in arid desert climates, increased air velocities can cause overheating. Research analysis based on Fanger's thermal comfort equation shows that at 60 percent relative humidity, 90 percent of people would be just as comfortable if the air dry bulb temperature were raised from 79.2^o to 82.5^o F (26.2 to 28.6 C) if air speed was also increased from still air to a velocity of 150 feet per minute (fpm), (0.76 meters per second m/s). At 80 percent relative humidity, 90 percent of people would also be as comfortable if set-points were raised from 77.9^o F to 81.8^o F (22.5 to 27.7 C) while similarly increasing air speeds. People can generally perceive air velocities over their skin of 0.3 m/s.

Gossamer Wind™ Blade Technology

In 1998, researchers at the Florida Solar Energy Center (FSEC) developed and tested new aerodynamically improved blade designs on alternating current (AC) powered residential and commercial ceiling fans. These fans, manufactured by Hampton Bay, are now commercially available throughout the United States. The new blade design referred to as Gossamer Wind provides 40 percent higher airflows without increasing energy use. Waste heat from paddle blade type ceiling fan motors, contributes greatly to increases in air conditioner usage and are noisier when compared to Gossamer Wind ceiling fans.

Solar Powered DC Ceiling Fans

In 2002, Gossamer Wind technology was combined with efficient DC motors resulting in commercially available Gossamer Wind Solar Powered (GWSP) ceiling fans. Previous GWSP research by the authors compared preliminary bench test results for energy efficient AC and DC conventional and Gossamer blade ceiling fans, and looked at GWSP cost, energy savings and economics. The research confirmed GWSP performance over a typical residential 120 volt alternating current (VAC) “paddle-fan” blade design with typical AC motors providing 60-70 cubic feet per minute (CFM), (28-33 liters per second l/s), per watt on high speed and 100-200 CFM (47-94 l/sec) per watt on low speed.

GSWP technology connected directly to photovoltaic (PV) panels combine energy efficiency, simple engineering and variable control. When more solar energy is available, the fan produces higher airflow. GSWP fans connected directly to PV panels are well suited for schools, medical clinics, commercial and institutional buildings, beach cabanas and other daytime applications.

Battery-tied, direct DC systems eliminate inverter losses associated with AC ceiling fans, and allow for nighttime usage. GWSP technology is very cost-effective especially for off-grid PV structures, where the utility grid connection is too expensive or unavailable.

Since 1989, RCH Fanworks has sold thousands of DC powered ceiling fans using conventional paddle blades. These fans have been installed throughout the world predominately in off-grid applications in tropical climates. In the last two years more than 400 GWSP ceiling fans have been installed and RCH Fanworks’ customers have noted a significant performance improvement over the DC paddle fans.

TEST DESCRIPTION

In 2004, the authors conducted GWSP fan testing at FSEC. Tests were conducted on a commercially available DC powered ceiling fan manufactured by RCH Fanworks, which employs Gossamer Wind technology. The fan blade span including the hub is 58 inches (147 centimeters cm).

The objectives of the tests were to evaluate rotations per minute (RPM), airflow and energy consumption at various voltages and fan blade configurations. Tests were conducted on the three- and four-blade fans using a 9 volt direct current (VDC), 14 VDC and 24 VDC power supplies. The three-blade Vari-Cyclone fan was also tested connected to 10 watt and 25 watt PV panels. The 25 watt PV panel is a prototype selected to better match the PV fan motor performance. These PV tests were conducted on sunny days at noon (965 watts per square meter W/m2) and late afternoon hours (350-375 W/m2), under typical June weather conditions for Florida. Commercially available testing equipment used included: a hot wire anemometer to measure air velocity, a hand-held laser RPM meter to measure fan rotation, a volt/amp meter to measure DC electricity, and solar pyranometers to measure solar insolation.

MEASUREMENT RESULTS:

Air velocity tests were conducted in accordance with American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55-1981. Measurements were taken 53 inches (135 cm) from the fan and 43 inches (109 cm) above the floor. Measurements were taken three times at each station and averaged. Measurements were taken at nine points from directly under the hub to 48 inches (122 cm) away. Figure 1 provides the air velocity measurement at various stations for three- and four-blade fans with various power sources. The three-blade fan on a 24 volt power supply produced the highest velocities, in the 1.6 to 1.8 m/s range below the fan hub, with airflows still perceptible as far as 2.5 feet (76 cm) from the hub. The 12 volt and 9 volt power supplies provided the maximum velocities, in the range of 0.8-0.9 m/s, with perceived velocities within 1-1.75 feet (30-46 cm) from the hub.

Fig. 1 - Ceiling Fan Velocity Profile

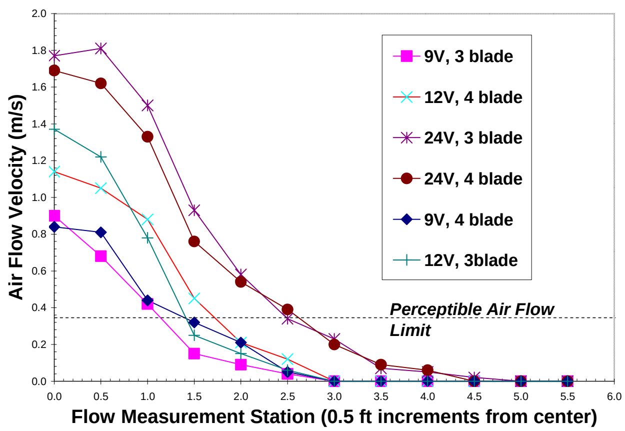


Table 1 provides the average and maximum velocity, total flow rates, watts and RPM for three- and four-blade models with 9, 12 and 24 volt power supplies. The average airflow presented is computed by averaging between the test points and computing the varying velocities across the positive flow zone created by the fan. The maximum velocity and RPM is highest for the three-blade fans, however the average velocity and computed CFM is higher on the four-blade configuration when the 9 and 12 volt power supplies are used. This indicates that the four-blade arrangement may provide better flow at lower power (smaller PV panel) and with larger PV systems under cloudy conditions.

Table 1
3 & 4 Blade Fan Performance with 9, 12 & 24 VDC Power Supply

Fan Type	**9V, 3 blade**	**9V, 4 blade**	**12V, 3 blade**	**12V, 4 blade**	**24V, 3 blade**	**24V, 4 blade**
Average Velocity (m/s)	0.19	0.22	0.32	0.32	0.61	0.56
Maximum Velocity (m/s)	0.90	0.84	1.37	1.14	1.81	1.69
Total CFM	852	1221	1476	1820	3925	3600
Total l/s	402	576	697	859	1853	1699
Total Watts	1.62	1.69	4.09	4.11	12.9	14.6
RPM	75	66	102	83	138	117

Table 2 shows the performance of the three-blade fan connected to the 25 watt and 10 watt PV panels. The panels were exposed to insolation at 5 p.m. and noon. The best fan performance was the 25 watt PV panel operating at noon, which provided 22.9 volts at 0.53 amps or 12.14 watts. Under this condition the fan ran at 135 RPM and provided a maximum velocity of 1.77 m/s directly below the hub. This configuration at 5 p.m. ran the fan at 123 RPM and provided a velocity of 1.4 m/s. The lowest fan performance was from the 10 watt PV panel running at 5 p.m., which provided 104 RPM and 1.3 m/s of maximum velocity.

Table 2
PV Powered Fan Performance

PV Watt Time-PM	Speed (RPM)	Power (Volts)	Current (Amps)	Energy (Watts)	Velocity (m/s)	RPM /Watt	m/s /Watt	Solar W/m2
10PV-12	108	16.2	0.35	5.67	1.45	19.05	0.26	965
25PV-12	135	22.9	0.53	12.14	1.77	11.12	0.15	965
10PV-5	104	14.3	0.31	4.43	1.3	23.46	0.29	351
25PV-5	123	18.7	0.42	7.85	1.4	15.66	0.18	351

Evaluation of Fan Laws:

The fan laws represent how performance varies when one of the operating conditions is changed. The following laws apply when the same fan in the same circumstances is operated at a different power level by changing the voltage applied. Eqns. 1 and 2 were applied to the maximum and minimum conditions. Applying Eqns. 1 and 2 to both RPM and velocity data yields comparable agreement:.

Eqn. 1: $$RPM_1/RPM_2 = Velocity_1/Velocity_2 = Q_1 / Q_2$$

Eqn 2: $$Power_1/Power_2 = (Watt_1 \cdot \eta_2)/(Watt_2 \cdot \eta_1) = (RPM_1/RPM_2)^3 = (Velocity_1/Velocity_2)^3 = (Q_1/Q_2)^3$$

Where:
RPM = fan revolutions per minute
Velocity = air velocity
Power = motor shaft power
Watt = Electrical power at motor terminals
η = motor efficiency as loaded
Q = volumetric air flow rate
Subscript 1 designates baseline conditions at 24 volts applied to the motor terminals.
Subscript 2 designates different conditions when 9 volts applied to the motor terminals.

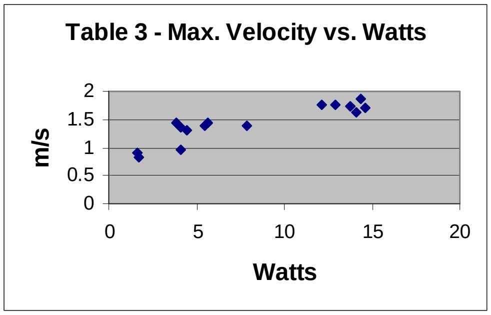
Eqn. 1:

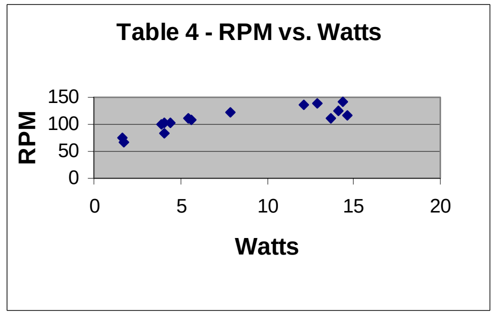
$$138\ RPM_{24v} / 66\ RPM_{9v} = 2.09$$
$$1.81 m/s_{24v} / .84\ m/s_{9v} = 2.15$$
$$2.09/2.15 = 97\%$$

Eqn. 2:

$$12.9W_{24v} / 1.69W_{9v} = 7.6$$
$$(138RPM_{24v}/66RPM_{9v})^3 = 9.1$$
$$7.6/9.14 = 83\%$$
$$12.9W_{24v} / 1.69W_{9v} = 7.6$$
$$(1.81\ m/s_{24v}/0.84\ m/s_{9v})^3 = 10.2$$
$$7.6/10.2 = 75\%$$

Eqn. 2 is applied to all tests shown in Table 1 and 2. Five additional “redundant” tests are not presented. A regression analysis was then conducted and presented in Table 3 and 4. The R-square values are comparable to the ratios in the examples above.





The fan laws would indicate that doubling the flow rate of a fan will increase the required shaft power by about eight times. For example, if flow was 1000 CFM (472 l/s) at 10 watts shaft power, the power expected to reach 2000 CFM (944 l/s) would be 2^**3** x 10 = 80 watts. In the data from the above test reports, velocity at 9 volts is reduced to 46.4 percent of the velocity at 24 volts. 46.4 percent cubed is 10 percent, so by the fan laws you would expect shaft power to drop to 10 percent. Shaft power was not measured but electrical power dropped to 13 percent. You would not expect electric power to drop quite as much as shaft power because motor efficiency is reduced at very low loads. The discrepancy here may be a result of the accuracy associated with the 0.19 amp measurement at 9 volts.

APPLICATIONS:

While GWSP ceiling fans have been used primarily in dwellings and schools to improve occupant comfort, these benefits may also apply in some warehouse applications. GWSP fans connected directly to PV panels are ideal in dwellings where ceiling fans are needed during daytime hours. GWSP ceiling fans benefits may include:

1) Reduced need for air conditioning, resulting in reduced greenhouse gas emissions;
2) Better ventilation and indoor air quality, due to increased mixing of outside air;
3) Health benefits during hot weather and reduced presence of insects that transmit disease;
4) Better air distribution and mixing of ducted HVAC systems;
5) Space heating energy savings, due to reduced temperature stratification.

New potential applications of GWSP ceiling fans for agriculture and livestock offer promise, provided air velocities are within acceptable ranges.

Livestock: The importance of air velocities is species and age dependent. Swine under 8 weeks of age experience slower weight gains and increased disease susceptibility when air velocity is increased from 25 fpm (0.13 m/s) to 50 fpm (0.25 m/s). Chickens benefit at air velocities up to 500 fpm (2.6 m/s) at temperatures from 75° F (24 C) to 95° F (35 C), however high-velocity air at a temperature above chicken feather temperature causes more not less heat stress.

Agriculture: Air speeds of 100 fpm (0.51 m/s) to 150 fpm (0.76 m/s) are considered suitable for plant growth. Greenhouse air circulation maintains suitable levels of carbon dioxide and humidity within the leaf canopy. Air speeds of 6 fpm to 20 fpm (0.03-0.10m/s) are needed to facilitate carbon dioxide uptake. Air speeds in excess of 200 fpm (1.02 m/s) can induce excessive transpiration, cause plant cells to close, reduce carbon dioxide uptake and inhibit plant growth.

CONCLUSIONS:

- Little difference was observed in RPM and velocity between the three- and four-blade fans. The three-blade fan costs less, while the four-blade may be slightly quieter, and provide better air moving performance with smaller PV arrays.
- The maximum performance was achieved at 138 RPM and 1.81 m/s maximum velocity with the 24 volt power supply providing 12.9 watts. The lowest performance was 66 RPM and maximum air velocity of 0.84 m/s, resulting from the 9 volt power supply providing 1.69 watts (8.9 volts at 0.19 amps).
- The 25 watt PV panel at noon under sunny conditions provided 12.14 watts (22.9 volts at 0.53 amps) and ran the fan at 135 RPM and 1.77 m/s.
- As expected, the GSWP fan connected directly to PV panels increased airflow and velocity in concert with solar availability, providing both comfort and energy benefits, assuming that sunshine and outdoor and/or indoor temperature, are related.

FUTURE RESEARCH:

- Demonstrate new applications discussed in this paper.
- Evaluate higher efficiency DC fan motors and PV panels to optimize performance.
- Assess cost effectiveness of optimum PV/motor packages in various applications.
- Evaluate PV powered non-ceiling fan designs in various building applications.

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