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GSA Green Proving Ground Smart Ceiling Fan – White Paper

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GPG
Green Proving Ground Program

The Green Proving Ground program leverages GSA's real estate portfolio to evaluate innovative sustainable building technologies and practices. Findings are used to support the development of GSA performance specifications and inform decision-making within GSA, other federal agencies, and the real estate industry. The program aims to drive innovation in environmental performance in federal buildings and help lead market transformation through deployment of new technologies.

Disclaimer

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I. Project Overview

The U.S. General Services Administration (GSA) - Green Proving Ground (GPG) program evaluates innovative sustainable building technologies and provides recommendations on their deployment. In 2009 GSA's Public Buildings Service published seven cost-effective strategies for energy savings (GSA 2009). On the top of that list was raising the cooling set point by 2°F to 4°F which GSA calculated would save 18.7 million kWh (Appendix A). Installing ceiling fans to produce air movement is one approach to raising the cooling setpoint while maintaining occupant comfort. This white paper explores the energy savings potential of smart ceiling fans and lays out the differences between the smart and standard ceiling fans.

II. Technology

A. OVERVIEW

Ceiling fans are commonly used today in residential applications and sometimes in commercial spaces with high ceilings for destratification, but current use in office spaces is rare. In the past, ceiling fans were common in office spaces but were eliminated from most commercial building spaces with the introduction and wide-spread adoption of air conditioning. However, as large commercial buildings strive for increasing levels of energy efficiency and operational performance, ceiling fans are again being considered as a viable way to save energy by increasing the cooling setpoint temperature while maintaining occupant comfort.

B. TECHNOLOGY ASSESSMENT

Competitive Landscape

The Environmental Protection Agency's ENERGY STAR® Program maintains a list of energy efficient ceiling fans for both residential and commercial applications (EPA 2016). Most of these ceiling fans are simple devices with manual on/off, fan speed, and fan direction controls either through a wall switch, pull chain, and/or a remote control. At least one manufacturer offers a "smart" ceiling fan with built in sensors and programmable intelligence that automatically controls the mode of operation (on/off, fan speed, and fan direction) based on the occupancy and thermal conditions in the space. This smart ceiling fan also has the option of customizing fan speed and temperature control settings and allowing occupants to control the fan speed through a smart phone app. The smart ceiling fan technology has achieved technology readiness level (TRL) 9; meaning the actual system has been proven through successful mission operations. However, the use of smart ceiling fans in traditional office spaces is still a relatively new concept.

Energy Impacts

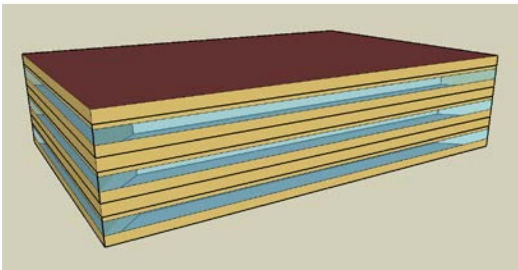
Ceiling fans do not save energy directly; energy savings are entirely dependent on being able to adjust the heating and cooling setpoints. Currently, there are no ceiling fans with the capability of linking to the HVAC system to adjust the setpoints, so space temperature is controlled separately from the fan speed. Energy savings in this report are estimated with whole building energy simulations by adjusting the cooling setpoint incrementally higher over a range of 74°F to 84°F.

The National Renewable Energy Laboratory (NREL) completed EnergyPlus energy simulations in 12 climate zones for the medium and large office DOE reference building models (Deru et al 2012) to estimate the impact on energy consumption with relaxing the cooling setpoint. The 12 selected simulation locations are representative of the locations/climates with significant cooling requirements and where savings may be available using this technology. Climate zones and representative cities are presented in Table 1.

The medium office building model has 3 floors with an area of 53,628 ft^2 (4,982 m^2) and is conditioned with a packaged air cooled chiller serving multi-zone variable air volume (VAV) boxes. The large office building model has 12 floors with an area of 498,588 ft^2 (46,320 m^2) and is conditioned with a water-cooled chilled water system serving multi-zone VAV boxes. Both building models were constructed to meet the minimum efficiency requirements of 90.1-2004 to represent existing buildings. The occupied cooling setpoint was raised in 2°F increments from 74°F to 84°F. The night time cooling set back temperature was maintained at 85°F and the supply air temperature was maintained at 55°F during cooling. Graphical representations of the energy model for medium and large office are presented in Figure 1.

Table 1. Climate Zones and Representative Cities

Climate Zone	Representative City
1A	Miami, Florida
2A	Houston, Texas
2B	Phoenix, Arizona
3A	Atlanta, Georgia
3B	Las Vegas, Nevada
3C	San Francisco, California
4A	Baltimore, Maryland
4B	Albuquerque, New Mexico
4C	Seattle, Washington
5A	Chicago, Illinois
5B	Denver, Colorado
6A	Minneapolis, Minnesota



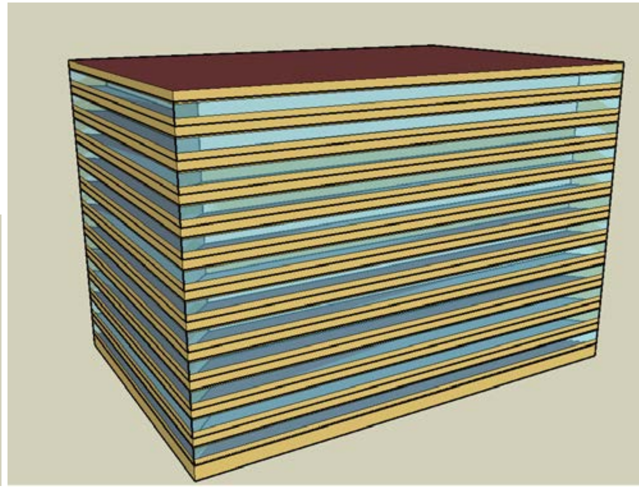


Figure 1. Graphical Representations of Energy Model for Medium and Large Office

The smart ceiling fans considered in this report have 7 fan speeds. It was assumed that they turn on above 74°F and step up one speed for each degree up to full speed above 80°F. Maintaining comfort at 80°F and above was not part of this study but may be difficult to achieve even with the ceiling fan providing air movement. The installed fan power for each speed from the manufacturer is shown in Table 3. The energy consumption for the smart fans is relatively small but was included in the energy simulations.

Table 2. Smart Ceiling Fan Speed and Power by Space Temperature

Air Temperature	Speed	Fan Power (W)	Fan Power (W/ft^2)
>74°F	1	1.5	0.003
>75°F	2	2.7	0.005
>76°F	3	3.6	0.006
>77°F	4	7.4	0.012
>78°F	5	14.1	0.024
>79°F	6	20.2	0.034
>80°F	7	29.2	0.049

The percent savings of total building energy for each building in the 12 climates is shown in Figure 2 and Figure 3. The energy savings per floor area for each building are shown in Figure 4 and Figure 5. The change in energy savings is greatest with the first 4 degrees and is between 1% and almost 3% per degree setpoint change for the medium office building and between 1.5% and almost 3% for the large office building. The energy savings for a 4°F increase in cooling setpoint ranges from 2.4 kBtu/ft^2/yr to 5 kBtu/ft^2/yr in the medium office building and 2.6 kBtu/ft^2/yr to 4.7 kBtu/ft^2/yr in the large office building. The range of savings is very similar for the two buildings, but the order of savings by location changes. The highest energy savings in the medium office building occurs in Phoenix, Houston, and San Francisco; and the highest energy savings in the large office buildings occurs in Baltimore, Seattle, and

San Francisco. The difference in performance by climate was not investigated in this study but is likely caused by differences in building form, cooling systems, and other factors.

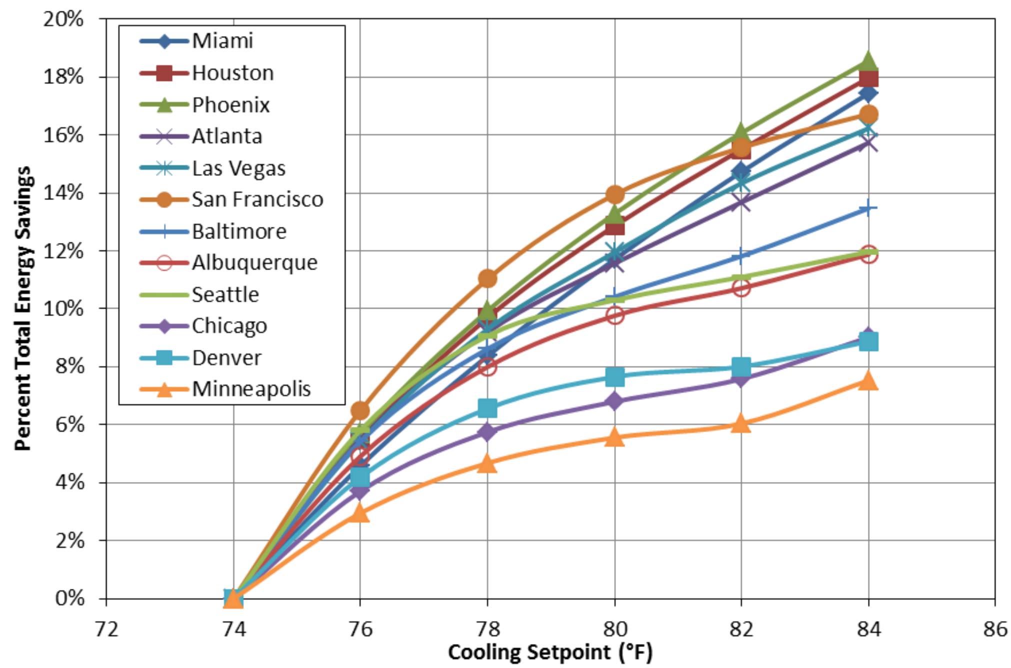


Figure 2. Percent Energy Savings for a Medium Office Building with Relaxed Cooling Setpoints

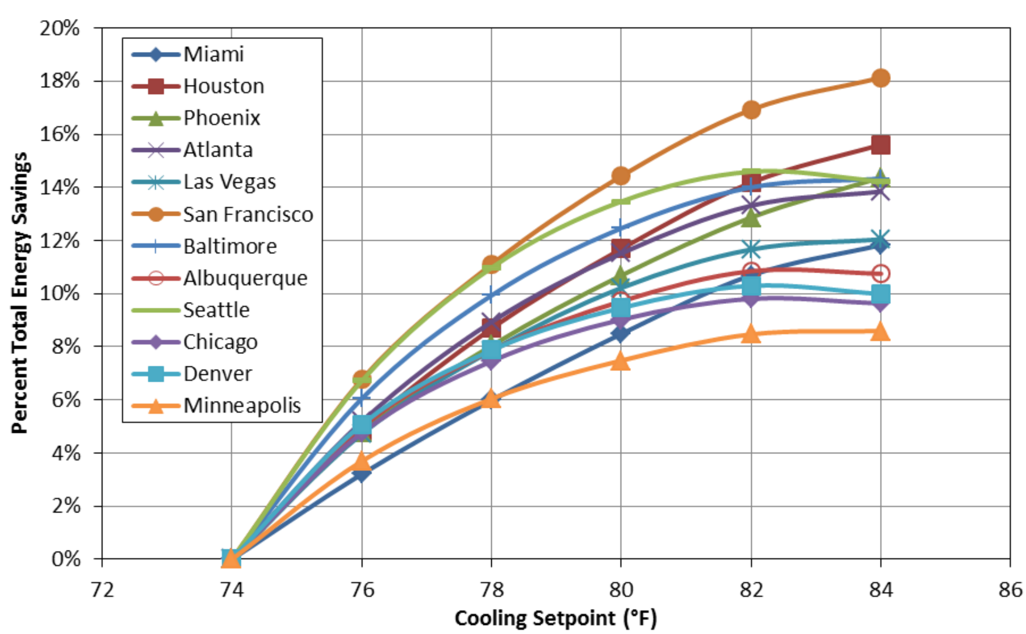


Figure 3. Percent Energy Savings for a Large Office Building with Relaxed Cooling Setpoints

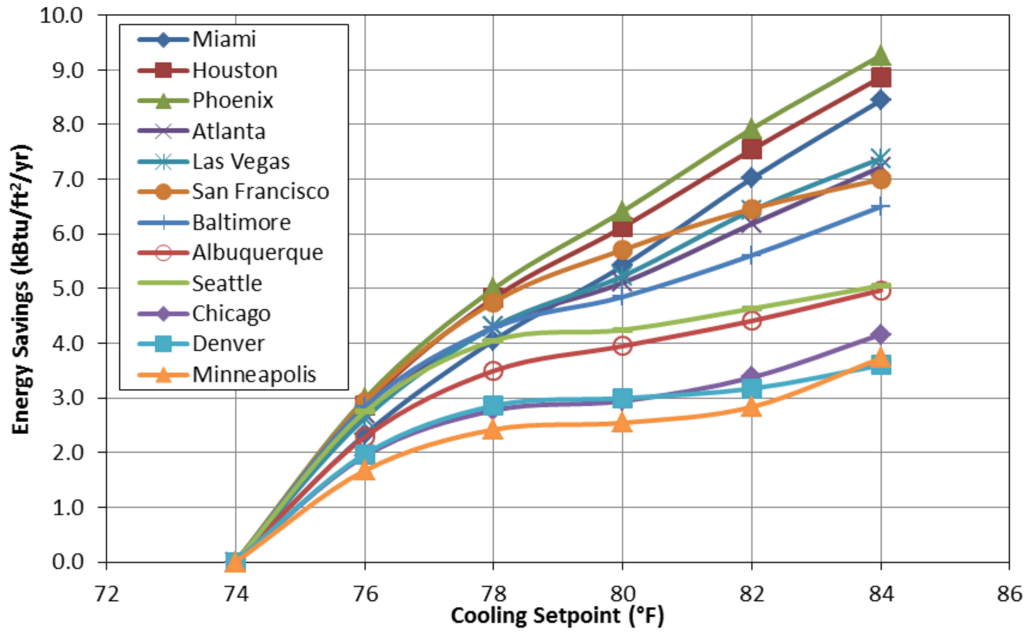


Figure 4. Energy Savings for a Medium Office Building with Relaxed Cooling Setpoints

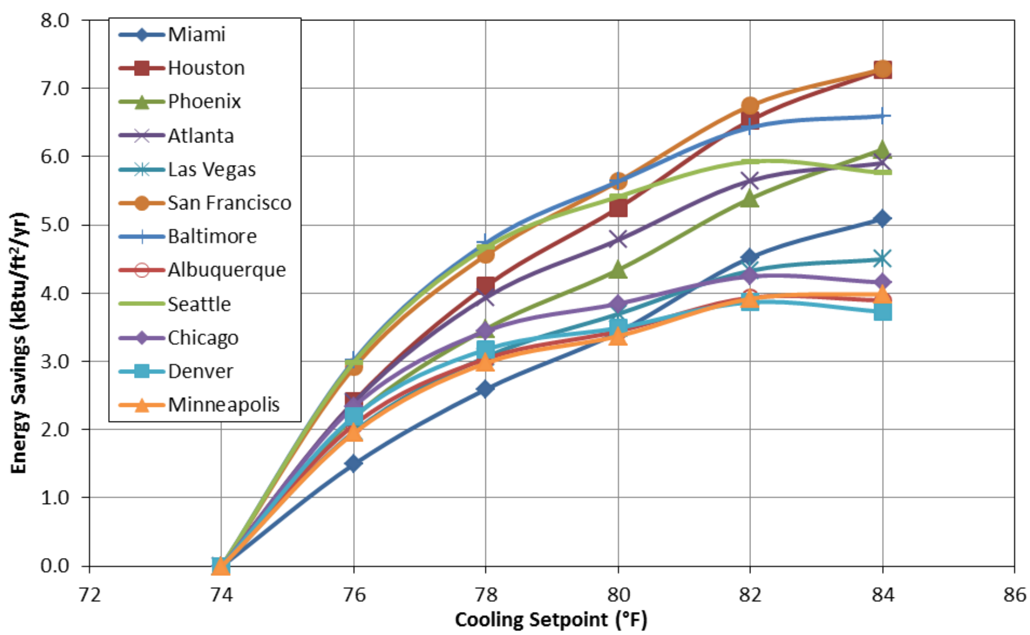


Figure 5. Energy savings for a large office building with relaxed cooling setpoints

Economic Analysis

The energy cost savings and the installed costs were calculated for each site in order to calculate the installed costs requirements to achieve a simple payback of less than 10 years. Energy cost savings were estimated from the annual energy simulations assuming the average commercial cost for electricity for

2014 by state from the Energy Information Administration (EIA) shown in Table 3 (EIA 2016). The results of this analysis for a 4°F increase in the cooling setpoint temperature are shown in Table 4 and Table 5. The estimated energy cost savings for both the medium and large offices are between $0.07/ft^2/yr and $0.22/ft^2/yr. The payback is highly dependent on costs and performance of each application. The estimated maximum installed costs for both the medium and large office buildings are between $0.70/ft^2 and $2.18/ft^2, which corresponds to an installed cost of $280 to $872 (based on a 60" fan covering 400 ft^2). The payback calculations can easily be adjusted for changes in the installed cost and utility rates for particular applications based on the energy savings per square foot.

Table 3. Average Commercial Price of Electricity for 2014

State	City	Average Electricity Price ($/kWh)
FL	Miami	$0.0987
TX	Houston	$0.0816
AZ	Phoenix	$0.1013
GA	Atlanta	$0.1036
NV	Las Vegas	$0.0947
CA	San Francisco	$0.1562
MD	Baltimore	$0.1115
NM	Albuquerque	$0.1027
WA	Seattle	$0.0797
IL	Chicago	$0.0926
CO	Denver	$0.1008
MN	Minneapolis	$0.0985

Table 4. Smart Ceiling Fan Energy Cost Savings and Fan Installed Cost for Simple Payback Less than 10 years for a 4°F Increase in Cooling Setpoint in the Medium Office

Location	Energy Savings ($kWh/ft^2/yr$)	Energy Cost Savings ($\$/ft^2/yr$)	Installed Cost for a 10 year payback ($\$/ft^2$)
Miami	1.19	$0.117	$1.17
Houston	1.41	$0.115	$1.15
Phoenix	1.47	$0.149	$1.49
Atlanta	1.26	$0.131	$1.31
Las Vegas	1.26	$0.119	$1.19
San Francisco	1.39	$0.218	$2.18
Baltimore	1.26	$0.140	$1.40
Albuquerque	1.02	$0.105	$1.05
Seattle	1.19	$0.095	$0.95
Chicago	0.81	$0.075	$0.75
Denver	0.84	$0.084	$0.84
Minneapolis	0.71	$0.070	$0.70

Table 5. Smart ceiling Fan Energy Cost Savings and Fan installed Cost for Simple Payback Less than 10 years for a 4°F Increase in Cooling Setpoint in the Large Office

Location	Energy Savings ($kWh/ft^2/yr$)	Energy Cost Savings ($\$/ft^2/yr$)	Installed Cost for a 10 year payback ($\$/ft^2$)
Miami	0.76	$0.075	$0.75
Houston	1.20	$0.098	$0.98
Phoenix	1.02	$0.103	$1.03
Atlanta	1.15	$0.120	$1.20
Las Vegas	0.90	$0.085	$0.85
San Francisco	1.34	$0.209	$2.09
Baltimore	1.39	$0.155	$1.55
Albuquerque	0.89	$0.091	$0.91
Seattle	1.37	$0.109	$1.09
Chicago	1.01	$0.094	$0.94
Denver	0.93	$0.094	$0.94
Minneapolis	0.87	$0.086	$0.86

Thermal Comfort Impacts

Occupant thermal comfort is defined by ANSI/ASHRAE Standard 55-2013 (ASHRAE 2013). Standard 55 defines comfort ranges for clothing levels, metabolic rates, and environmental conditions defined by the ambient dry bulb temperature, mean radiant temperature, relative humidity, and air speed. Standard 55 requires that occupants have control of the air speed for operative temperatures above 78°F (25.5°C) and air speeds above 160 fpm (0.8 m/s).

Occupant thermal comfort with the use of ceiling fans was the subject of a study conducted by the Center for the Built Environment in 2013 (Zhai et al 2013). Subjective thermal comfort impacts were collected from 23 test subjects under different dry-bulb temperatures (75°F to 86°F), relative humidity (40% to 60%) and occupied space air speeds (40 fpm to 240 fpm). Specifically, 4 conditions were examined:

- No ceiling fan
- Automatic fan speed control that varied with temperature and relative humidity
- Occupant controlled fan with 6 speeds for typical office metabolic rates (computer work, 1.1 met)
- Occupant controlled fan with 6 speeds for higher office metabolic rates (1.4 met).

Table 6. Fan Speed Control for Thermal Comfort Study (Zhai et al 2013)

Temperature °F (°C)	Relative Humidity %	Fan speed level	Air speed (m/s)
75.2 (24)	40	1	0.2
75.2 (24)	60	1	0.2
78.8 (26)	40	2	0.6
78.8 (26)	60	2	0.6
82.4 (28)	40	3	0.8
82.4 (28)	60	4	1.0
86.0 (30)	40	4	1.0
86.0 (30)	60	5	1.2

The occupants were asked to rate the thermal sensation on a scale from +4 (too hot) to -4 (too cold) with 0 representing neutral. Figure 6 shows the results of these tests. Increasing relative humidity had very little effect on the average responses, but it did narrow the range of responses meaning that fewer occupants were uncomfortable (both hot and cold) with the higher relative humidity. The occupant responses with no fan showed an increase in discomfort with rising temperatures as expected. Yet with any of the ceiling fan conditions, most of the subjects remained comfortable up to 26°C (78.8°F) and showed minor discomfort at 28°C (82.4°F) and more discomfort at 30°C (86°F). An interesting result from this testing is that the occupant fan control provided very similar results to the automatic fan speed control.

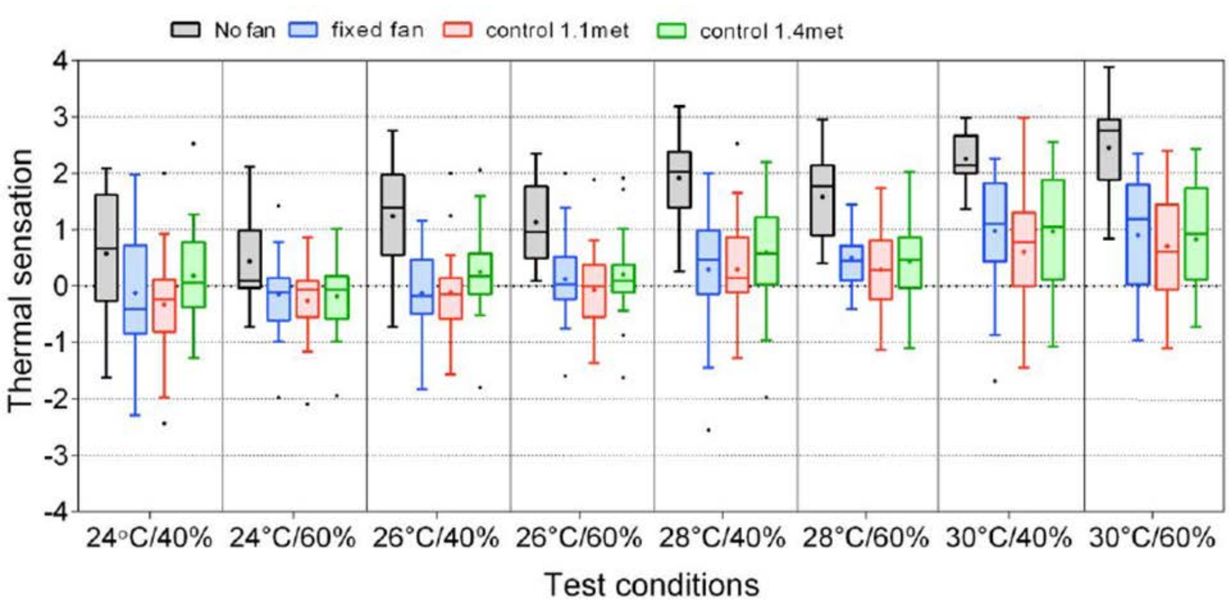


Figure 6. Thermal Sensation Votes from Test Subjects (Zhai et al 2013)

III. Site Selection Criteria

Proper site selection for the application of the technology is crucial to the successful deployment of this technology. Selection of sites that are not well-suited for the technology potentially wastes resources and puts further adoption of the technology at risk. To screen potential sites for issues, the following questionnaire was developed. The questions are categorized as either site/building questions or space questions, and a rationale for the inclusion of each question is included.

Part 1 – Site/Building Questions

1. What is the building site's climate zone?

   Hotter climates with relatively high building cooling loads can benefit from the increased air circulation provided by the technology. The larger the cooling demand of the building across the year, the more significant the energy savings. The site should be in a climate zone with at least 2,000 cooling degree days (50°F base temperature).

2. Is the building primarily used as commercial office space? (Yes|No) If "No", please describe the primary use.

   The technology specifically targets office environments, so application of the technology in other space types should be approached with caution.

3. Does the building operation schedule align with typical office hours? (Yes|No) If "No", please describe the schedule.

   Building operating schedules that are shorter than the typical 8 a.m. to 5 p.m. may not be able to fully realize the possible savings from the technology and might be better served by other technologies. Shorter than typical hours reduce the period of time in which the smart control of the fan is active and may lengthen the payback period relative to alternatives.

4. Does the building have any thermal comfort problems? (Yes|No)

   While it is possible that the technology could fix some thermal comfort issues, any existing issues should be thoroughly investigated before deploying this technology. Installing the technology in a building with existing thermal comfort problems that are not well-addressed by this technology risks spurious failure – i.e. the technology is working exactly as intended but is perceived to be a failure because of existing issues within the building.

5. Are there any tenant agreements (or any other similar agreements) that would prevent the changing of thermostat setpoints within the building?

   Proper utilization of the technology requires that space setpoints be changed. If this is not possible for any spaces within the building, then it is possible that the technology will not realize the maximum savings. If there are agreements that would impact the ability to change the setpoints then the site is not an appropriate application of the technology.

Part 2 – Space Questions

1. Are there spaces within the building that meet the following criteria?
   a. The space is of sufficient size and occupancy.

b. The space ceiling height it at least 9 ft.

c. The space lighting is configured so that the ceiling fans can be installed

   i. Above the lights, or

   ii. Between lights.

d. The space contents, geometry, and usage will not interfere with the effectiveness of the ceiling fans.

These are the minimal conditions the space must meet to be considered as a potential space. Small or oddly shaped spaces may not effectively utilize the ceiling fans, while interactions with lighting could lead to unpleasant strobing or flashing. Spaces with few occupants may not require the smart ceiling fan capabilities and may be better served by more traditional control schemes.

2. Is the operational thermostat setpoint of the potential space less than or equal to 75°F?
   This is the maximum temperature range that the team is willing to use as a starting point. Setpoints higher than 75°F may not allow for the temperature to be raised enough for the technology to reach its full potential.

3. Can the thermostat setpoint of the potential space be modified and will the modifications result in measureable energy savings?
   If the setpoint cannot be raised, then the technology is very unlikely to save any energy. Spaces for which the setpoint temperature cannot be changed are not appropriate for this technology. For some HVAC systems (e.g. underfloor air distribution systems) changing the setpoint and installing fans may not result in energy savings. Spaces for which setpoint changes will not result in energy savings are not appropriate for this technology.

4. What is the ceiling configuration (open plenum, drop ceiling, etc.) and cubicle partition height of the potential space?
   It is vitally important that the space be appropriate for the installation of ceiling fans in a way that will not interfere with occupants, safety equipment, or other building systems.

IV. Deployment Strategies

Ceiling fans can be an inexpensive and effective way to replace or reduce air conditioning use in GSA buildings. Ceiling fans evenly distribute conditioned air throughout a space, which may improve occupant comfort and reduce HVAC operations. In the heating season, the ceiling fan redistributes warmed/stratified air collecting at the ceiling back throughout the room, especially around the perimeter and near the floor. The same wind chill can actually feel like a draft in winter, so some ceiling fan motors can be reversed to pull air upward in winter. Ceiling fans can extend the shoulder season as well by reducing the number of cooling days in the summer and heating days in the winter.

Ceiling fans can be controlled through a remote controller, wall controller, or mobile application. For commercial building applications, the wall controller is commonly used, but this means that the fan may be on or off for extended periods. This is especially a problem when the fan is frequently left running while nobody is there. A smart ceiling fan integrates a smart control with a motion sensor to detect and turn the unit on/off based space occupancy. The smart controller also monitors the room temperature and humidity, and adjusts fan speed automatically to maintain space comfort.

Per a smart ceiling fan manufacturer, the ceiling fan is optimal for office buildings with ceilings at least 9 feet high featuring open floor plans with low height partition walls. Low height partitions allow a ceiling fan to cover multiple cubicles and get better air circulation.

GSA Public Building Service's portfolio consists of federal-owned and leased assets across the United States managed via 11 GSA regional offices. This managed space includes office buildings, courthouses, land ports of entry, warehouses, laboratories, childcare facilities, and parking structures. Figure 7 shows a map of GSA regions.

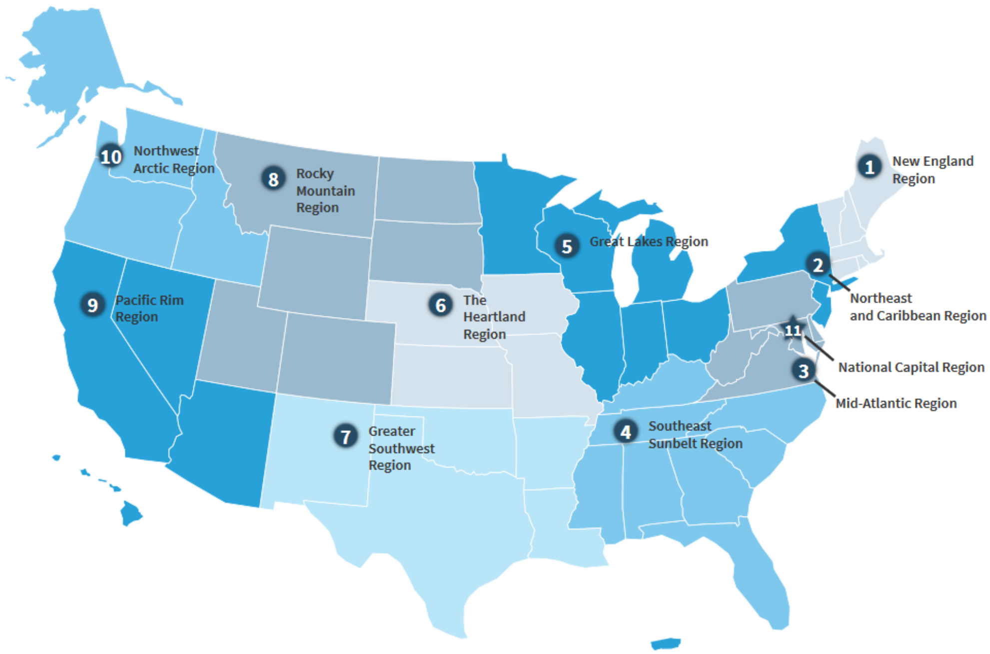


Figure 7. GSA Region Map (Source: GSA)

A typical GSA office building includes private executive offices and open offices. Most open offices have a full height partition walls. Full height partitions are not an ideal setting for ceiling fans and may prevent multiple cubicles from sharing one ceiling fan. Typical full partition height is 80 inches. Low partition height is 54 inches or under. GSA's Total Workplace Program incorporates a new form of work space and interior design that may be more appropriate for ceiling fans. The new interior design includes low height partitions for open offices and presents a great opportunity to deploy ceiling fans in both new construction and major renovations. Other suitable GSA buildings and space types may include courts, border stations, childcare centers, laboratories, and conditioned warehouses. Figure 8 presents an example of open office design from the Total Workplace Program.

Figure 8. GSA Total Workplace Program – Open Office Design and layout (Source: GSA)

According to a smart ceiling manufacturer, ceiling fans are suitable for climates with more than 2,000 cooling degree-days or more than 5,500 heating degree-days. These recommended cooling and heating degree-days cover all climate zones in the continental United States. Most claimed energy savings from the use of ceiling fans to supplement HVAC operations are associated with cooling energy savings. Climate zones 1 to 4 would meet the recommended cooling degree-days. From NREL energy simulation analysis in the previous section, the highest energy cost savings in the medium office building occurs in San Francisco (climate zone 3C), Phoenix (climate zone 2B), and Baltimore (climate zone 4A). The highest energy cost savings in the large office buildings occurs in San Francisco (climate zone 3C), Baltimore (climate zone 4A), and Atlanta (climate zone 3A). There are potential savings on the heating side, but most claimed benefits are qualitative (improved occupant comfort, well-mixed air, etc.). GSA may refer to the climate zone of the office building location to assess its appropriateness for deploying this technology. Table 7 presents a range of cooling and heating degree-days of the climate zones and the climate zone map is presented in Figure 9.

Table 7. Climate Zone Definitions

Zone Number	Zone Name	Thermal Criteria (I-P Units)
1A and 1B	Very Hot – Humid (1A) Dry (1B)	9000 < CDD50°F
2A and 2B	Hot – Humid (2A) Dry (2B)	6300 < CDD50°F ≤ 9000
3A and 3B	Warm – Humid (3A) Dry (3B)	4500 < CDD50°F ≤ 6300
3C	Warm – Marine (3C)	CDD50°F ≤ 4500 AND HDD65°F ≤ 3600
4A and 4B	Mixed – Humid (4A) Dry (4B)	CDD50°F ≤ 4500 AND 3600 < HDD65°F ≤ 5400
4C	Mixed – Marine (4C)	3600 < HDD65°F ≤ 5400
5A, 5B, and 5C	Cool – Humid (5A) Dry (5B) Marine (5C)	5400 < HDD65°F ≤ 7200
6A and 6B	Cold – Humid (6A) Dry (6B)	7200 < HDD65°F ≤ 9000
7	Very Cold	9000 < HDD65°F ≤ 12600
8	Subarctic	12600 < HDD65°F

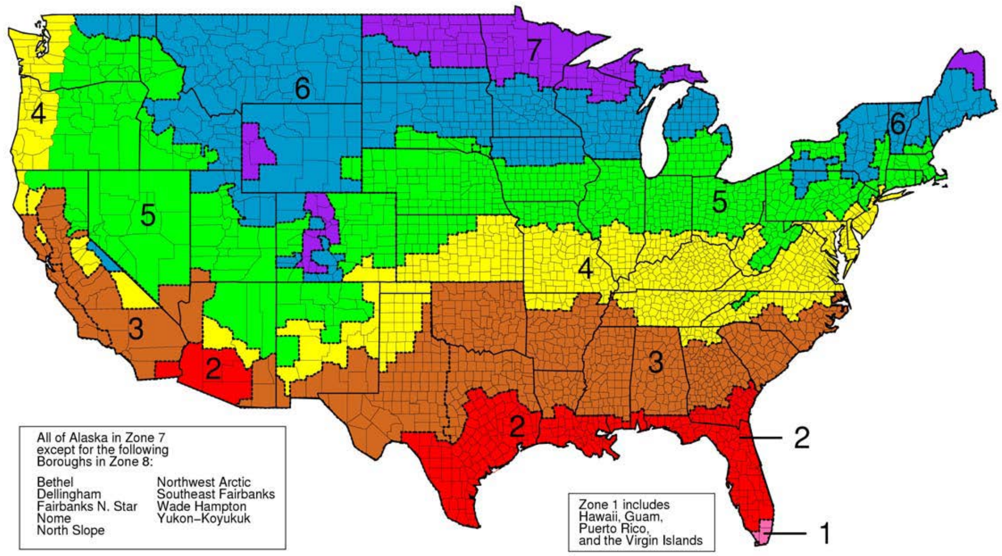


Figure 9. Climate Zone Map (Source: DOE)

V. Deployment Considerations for Ceiling Fans

- Ceiling fan placement should be carefully planned to avoid lighting interference and occupant discomfort. Consult with lighting engineer, designer and ceiling fan manufacturer.
- Aesthetic appearance of ceiling fans is an important factor for some users. Designed products come with a cost premium.
- There are two types of electric ceiling fan motors: AC (alternating current) and DC (direct current). DC fan motors are typically more efficient than AC fan motors; come with more speed options; and are faster to start, stop, and change speed. Another advantage of DC motors is that they tend to be smaller and make less noise than AC motors. Most manufacturers offer ceiling fans with DC motors.
- Ceiling fans with DC motors are often controlled with a handheld remote. In some applications the handheld remote is preferable, but is often not preferred in commercial applications. There are ceiling fan models available that have optional wall-mounted controls.
- Larger ceiling fans can move more air than smaller ceiling fans and more effectively cool a larger room. Multiple fans work best in rooms longer than 18 feet. Table 8 presents ceiling fan diameters, area served, maximum power, and an estimate of number of fans for a 5,000 ft^2 space.

Table 8. Ceiling Fan Sizes and Areas Served

Fan Diameter	Area Served (ft^2)	Max Power (W)	Max Power Density (W/ft^2)	# of fans for example 5,000 ft^2 space
52 inch (4.3 ft)	225	14.8	0.07	22 fans
60 inch (5.0 ft)	400	21	0.05	12 fans
84 inch (7.0 ft)	900	63.8	0.07	6 fans

- Consider ENERGY STAR ceiling fans. Fans that earn the ENERGY STAR label move air 20% more efficiently, on average, than standard models. The ENERGY STAR Ceiling Fans Key product criteria for ceiling fan can be found in Appendix B.
- Look for models with the highest air flow efficiency (CFM/watt) at each of their speeds. ENERGY STAR products have to meet the performance requirements presented in Table 9.

Table 9. ENERGY STAR – Air Flow Efficiency Requirements

Fan Speed	Minimum Airflow	Minimum Efficiency Requirement
Low	1,250 CFM	155 CFM/watt
Medium	3,000 CFM	100 CFM/watt
High	5,000 CFM	75 CFM/watt

- Ceiling fan performance is the combination of all of components. ENERGY STAR ceiling fan component performance is presented in Appendix C.
- Pay close attention to the downrod length of a ceiling fan, particularly in rooms with tall ceilings. A fan will provide a greater wind chill effect if it is close to occupants than if it is far away. Fans that mount close to the ceiling (hugger models) are often inefficient because the fans have difficulty bringing in air behind the blades to push downward. Fans should be installed so their blades are no closer than 8 inches from the ceiling and 18 inches from the walls.
- Ceiling fans can only save energy if users raise thermostat setpoints during cooling season and lower the thermostat setpoints in heating season. Therefore a facility that uses ceiling fans without adjusting thermostat can have higher energy cost.
- Ceiling fans are circulation devices and cannot duplicate the wide range of functions traditional HVAC systems perform, including ventilation, filtration, humidification, dehumidification, heating, and cooling.
- Check the noise ratings of the ceiling fans. Sound levels are measured in sones. The higher the sone level, the noisier the fan. Very quiet fans are rated at 1.5 sones and low-capacity fans rated as low as 0.5 to 1 sones are nearly inaudible. Consider the quality of the sound as well. Different sound frequencies produce different tones, even at the same sone level. Not all

ceiling fan manufacturers provide the noise rating in their specifications. The industry is still working on a standard test procedure. A poor installation can affect a fan noise's level. If a fan isn't installed securely, it can vibrate and rattle, making much noise as a poorer-quality fan. A fan that is too noisy may offset the thermal comfort benefits with additional noise, resulting in thermally comfortable occupants that are bothered by the fan noise.

- Ceiling fan design and installation should comply with building, electrical, and fire code.

VI. Summary/Conclusion

The results presented and discussed here indicate that the use of ceiling fans with corresponding changes in HVAC operation may enable substantial energy savings if applied correctly. A smart ceiling fan integrates sensors to monitor the space temperature, relative humidity, and occupancy and adjusts its speed to maintain occupant comfort and minimize energy consumption. The smart ceiling fan may better ensure the occupant comfort than standard ceiling fans. There are three key issues that must be addressed in order to properly apply ceiling fans. These issues are: 1) finding a suitable building, 2) adjustability of the thermostat, and 3) installed cost.

Suitable Space/Location – As indicated in the site selection and deployment discussions above, there are several conditions that must be met in order for a space to be suitable for the application of the technology. For many office buildings in the present GSA portfolio, there may be few spaces in the building that are large enough, have low enough partitions, and have lighting that is compatible with the technology. Thus, it can be a challenge to apply the technology for the existing office building stock. However, as noted above, if current trends toward more open-office designs continue, spaces that are appropriate for the technology will be available either in new construction or major renovations. Other suitable GSA buildings and space types for ceiling fans may include courthouse, border station, childcare center, laboratory, and conditioned warehouse.

Thermostat Adjustability – The ability to relax thermostat settings is vital to the technology's energy savings success. If tenants/owners do not have freedom to change setpoints, then the technology cannot save energy. It does not matter if the barriers are technical (e.g. inability to separately control space temperatures) or contractual (e.g. tenant agreements that forbid changing thermostat settings). Any barriers to thermostat changes will limit the achievement of savings.

Installed Cost – As with any potential energy-saving technology, the length of the payback period is an important consideration. If the payback period is too long, the technology is less likely to be considered. Table 5 shows that for all but one of the modeled locations the installed cost must be under $1.50/ft^2 in order to have less than 10 years payback.

A final consideration when considering smart ceiling fans is the comparison to standard ceiling fans. Standard ceiling fans that offer fewer control options and no environmental sensing are typically less expensive, but may not offer sufficient controllability to be acceptable to occupants. The value of this "smart" aspect of the technology is difficult to assess, but it is clear that there are situations in which standard ceiling fans may be able to save nearly as much energy if the above three key considerations can be addressed. However, without the benefit of additional controllability and environmental sensing, it is likely that the first consideration (suitable space/location) will be even more difficult, if not impossible, to address.

VII. References

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VIII. Appendix A: GSA's Public Buildings Service Estimate

In 2009, GSA's Public Buildings Service developed 7 cost-effective strategies for saving energy across GSA's portfolio. The top on the list was increasing the space temperature from 74°F (standard GSA setpoint) to 76°F and possibly 78°F. Based upon a California Energy Commission finding that a building will realize 1-3% energy savings for each degree the thermostat is set about 72°F, GSA estimated that raising room temperatures 2°F will save approximately 4% averaged across their facilities. The snapshot from the study shows the calculation made to arrive at 18.7 million kWh of energy savings.

Savings Calculation

2.7 kWh/sf/year (average office cooling load*)

x 4% (estimated percentage reduction in energy use)

0.106 kWh/sf/year (energy saved/sf/year)

0.106 kWh/sf/year

x 176.4 million sf (total area of GSA-owned facilities)

18.7 million kWh/year (total energy savings/year)

18.7 million kWh/year

x $0.10/kWh (GSA average electric energy cost**)

$1.87 million/year (total cost savings/year)

* U.S. Department of Energy: ***Buildings Energy Databook 2007***.

**GSA's average cost for electric energy in fiscal year 2008.

Figure 10. Estimated GSA-wide Energy Savings for a 2°F Increase in Cooling Setpoint

IX. Appendix B: ENERGY STAR - Ceiling Fans Key Product Criteria

Specifications

- Specification defines ceiling fan airflow efficiency on a performance basis: cfm of airflow per watt of power consumed by the motor and controls.
- Motor warranty provided must be a minimum of 30 years
- Component(s) warranty must be a minimum of one year
- Light kit warranty requirements are provided in the ENERGY STAR Luminaires specification.
- Integral or attachable lighting, including separately sold ceiling fan light kits, must meet requirements provided in the ENERGY STAR luminaires specification.
- Qualifying products must permit convenient consumer adjustment of fan speed, by means of one or more wall-mounted switch(es), a remote control, or readily accessible pull chains.

X. Appendix C: Ceiling Fan Performance: Components

Motor

Basically, there are two types of ceiling fan motors: those with sealed and lubricated ball bearings and those with bearings that rotate in an oil bath. Lubrication provides smooth operation and contributes to the longevity of the motor. Motors with sealed bearings require little or no maintenance whereas motors with oil baths need occasional service, such as adding oil.

Motor Grade

- Performance Grade fans use larger and more powerful motors that are designed for continuous use and quiet operation. These are usually the most expensive models
- Medium Grade fans are suitable for operating 12 hours or less per day.
- Moderate or Economy Grade fans work best in a room with 8 foot ceilings, running no more than 8 hours a day. They are the most inexpensive ceiling fans

Motor Housing

The housing is the decorative body of the fan that encloses the fan motor. Fans that use heavier materials, such as die cast metals, for housing tend to vibrate less, provide more stability for longer downrods, and provide a good surface for high quality finishes.

Other features that ensure longevity and quiet operation include heavy-duty windings, precision engineering bearings, and shock-absorbent internal components**.** These features are commonly found in more expensive ceiling fan models.

Blade

- Pitch is the angle of the fan's blades, and it's measured in degrees. Higher blade pitches usually move more air, which is given in cubic feet per minute, or CFM. However, blade pitch alone does not determine air movement. Other factors such as the motor design and speed, as well as blade design, material, number, and length can contribute to the amount of air movement. Higher pitch is NOT always better — some models offer a higher blade pitch to compensate for a smaller, less efficient motor.
- Blades should be sealed from moisture to prevent warping, bubbling, or peeling. Some manufacturers offer special coatings on metal finishes to prevent scratches or tarnishing.
- High quality blades are weighed and balanced prior to shipment and come in factory-matched sets. For this reason, they cannot be switched out with other fans. For flexibility in design, a number of manufacturers offer a variety of blade styles and finishes for a particular fan. However, changing the blade style could affect the performance of the fan.

Controls

Some ceiling fans (and all ENERGY STAR qualified fans) feature the ability to reverse the motor and airflow direction, allowing user to operate the fan year-round. This control is usually found on the fan's switch housing.

XI. Appendix D: Example of Smart Ceiling Fan Specifications

The ceiling fan, reinvented

The 60-inch [redacted] is the first [redacted] designed specifically for homes and small spaces. Its precision hand balancing and silent operation combine for lasting perfect performance. [redacted] is handcrafted with premium materials, including sustainable Moso bamboo and a durable glass-infused matrix composite. As the world's most energy-efficient ceiling fan, [redacted] earned the top ENERGY STAR® ranking, exceeding testing requirements by more than 450%. Sophisticated control options include seven speeds, as well as special settings such as [redacted] mode, a proprietary feature which simulates the variations in natural airflow for greater cooling effect.

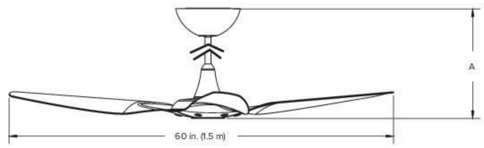
Winner of more than 20 international design and technology awards, [redacted] is everything you expect from [redacted], designed specifically for your home.

Features and Benefits

- Top-ranked ENERGY STAR fan
- Ten unique control settings, including the exclusive Whoosh mode
- Variety of mounting options for flat or pitched ceilings 8 feet and taller
- Hand balanced for wobble-free operation at all speeds
- Patent-pending LED module
- Slender remote control and optional wall control
- Finish options include caramel bamboo, cocoa bamboo, black matrix composite and white matrix composite

[redacted]

TECHNICAL SPECIFICATIONS



Technical Specifications					
Model	Extended Mount				
Model number					[redacted]
Fan diameter	60 in. (1.5 m)				
Fan height (A)	16.5 in. (419 mm)	29.5 in. (750 mm)	41.5 in. (1054 mm)	57.5 in. (1461 mm)	69.5 in. (1765 mm)
Hanging weight	12.8 lb (5.8 kg)	13.2 lb (6 kg)	13.5 lb (6.1 kg)	14.0 lb (6.4 kg)	14.4 lb (6.5 kg)
Motor and assembly finishes	Caramel: Black or white Cocoa: Black				
Airfoil material	Bamboo				
Airfoil finishes	Caramel or Cocoa				
Number of airfoils	3				
Motor type	EC motor with digital inverter drive				
Number of fan speeds	7				
Operating voltage and frequency	100–240 VAC, 1 Φ, 50–60 Hz				
RPM (min/max)	35/198 RPM				
Amps (min/max)	0.05/0.363 A				
Watts (min/max)	4/60 W				
Remote control	Included				
Wireless wall control	Optional				
Controller features	**FAN:** Whoosh® mode On/off Sleep mode Timer Speed **LIGHT:** Light on/off 16 dimmable light settings				
Operational temperature range	32 to 104°F (0 to 40°C)				
Environment	For indoor use only				
Fan mode indicator	LED display				
Warranty	Limited lifetime				

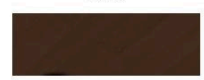
Accessories

Standard Controller

Optional Wireless Wall Control

Airfoil Finishes

Caramel



Cocoa

LED Module

[redacted]