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Citation

Holly Samuelson. Comparing Modes of Operation for Residential Ceiling Fans to Achieve Thermal Destratification. unpublished, 2015.

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Comparing Modes of Operation for Residential Ceiling Fans to Achieve Thermal Destratification*

Dr. Holly W. Samuelson, AIA, LEED

Assistant Professor of Architectural Technology, Harvard University Graduate School of Design

Abstract

This study investigated the performance of residential ceiling fans used in winter heating mode to deliver warm air, otherwise collecting at the ceiling level, to lower portions of the room. Researchers used physical measurements to compare forward and reverse fan settings and two different fan models in three different room heights. Contrary to conventional wisdom, which advocates running ceiling fans in reverse mode in the winter, this research found that a ceiling fan operating in the forward direction and using variable speeds to destratify a room can use less energy than a leading paddle fan operating in reverse. The researchers also found that when operating at fan speeds high enough to adequately mix the air, a ceiling fan operating in the forward direction can create lower overall air speeds throughout the room compared to a leading paddle fan operating in reverse.

Introduction

Conventional wisdom says to reverse the direction of a ceiling fan's rotation in the winter. Warm air rises, filling a room from the top down and requiring heaters to run more to achieve a desired ambient air temperature at the height of the thermostat or occupant. Ceiling fans can help reduce this imbalance by mixing the air, but even the lowest speed setting of a paddle fan is intended to create a cooling breeze by blowing air downward and directly onto occupants. Because of this effect, consumers have been urged for decades to run their fans in reverse since this helps push warm air across the ceiling and down the walls, theoretically recirculating it through the space.

*Note: Funding for this research was provided by Big Ass Solutions

In fact, federal legislation was passed in 2007 that required ceiling fans to have a reverse function. [1]

Here, researchers aim to evaluate manufacturer-recommended operation of ceiling fans to determine if there is a more energy-efficient way to handle winter heating. This study compares the performance of a leading paddle fan in forward and reverse modes as well as Big Ass Fans' Haiku ceiling fan, operating in the forward direction at lower speed settings.

While thermostats respond to temperature alone, occupants are also susceptible to drafts, or "unwanted local cooling of the body caused by air movement." [2] Since saving energy by destratifying rooms in a home requires inducing air movement during colder times of the year, this research considers both air temperature mixing and air velocity while investigating the following hypotheses.

Hypotheses

Primary Hypothesis: Reverse Operation Can Be Less Efficient

A ceiling fan operating in the forward direction and using variable speeds to destratify a room can use less energy than a leading paddle fan operating in reverse.

Secondary Hypothesis: Reverse Operation Can Cause Higher Air Speeds and Increased Draft Risk

When operating at fan speeds high enough to adequately mix the air, a ceiling fan operating in the forward direction can create lower overall

air speeds throughout a space compared to a leading paddle fan operating in reverse.

Methodology

Two fan models were used in this study: one 60-inch diameter Haiku fan, and a “paddle fan”, a 60-inch diameter representative example of the most well-known residential ceiling fan brand, as determined by Big Ass Fans’ consumer studies. A 1300 watt Maxi-Heat NH600D portable heater with an integral blower was used to heat the test room continuously through all series of testing. The heater was not thermostatically controlled.

The Haiku fan was tested in the forward direction on speed settings 1 through 7. The Haiku fan does have a reverse function, but due to the airfoil shape of the blades, similar to an airplane wing rather than a flat paddle, the fan is not intended to be operated in reverse. The paddle fan was tested on low, medium and high speed settings in the forward and reverse direction.

Testing took place in three different room configurations, each 20-ft x 20-ft in area with adjusted ceiling heights of 9-ft, 10-ft, and 12-ft. In these room configurations, the lowest fan blade was 93”, 105”, and 129” respectively (+/- 3”) above finished floor elevation (AFF). The testing chamber was constructed of plywood on both the interior and exterior surfaces, supported with metal studs with no supplemental insulation. The floors were concrete. This chamber was built within a much larger structure (~60,000 square feet) of which the temperature was loosely controlled via radiant heaters.

Air velocity was tested at several elevations AFF using Cambridge Accusense – Degree C anemometers (Model: UAS1000LP-ES). These measurements were used to establish whether drafts would be felt at the floor (4” AFF), the typical height of a seated adult (43” AFF), and the typical height of a standing adult (67” AFF).

Air velocities were tested for a period of five minutes, with samples taken every second at various distances radially from the center of the fan. (See Figures 1 and 2.) Each fan was operated for 10 minutes prior to data collection. This procedure was repeated for each speed setting and direction of operation.

The Standard for Thermal Environmental Conditions for Human Occupancy, ANSI/ASHRAE 55-2013, describes a threshold for air movement of 30 feet per minute (fpm) for cool operative temperatures (those below 72.5°F). [2] The Standard labels speeds below this limit as “still air” and considers the draft effect of higher air speeds. Therefore, in this research a 30 fpm threshold was used to categorize the air speed results.¹

Temperatures were tested at the elevations listed above as well as 12” below the ceiling height. Ambient temperatures outside the test room were also collected. Temperatures were measured with an Onset UX100 data logger and J-type thermocouples from a single manufacturing lot with an accuracy of +/- 1.08°F. Temperatures were tested every second, and were logged continuously through all speed settings with the fans both on and off.

The test room was allowed to stratify and reach steady state before each temperature test. With the fan off, the room was heated using the portable heater for 40 minutes. During this period, warm air rose to the top of the room, causing stratification. After the 40 minute stratification period, the fan was switched on for an additional 40 minutes, reaching steady state. Following this, the fan was switched off for another 40 minutes, allowing the room to re-stratify. Then the fan was adjusted to the next speed setting and operated for another 40

¹ The Standard is more lenient when occupants can control the air speed, expanding the “still air” label up to 40 fpm in that case. Whether a threshold of 30 or 40 fpm was used in this research, the results would not change substantially, and the recommendations for fan modes and settings would not change.

minutes. This procedure was repeated for each speed setting and direction of operation for each fan.

mean value was reported. The equipment used to collect this information was a Hioki Model: 3169-20, with an accuracy of $\pm 0.2\%$.

The power used by each device was recorded at one second intervals for thirty seconds and the

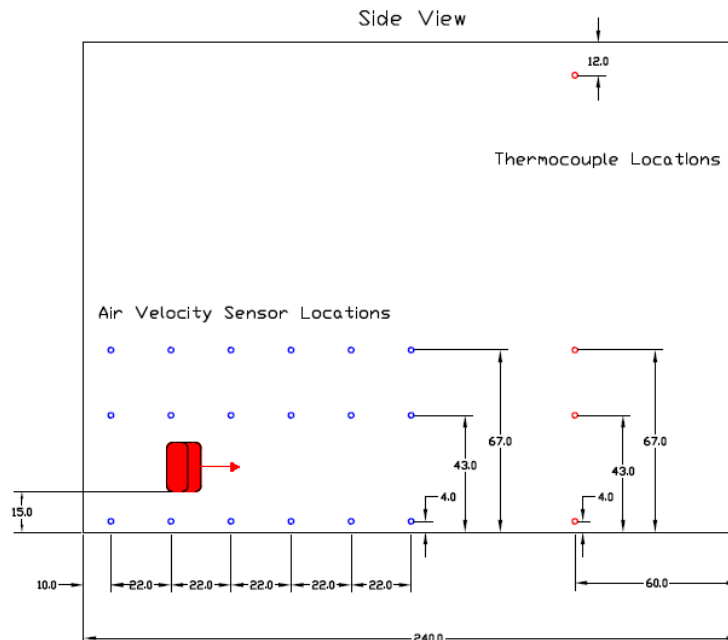


Figure 1: Room Section Showing Sensor Locations in Inches

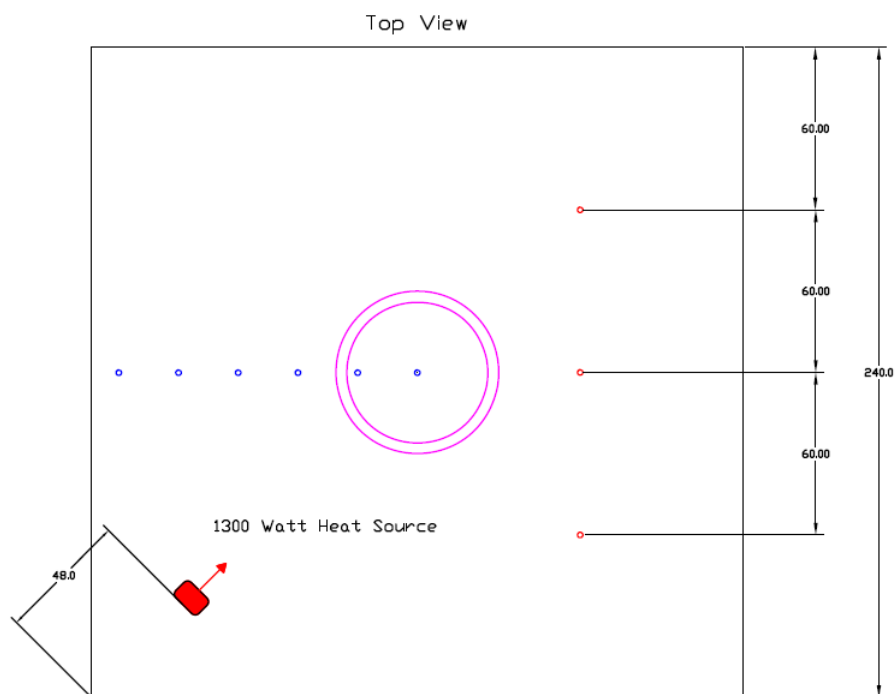


Figure 2: Room Plan Showing Sensor Locations in Inches

Results

Paddle Fan in Forward and Reverse

The following diagrams illustrate the temperature gradient, i.e. the temperature recorded at each height, in the room before and during fan operation. Figure 3 shows the effects of running the paddle fan in the *forward* direction at low speed. One can see that before turning on the paddle fan, the hot air collected

at the ceiling, thus the temperature near the floor was 9.5°F lower than the temperature near the ceiling. Operating the paddle fan helped slightly, but a temperature differential of 8.3°F remained. In fact, the temperature near the floor only increased by 0.3°F over baseline conditions when the fan was running. The fan consumed 11.5 Watts of power during operation.

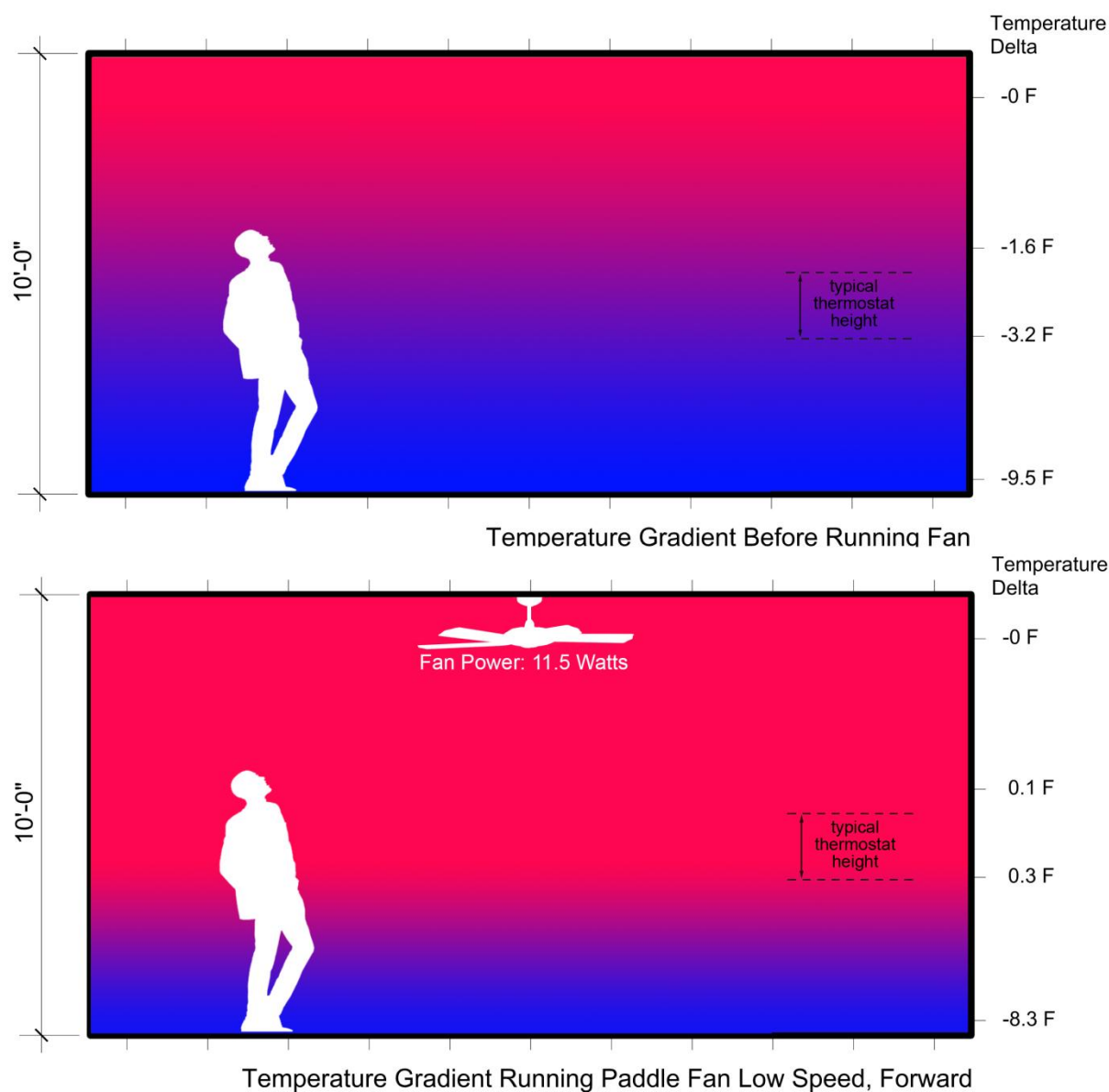


Figure 3: Ten-Foot Room Section, Before and During Paddle Fan Use - Forward Direction

What about operating the paddle fan in the *reverse* direction? In the reverse operation, the fan still consumed 11.5 Watts of power. In Figure 4, one can see that with this operation, the overall temperature differential reduced to 7.3°F. Thus, the situation improved slightly at foot level. However, the temperatures experienced at torso and thermostat height were actually cooler than when running the paddle fan in the *forward* direction, making the

choice between forward and reverse direction a complicated one. Under these conditions, if one prefers slightly warmer feet, [s]he should run the fan in reverse. If one prefers a warmer torso and thermostat, [s]he should run the fan in the forward direction. With either direction, substantial stratification remained. In fact, when running the fan in reverse, the temperature near the floor only increased by 1.0°F over baseline conditions.

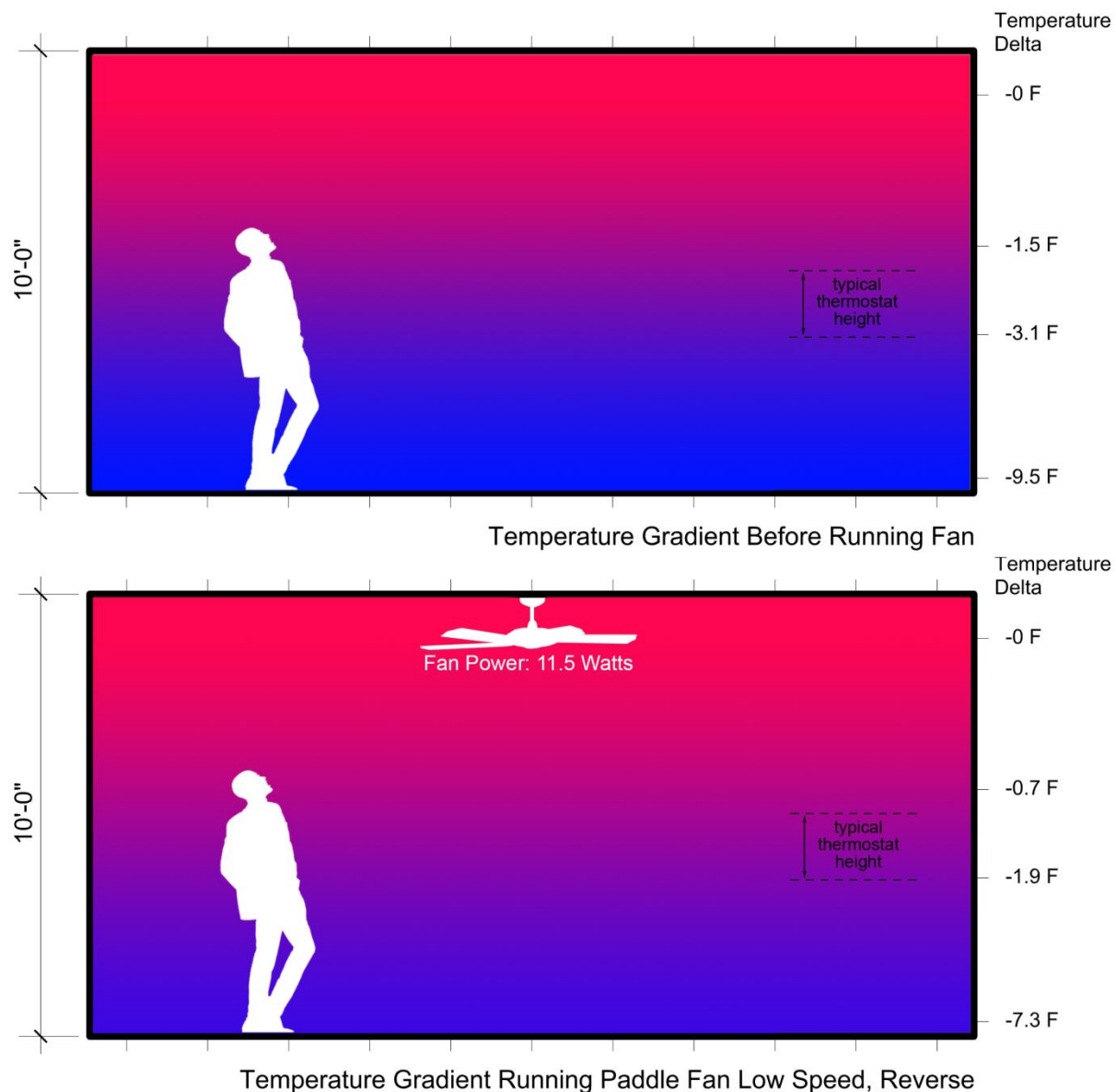


Figure 4: Ten-Foot Room Section, Before and During Paddle Fan Use - Reverse Direction

What about turning up the fan? Logic suggests that, regardless of direction, running the paddle fan at a higher speed would better circulate warm air downward. Indeed, using the next highest setting, i.e. *medium* speed, increased the temperature at floor level by 4.2°F, in reverse mode, and 6.1°F, in forward mode, over baseline (no-fan) conditions, while consuming 30.1 Watts of power.²

Unfortunately, the paddle fan operation at these settings also produced potentially uncomfortable air speeds. In the reverse mode, 15 out of 36 sensors at person-height (67" or below) measured air velocities of 30 feet-per-minute or faster. In the forward direction the situation was worse, with such air velocities measured at 19 of 36 locations, and air speeds over 100 fpm recorded at multiple locations.

In summary, operating the paddle fan at low speed, in both forward and reverse direction, helped deliver warm air to lower parts of the room --but only slightly. Increasing the paddle fan speed to the medium setting substantially improved temperature mixing but at the expense of increased power consumption and potential drafts throughout most of the space. Repeating the paddle-fan experiment in the 9-ft and 12-ft tall room corroborated these results.

A Different Fan

Do all fans behave the same way? The following diagrams show the results of the experiment running a Haiku fan in the forward direction. For each room height, the "preferred" fan speed is shown here, i.e. the speed setting that produced the most temperature destratification, without introducing drafts in a substantial portion of the room. In the 9-ft and

10-ft tall rooms, the preferred speed setting was 1.5, which increased to speed setting 2 in the 12-ft tall room. These settings consumed 1.8 and 2.5 Watts of power respectively, or 84% and 78% less power (and energy³) than the paddle fan on its lowest speed setting.

Similar to the previous diagrams, Figure 5 shows the 10-ft tall room configuration. Once again, before turning on the fan, the hot air collected at the ceiling, thus the temperature near the floor was 8.4°F lower than the temperature near the ceiling. Operating the fan decreased this temperature difference to 2.8°F. In fact, the temperature near the floor increased by 4.1°F over baseline conditions when the fan was running.

To achieve this substantial improvement, a compromise was made regarding air velocity. At this fan speed, "setting 1.5", a portion of the room experienced air velocities of 30 fpm or faster. Specifically, 6 out of 36 person-height sensors recorded such velocities. Figure 5, identifies this area of the room.⁴ The air velocity decreased with distance from the fan,⁵ so that the average velocity at the other 30 sensors was only 7 fpm. One can imagine real-world room configurations, such as living rooms, in which people mainly occupy the perimeter of the space. Therefore, despite the presence of potential draft conditions, this fan speed was deemed preferable. Running the fan at a lower

² Fan operations resulted in a vertical temperature differential of 2.1°F using the reverse mode and 0.2°F using the forward mode. Starting conditions for these two tests were a temperature differential of 9.7°F and 9.9°F, respectively.

³ In each case the fans needed to run continuously to maintain destratification. Therefore, power savings equals energy savings, since energy is simply power multiplied by time, and each fan would need to run for the same amount of time.

⁴ The hatched area was determined by linearly interpolating velocities between sensor points. This is an approximation of complex phenomena, but it is a more conservative approach than simply highlighting problematic sensor locations.

⁵ In the previous case, the paddle fan at medium speed, the air velocity pattern was not as regular, and areas of high velocity were located throughout the occupiable areas of the room.

speed could be preferable in other scenarios, but a lower fan speed also produces less air-

temperature mixing.

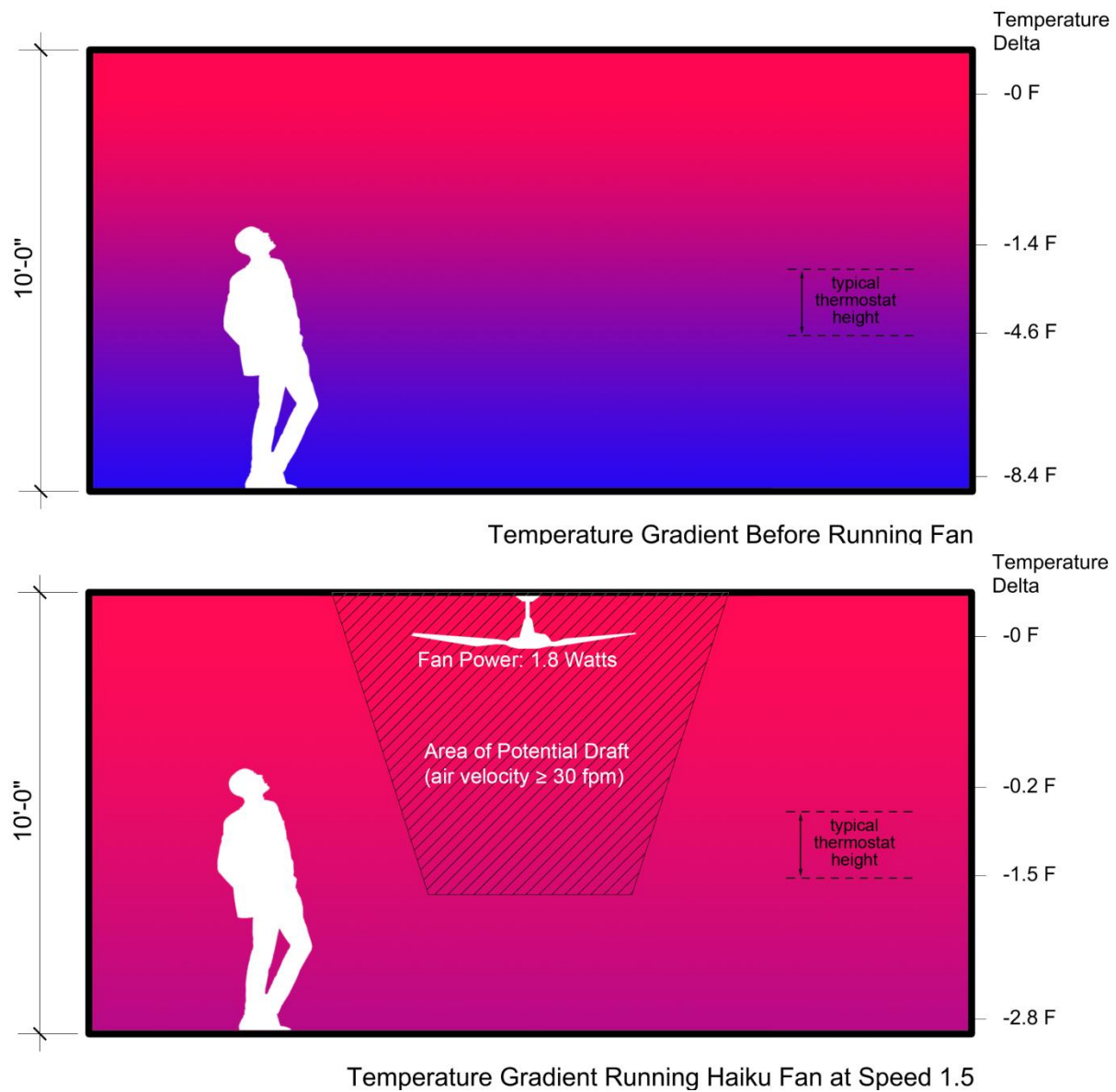


Figure 5: Ten-Foot Room Section, Before and During Use of Haiku Fan

Figures 6 and 7 show the same results for the 9-ft tall and 12-ft tall rooms respectively. Operating the fan in the forward direction increased the temperature near the floor by 5.2°F and 5.5°F respectively over baseline (no-

fan) conditions. In contrast, the paddle fan running in reverse mode at medium speed only increased these temperatures by 2.9°F and 4.0°F respectively and in each case exposed a larger portion of the room to potential drafts.

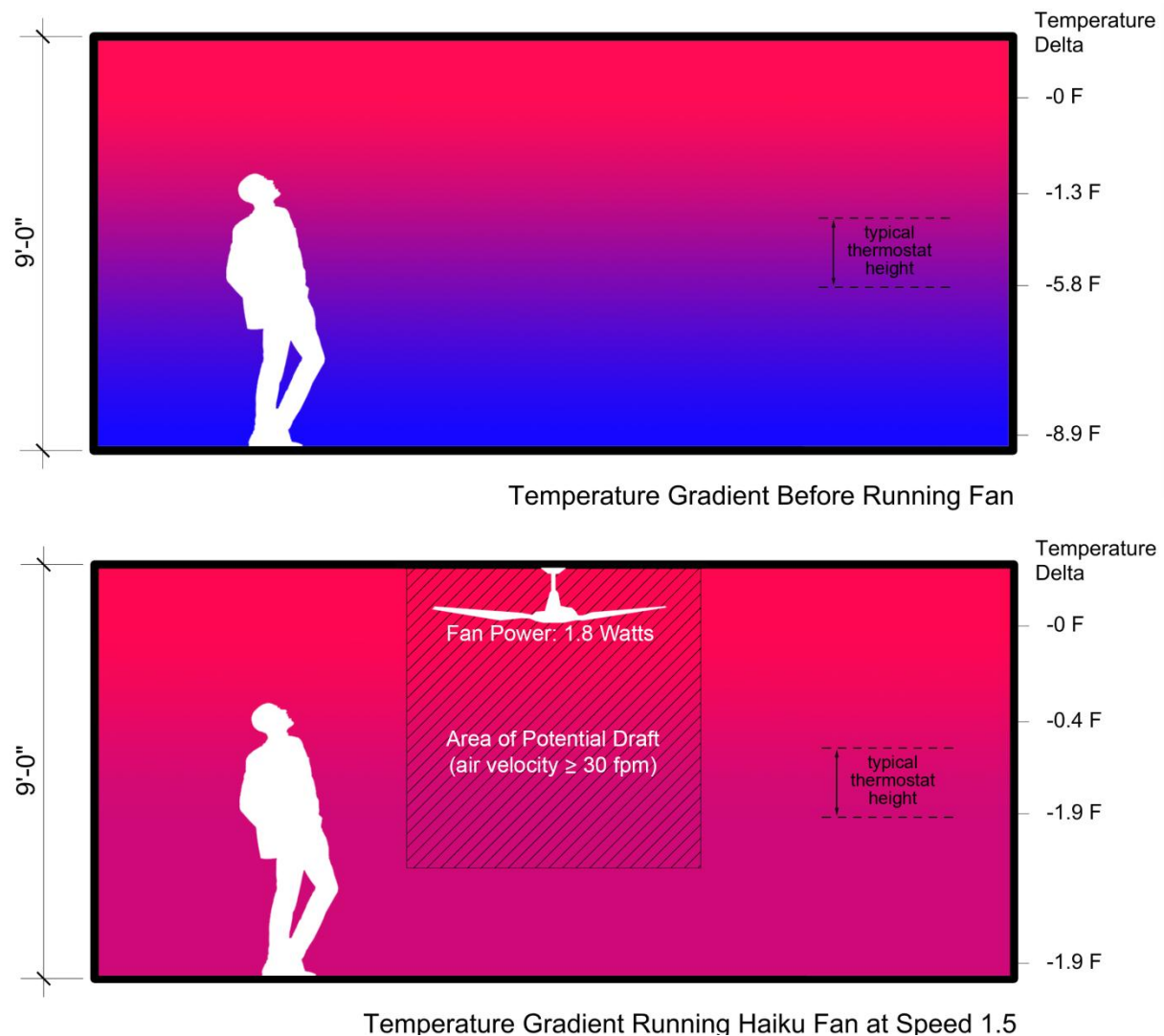


Figure 6: Nine-Foot Room Section, Before and During Use of Haiku Fan

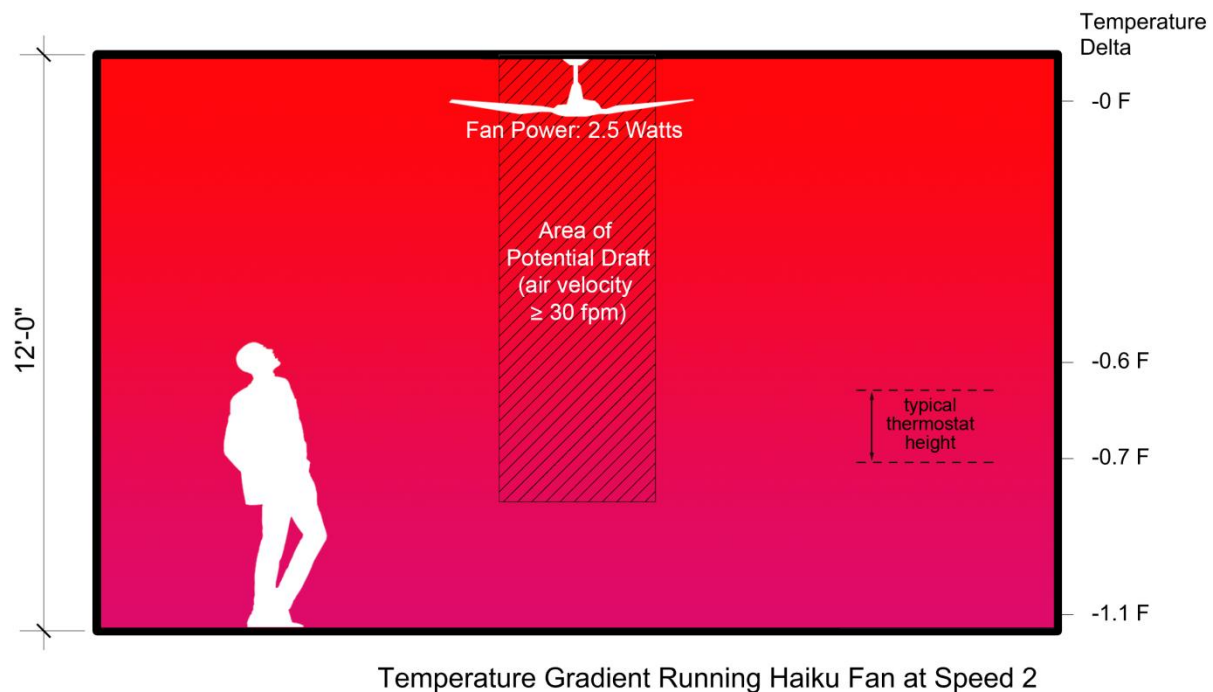
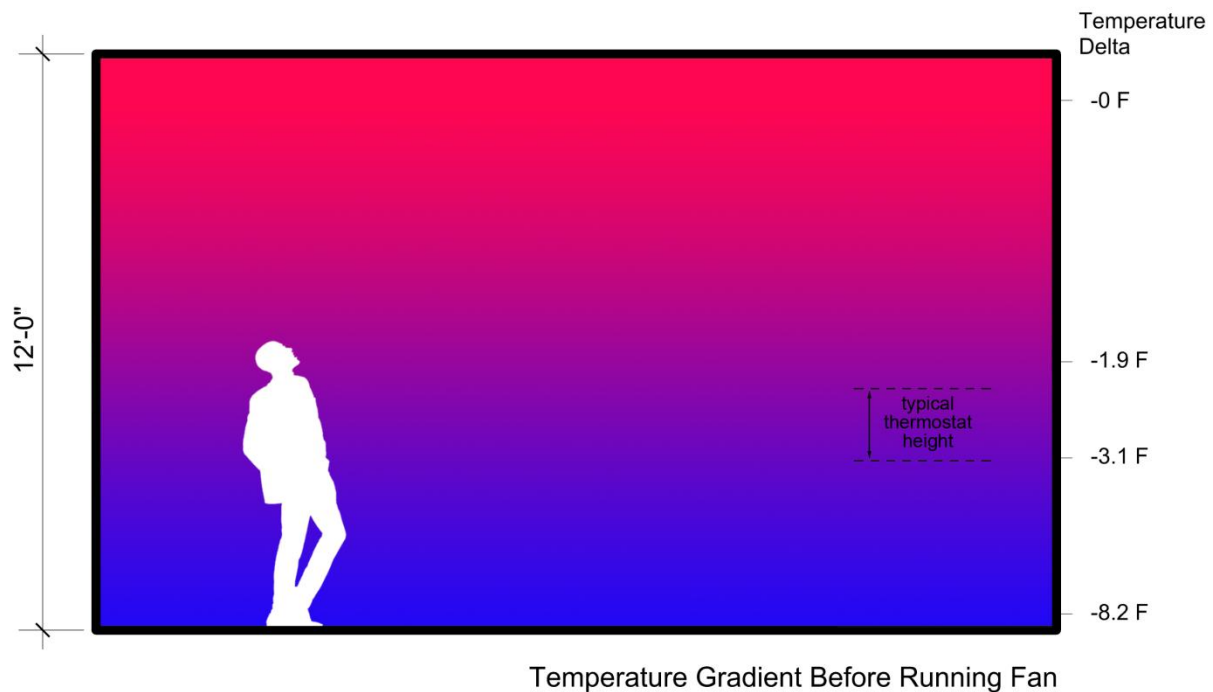


Figure 7: Twelve-Foot Room Section, Before and During Use of Haiku Fan

In addition, the Haiku fan at speed setting 1.5 used 95% less power and energy than the paddle fan at medium speed. (At speed setting 2 the Haiku fan used 91% less power and energy than the paddle fan at medium speed.) Figure 8

shows the electrical power consumed by each fan at each setting.

Table 1 summarizes the temperature improvements and average air speeds for the preferred operation modes for each room

height. (The preferred operation mode here is defined as the one that produces the greatest ceiling-to-floor temperature destratification with average air speeds at or below 30 fpm.) For example, the paddle fan in reverse raised the foot-level temperature of the 9-ft tall room by 2.9°F (over baseline [no fan] conditions) with average air speeds of 30 fpm, while the Haiku fan in forward mode raised the temperature by

5.2°F with average air speeds of 19 fpm. It is worth noting that the paddle fan in reverse did provide some level of temperature destratification at very low air speeds. In the 9-ft and 10-ft tall rooms, the paddle fan in reverse raised the temperature at foot-level by 1°F with average air speeds of 4-6 fpm (but this left a 5.3°F to 7.3°F temperature difference between the top and bottom of the room).

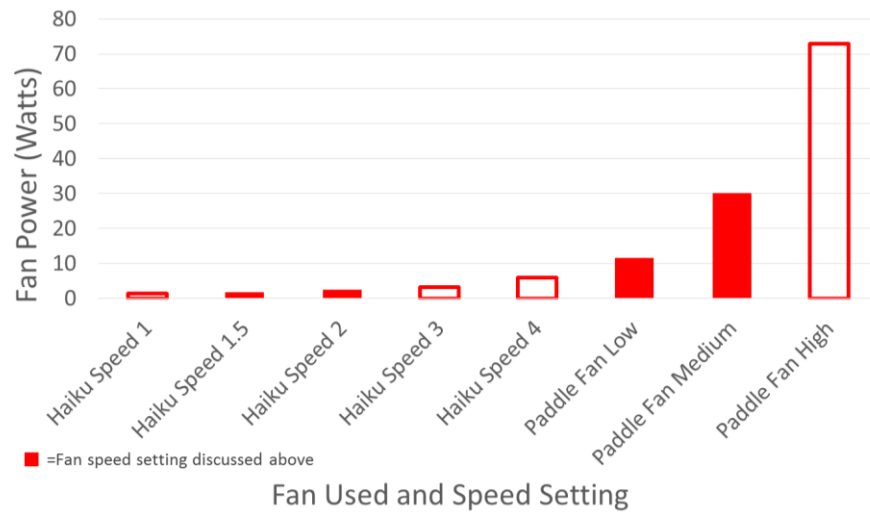


Figure 8: Comparison of Fan Power Consumption

Table 1: Comparison of Foot-Level Temperature Increases (from Before to During Fan Operation) and Air Speeds

	Paddle Fan in Reverse Mode		Haiku Fan in Forward Mode	
	Temperature Increase at the 4" Sensor*	Air Speed **	Temperature Increase at the 4" Sensor*	Air Speed **
9-ft tall room	2.9°F	30 fpm	5.2°F (warmer)	19 fpm (slower)
10-ft tall room	4.2°F (slightly warmer)	29 fpm	4.1°F	14 fpm (slower)
12-ft tall room	4.0°F	25 fpm	5.5°F (warmer)	16 fpm (slower)

*Comparing fan on vs. fan off conditions: a measure of the fan's ability to move warmer air from the ceiling to the floor

** Average of all 36 sensors

Conclusions

Primary Hypothesis: Reverse Operation Can Be Less Efficient

Can a ceiling fan operating in the forward direction and using variable speeds to destratify a room use less energy than a leading paddle fan operating in reverse?

Yes, in each ceiling height case, the Haiku fan running in the forward mode used 78-95% less energy --to create greater destratification-- than the paddle fan did running in either forward or reverse mode.

Secondary Hypothesis: Reverse Operation Can Cause Higher Air Speeds and Increased Draft Risk

When operating at fan speeds high enough to adequately mix the air, can a ceiling fan operating in the forward direction create lower overall air speeds throughout a space compared to a leading paddle fan operating in reverse?

Yes, as shown in Table 1, in each ceiling height case, the Haiku fan running in the forward mode was able to produce a similar (or higher) temperature increase at floor level with lower average air speed measurements than the paddle fan operating in reverse.

References

[1] The Electronic Code of Federal Regulations, CFR-title 10-chapter 2-subchapter d-part 430-subpart c-430.32-paragraph s.

[2] The American National Standards Institute/American Society of Heating, Refrigerating, and Air Conditioning Engineers Standard 55-2013