WHITE PAPER

COMPARING MODES OF OPERATION FOR RESIDENTIAL CEILING FANS TO ACHIEVE THERMAL DESTRATIFICATION

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Overview

Conventional wisdom says to reverse the direction of a ceiling fan's rotation in the winter. Heat rises, filling a room with warm air from the top down and requiring heaters to run longer to achieve a desired ambient air temperature at the height of the thermostat and occupants. Running a fan in reverse helps move this heat across the ceiling and down the walls, recirculating the warm air through the space.

Fans have been capable of reversing direction for decades, and legislation was passed in 2007 that required ceiling fans to have a reverse function. The logic behind reversing a fan is simple: since running fans in the forward direction creates a cooling effect through air movement, reversing those fans helps recirculate heat in the winter without creating an uncomfortable cooling draft.

Big Ass Fans is aiming to prove that there's a more energy-efficient and comfortable way to address heating conservation with ceiling fans. This study compared the effects of paddle fan reversal with Big Ass Fans' Haiku ceiling fan, operating in the forward direction at lower speed settings than a paddle fan.

Hypothesis

Primary Hypothesis: Reverse Operation Is Less Efficient

Reversing a paddle fan is not the best way to efficiently recirculate heat and fight heat stratification. A Haiku ceiling fan, operating in the forward direction, can destratify a room more efficiently than paddle ceiling fans operating in reverse.

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

One of the major reasons for reversing a fan is avoiding drafts—unwanted, perceptible air movement during the heating season. However, operating a paddle fan in reverse at a speed that can thoroughly mix the air causes higher overall air speeds throughout the space when compared to operating Haiku slowly in the forward direction. Additionally, a higher percentage of the overall occupied space will experience drafts when operating a paddle fan in reverse, compared with the Haiku in the forward direction.

Testing Objectives

To evaluate each hypothesis, there were three main testing objectives to guide data collection:

1. Measure the remaining difference in temperature between the ceiling and typical thermostat height after the air in the space has been thoroughly mixed. For this test, thorough mixing or destratification is defined as less than 1.5° F difference in temperature between the ceiling and occupant level (43-in above floor level).
2. Measure the amount of energy (in watts) required to destratify the space.
3. Measure air velocity profiles and assess draft risk.

Experiment Protocols

Two fan models were used in this study: one 60-inch diameter Haiku fan, and 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 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 by 20-ft in area with adjusted ceiling heights of 9-ft, 10-ft, and 12-ft, respectively. In the test with the 9-ft ceiling, the lowest fan blade was 93-in (plus or minus 3-in) above finished floor elevation (AFF). With the 10-ft ceiling, the lowest fan blade was 105-in (plus or minus 3-in) AFF, and with the 12-ft ceiling, the lowest fan blade was 129-in (plus or minus 3-in) 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 (about 40,000 sq-ft), which is heated with gas-fired radiant heaters.

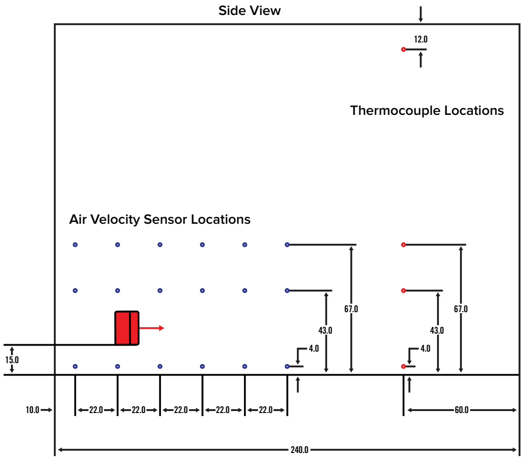
Air velocity was tested at several elevations AFF using Cambridge Accusense—Degree C anemometers (Model: UAS1000LP-ES). These measurements were used to establish whether drafts would be felt at the floor (4-in AFF), at the typical height of a seated adult (43-in AFF), and at the typical height of a standing adult (67-in AFF), the heights recommended by ASHRAE Standard 55-2013. 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 "Side View" and "Top View" diagrams, below).

Temperatures were measured and recorded at the same elevations, as well as 12-in below the ceiling height. Ambient temperatures outside the test room were also collected. Temperatures were also measured and recorded every second, and were logged continuously through all speed settings with the fans both on and off.

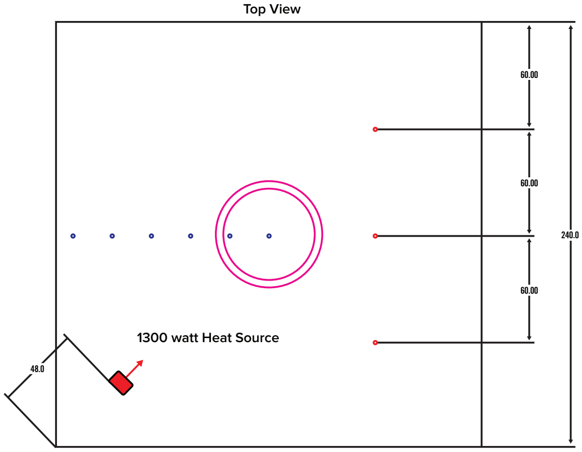
The test room temperature was allowed to stratify and reach steady state before each temperature test. With the fan off, the room was heated with the portable heater for 40 minutes. During this period, heat rose to the top of the room, causing stratification. After the 40 minute stratification period, 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 minutes. This procedure was repeated for each speed setting and direction of operation for each fan.

The power used by each fan was recorded at a one-second interval for thirty seconds, and the mean value was reported. The equipment used to collect this information was a Hioki Model 3169-20.

To test for drafts, the procedure was slightly different. For each speed setting, each fan was operated for 10 minutes prior to data collection to allow the airflow in the space to reach steady state values. This procedure was also repeated for each speed setting and direction of operation.



All dimensions are in inches



Results

Energy Consumption

To evaluate which fan rotational direction is most efficient in reducing thermal stratification, fan power consumption was compared for each fan speed. Based on data collected during this study, it was determined that the Haiku fan must operate at either speed 1.5 or 2 to adequately minimize thermal stratification. At these speeds, the Haiku drew 1.8 watts and 2.5 watts, respectively. To achieve the same level of mixing, the paddle fan must operate at medium speed, drawing 30.1 watts. Figure 1 demonstrates this comparison.

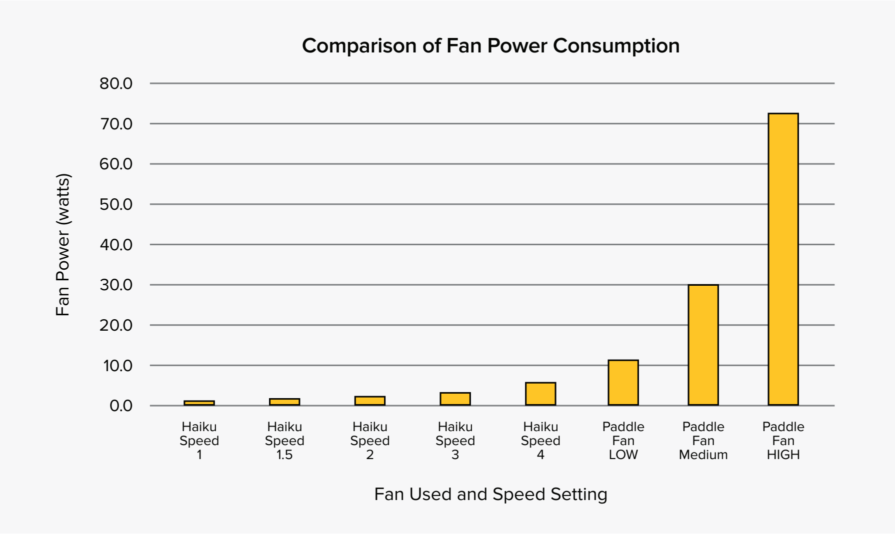


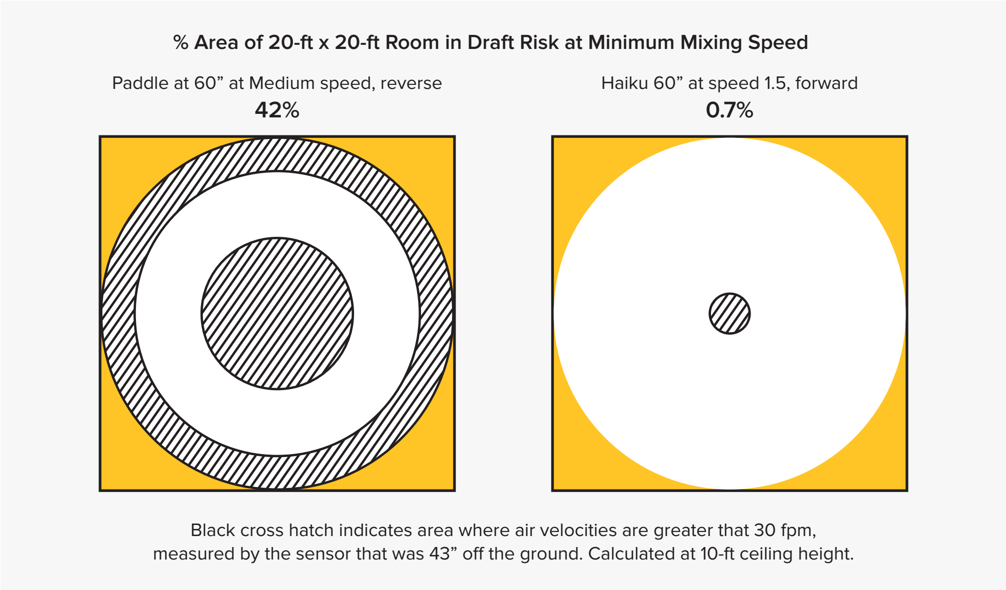
Figure 1

Average Air Speed

Average air speeds for each ceiling height were calculated at seated height (43-in) at the minimum fan speed that could mix the air. Between all ceiling heights that were tested, the average decrease in air speed realized by using Haiku was 38.8%.

Area of Draft Risk

Another way to compare whether or not perceptible air movement is increased or decreased is to view draft spatially throughout the testing area. The metric used was percentage of the 20-ft by 20-ft space that experienced perceptible air movement (30 fpm or greater, the accepted draft threshold as set forth in ASHRAE Standard 55-2013) at the fan speed that could mix the air. The results of these calculations are shown on the following page in Figure 2.



Black cross hatch indicates area where air velocities are greater that 30 fpm, measured by the sensor that was 43” off the ground. Calculated at 10-ft ceiling height.

Figure 2

Conclusions

Comparing Power Required to Destratify

The primary hypothesis was evaluated by comparing the power used by each fan when operating at speeds that could achieve thermal mixing. Results showed that, at those speeds, the Haiku fan used 1/12th to 1/16th the power of the paddle fan, depending on ceiling height. Thus, it is concluded that the Haiku fan operating in the forward direction is more energy-efficient at destratifiying the air than a paddle fan operating in reverse direction.

Comparing Air Speeds and Draft Risk

The first part of the secondary hypothesis was evaluated by comparing the average air speeds in the room when each fan was operating at a speed that could mix the air. The average decrease in overall air speed was nearly 40%, showing that Haiku mixed the air in the space while creating significantly lower air speeds. Thus, it is concluded that operating Haiku in the forward direction at a speed that can thoroughly mix the air causes lower overall air speeds throughout the space, compared to operating a paddle fan in the forward direction.

It should be noted that during this analysis, it was observed that the Haiku did not eliminate draft risk in the space, as there were still areas directly beneath the fan that experienced air movement that could be felt by humans when operating at speeds higher than 1.5. Assuming that draft will be a concern for occupants during colder months, opportunity may exist to maximize the benefits of using a ceiling fan without causing unwanted air movement when occupied.

If a fan could automatically determine if a space were occupied or unoccupied, the fan could be controlled to operate in an optimal way for this application. The fan could be operated at a higher speed when the room is unoccupied and a lower speed when the space is occupied to avoid causing discomfort to the occupants.

In reviewing the spatial comparison of draft risk, the secondary hypothesis was further evaluated. The Haiku created draft in only a few square feet in the center of the test room, whereas the paddle fan created draft in a significantly higher percentage of the test area: More than 40% of the total area of the test room experienced air movement that would be perceived by the occupants.

It was also noted that this air movement was much faster near the walls of the test space when the paddle fan was used, compared with the Haiku. This may be important to occupants because furniture is often located near walls, leading to undesirable air movement in the seated areas when the paddle fan is used.

Overall

Based on the results of this study, it can be said that the Haiku ceiling fan, operating in the forward direction, can destratify a residential-sized space using less energy and producing less perceptible air movement than a paddle fan operating in reverse.