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Impact of HVLS Fans On Airplane Hangar Air Destratification

BY CHRISTIAN TABER, BEMP, HBDP, MEMBER ASHRAE; BRANDON A. STEELE, STUDENT MEMBER ASHRAE

Thermal air stratification results when heated air rises due to its having a lower density relative to ambient air, which results in a thermal gradient from floor to ceiling. The heated air typically stagnates at the ceiling of large facilities due to a lack of air circulation.[1,2] Air stratification presents an important consideration in facility energy savings for buildings with tall ceilings; elevated air temperature at the ceiling level increases the rate of heat loss through the building envelope. A substantial opportunity to reduce annual heating costs for facilities is available by reducing floor-to-ceiling stratification.

Airports present a tremendous air destratification energy savings opportunity because many of the buildings have large, open spaces with high ceilings. Heating airport hangars to meet comfort temperature requirements often consumes large amounts of energy and produces an excessive amount of emissions. Like many other areas of industry,[3] airports are now under pressure to use energy-efficient systems and comply with increasingly stringent regulations while still providing occupant thermal comfort, all in an effort to reduce operating costs and reduce carbon footprint.

High volume, low speed (HVLS) fans are a prominent and practical means for reducing the floor-to-ceiling temperature gradient in large spaces. Large-diameter, HVLS fans are operated in the downward direction at low speeds during winter to mix warm air at the ceiling with cooler air at the floor, all while not creating the sensation of unwanted cooling across an occupant's skin. Fans can be operated in the upward direction to destratify air, but this typically requires higher operating speeds and costs, as the fan has to push the heated air along the ceiling and down a vertical surface to reach the thermostat level. The fans lower the average space temperature by minimizing excess heat at the ceiling, which reduces HVAC system use. The study presented in this article seeks to quantify the effects on energy cost and consumption from use of an HVLS fan for air destratification in an airport hangar.

Methods

The test building is 15,000 ft^2 (1,400 m^2), has a peak ceiling height of 40 ft (12 m) and height of 20 ft (6 m) at

Christian Taber, BEMP, HBDP, is principal engineer-codes and standards for Big Ass Fans in Lexington, Ky. Brandon A. Steele is Big Ass Fans' sustainability engineering intern and a student at the University of Kentucky.

the eaves and is located in Frankfort, Ky. A 20 ft (6 m) diameter HVLS fan was installed in the center of the facility with a blade height of approximately 27 ft (8 m) from the floor. The primary goal of this study is to measure and evaluate the energy and cost impacts associated with using an HVLS fan for air destratification during the cold weather season.

Temperature Loggers

Air temperatures were monitored using temperature and humidity loggers, shown in *Figure 1*. Three loggers were placed along the back wall of the facility at 5 ft, 15 ft and 35 ft (5 m, 4.6 m and 10.7 m) above the floor. An additional logger was placed in a sheltered location outside the facility to collect outdoor air temperature. Loggers were set to collect a data point once every 5 minutes.

Gas Heaters

Forced air natural gas unit heaters are used to heat the facility. A single heater unit was located at each of the four corners of the hangar near the ceiling. All unit heaters are rated at 250,000 Btu/h (73 kW). A dedicated digital meter was installed on the natural gas supply line to monitor gas consumption for the duration of the study. The space temperature setpoint was 65°F (18°C). The forced air gas heaters used in the hangar are shown in *Figure 2*.

Fan Operation

The HVLS fan was operated on an alternating weekly schedule. The alternating fan operation allowed data collection to be consistent and to allow stratification when the fan was off. Data collection began on November 2.

In the week when the fan was operational, the speed was maintained at 25% of the maximum operating speed to provide continuous air mixing. At 25% speed, the fan drew approximately 100 W of power. When the fan was turned on, it remained operational for 24 total hours spanning a 16-day period. With a utility cost of $0.0969/kWh, the electricity cost equates to $1.65 per week. The fan operated in the downward direction only, generating a column of warmer air moving directly downward to the occupant and thermostat level. The fan speed was selected so the air movement produced by the fan did not interfere with worker operations or produce a noticeable breeze (approximately 30 fpm (0.15 m/s) per ANSI/ASHRAE Standard 55-2017) at the occupant level. *Figure 3* displays the fan location in the center of the facility.

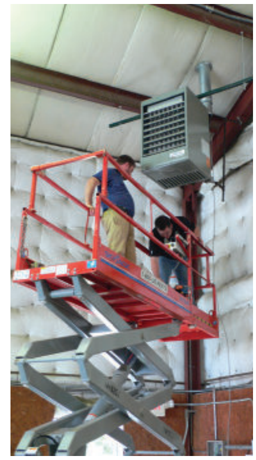
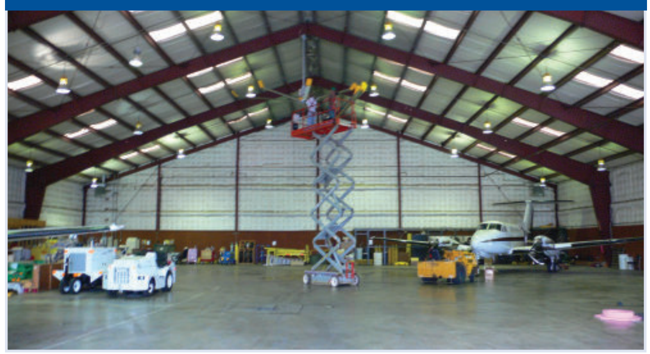


FIGURE 1 (ABOVE) Temperature and humidity loggers used to record air temperature in the facility. Figure 2 (RIGHT) Workers on a lift near the forced air gas heaters inside the hangar.

FIGURE 3 Workers installing an HVLS fan in the center of the hangar. Forced air gas heaters are located in all four corners of the facility.



Results & Discussion

Scenario One – Fan "Off"

Figure 4 shows the comparison between indoor air temperatures at various heights, along with outdoor temperature, for the week of November 2 with the fan off. Temperature varies significantly with space height. The maximum recorded indoor temperature was 81°F (27°C) at 35 ft (10.7 m) on November 6, with an average outdoor air temperature of 52°F (11°C) recorded on site.

According to *Table 1*, over the recorded week the fan was off, the highest temperatures were consistently recorded at the 35 ft (10.7 m) level, while the lowest temperatures remained at the 5 ft (1.5 m) level. The maximum daily average temperature gradient of 8.5°F (4.7°C) between the 35 ft (10.7 m) and 5 ft (1.5 m) level occurred on November 6, while the outdoor air temperature was one of the lowest recorded during the week. The relevance of the temperature differential being the highest on a low temperature day is apparent by the gas heaters in the space operating more frequently, consuming more natural gas.

Scenario Two – Fan "On"

The second set of data, *Figure 5*, displays measured indoor air temperatures over the week of November 9 to November 16 in addition to the outdoor air temperature with the fan operating slowly in the downward direction. *Table 2* shows average daily temperatures while the fan was on as well as temperature gradients between 5 ft (1.5 m) to 35 ft (10.7 m) and 15 ft (4.6 m) to 35 ft (10.7 m) above the floor.

In contrast to when the fan was off, the indoor temperatures across all heights were significantly more uniform, as shown in *Figure 5*. The maximum daily average recorded temperature gradient during the study occurred on November 16 at 1.3°F (0.7°F) between 5 ft (1.5 m) to 35 ft (10.7 m). The average outdoor air temperature was one of the lowest during the week at 53°F (11.7°C), meaning on cold days when gas heaters were operating frequently, stratification was greatly reduced when compared to the "fan off" measurements in the facility. Additionally, the lower air temperatures high in the space reduce the difference between the indoor and outdoor air temperatures. Overall temperature gradients for both 5 ft (1.5 m) to 35 ft (10.7 m) and 15 ft (4.6 m) to 35 ft (10.7 m) remained within 1.3°F (0.7°F) despite the average outdoor air temperatures being colder than when the fan was off.

FIGURE 4 Indoor temperature data (°F) collected from November 2 to November 10 at 5 ft, 15 ft and 35 ft (1.5 m, 4.6 m and 10.7 m) above finished floor (AFF) and plotted with outdoor air temperature for comparison.

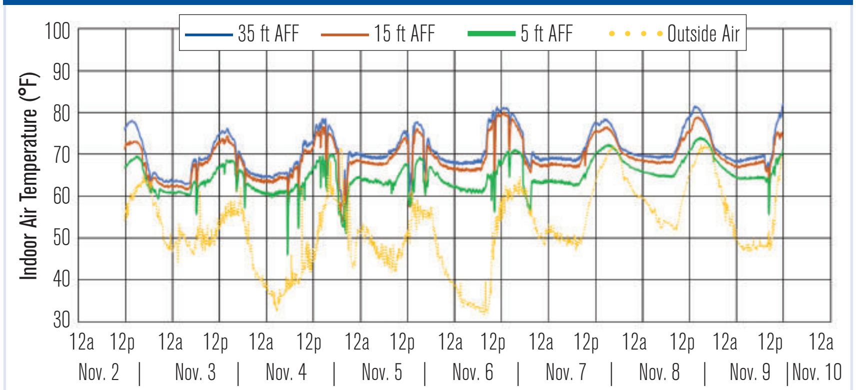
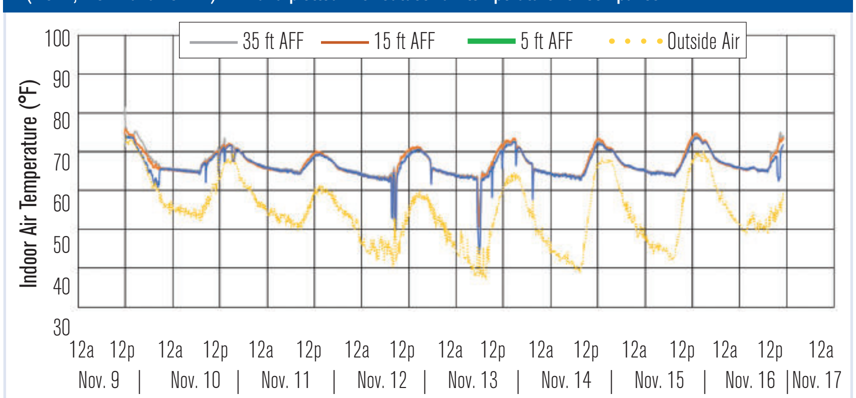


TABLE 1 Stratification results while fan was "off" showing daily average temperatures (°F) from 5 ft, 15 ft and 35 ft (1.5 m, 4.6 m and 10.7 m) away from floor with outside air conditions (OA) for comparison. Temperature differentials (Δ*T*) from 35 ft (10.7 m) and 15 ft (4.6 m), and 35 ft (10.7 m) and 5 ft (1.5 m) are displayed.

FAN OFF	35 FT	15 FT	5 FT	OA	Δ*T* (°F)	
DAILY AVERAGES	TEMP. (°F)	TEMP. (°F)	TEMP. (°F)	TEMP. (°F)	35 FT – 5 FT	35 FT – 15 FT
Nov. 2	69.5	66.9	64.2	57.7	5.2	2.6
Nov. 3	68.2	66.9	63.3	50.1	4.9	1.4
Nov. 4	69.2	67.4	62.5	47.4	6.8	1.8
Nov. 5	70.8	69.0	64.1	48.8	6.6	1.8
Nov. 6	72.6	70.8	64.0	47.6	8.5	1.7
Nov. 7	71.9	70.6	66.8	58.9	5.2	1.3
Nov. 8	72.7	71.2	67.8	60.3	4.9	1.5
Nov. 9	70.7	68.9	65.1	51.2	5.7	1.8
Overall Average	70.7	69.0	64.7	52.8	6.0	1.7
Maximum Value	72.7	71.2	67.8	60.3	8.5	2.6

FIGURE 5 Indoor temperature data (°F) collected from November 9 to November 16 at 5 ft, 15 ft and 35 ft (1.5 m, 4.6 m and 10.7 m) AFF and plotted with outdoor air temperature for comparison.



Time to Destratify and Restratify

Figure 6 compares the duration required for the indoor air temperatures to reach a near uniform profile across all space heights. The chart is labeled to indicate the time when the fan was turned on, the amount of time mixing occurred and the point at which the temperature gradient was minimized.

The indoor temperature variation in *Figure 6* displayed air stratification before the fan was turned on, the unsteady state mixing conditions caused by the fan and finally the near uniform temperatures across all recorded heights. Beginning at 8:40 p.m. on November 9, only 10 minutes of mixing were required for the temperature difference to fall within 1°F (0.6°C).

Figure 7 shows the amount of time after the fan was turned off for the indoor temperature to restratify.

When the fan was turned off November 16 at 7:45 a.m., the heated air began to restratify in the facility to a temperature difference of 3°F (1.7°C) between the 5 ft (1.5 m) and 35 ft (10.7 m) temperature loggers. The amount of time observed for the air to restratify was 10 minutes. The rapid return to stratified air indicates fans need to be operated continuously during the cold weather season.

Gas Consumption

Gas heater use was also monitored during the same weeks with *Table 3* summarizing use when the fan was off, and *Table 4* summarizing use when the fan was on.

The HVLS fan created indoor air temperature uniformity in the facility, reduced heat loss from the building and caused the heaters to operate, consuming less natural gas. Gas prices are based on November 2018 data provided by the U.S. Energy Information Administration for commercial supply at $7.69 per thousand cubic feet ($0.272 per cubic meter). The total cost of natural gas was $277 with average use of 465 ft^3/heating degree day (13.2 m^3/heating degree day) while the fan was off. By comparison, the total gas cost was $191 with the average use of 330 ft^3/heating degree day (9.3 m^3/heating degree day) when the fan was on. Overall, while the fan was operational, a 29% decrease in the normalized gas use was experienced. Based on an estimated annual 4,500

TABLE 2 Stratification results while fan was operational showing daily average temperatures from 5 ft, 15 ft and 35 ft (1.5 m, 4.6 m and 10.7 m) away from floor with outside air conditions for comparison. Temperature differentials from 35 ft (10.7 m) and 15 ft (4.6 m), and 35 ft (10.7 m) and 5 ft (1.5 m) are shown.

FAN ON	35 FT	15 FT	5 FT	OA	ΔT (°F)	
DAILY AVERAGES	TEMP. (°F)	TEMP. (°F)	TEMP. (°F)	TEMP. (°F)	35 FT – 5 FT	35 FT – 15 FT
Nov. 10	67.8	67.4	67.2	59.1	0.6	0.4
Nov. 11	66.4	66.2	66.0	54.7	0.4	0.2
Nov. 12	65.9	65.7	65.1	50.0	0.8	0.2
Nov. 13	66.6	66.5	65.5	50.9	1.1	0.1
Nov. 14	66.8	66.9	66.5	52.8	0.3	-0.1
Nov. 15	67.7	67.8	67.4	55.3	0.3	-0.1
Nov. 16	67.7	67.4	66.4	52.6	1.3	0.3
Overall Average	67.0	66.8	66.3	53.6	0.7	0.2
Maximum Value	67.8	67.8	67.4	59.1	1.3	0.4

FIGURE 6 Indoor temperature conditions showing the amount of time to reach temperature uniformity after the HVLS fan was turned on. Comparisons reveal air stratification before the fan was turned on at 8:40 p.m. on November 9, and a small vertical temperature gradient after 8:50 p.m. on November 9.

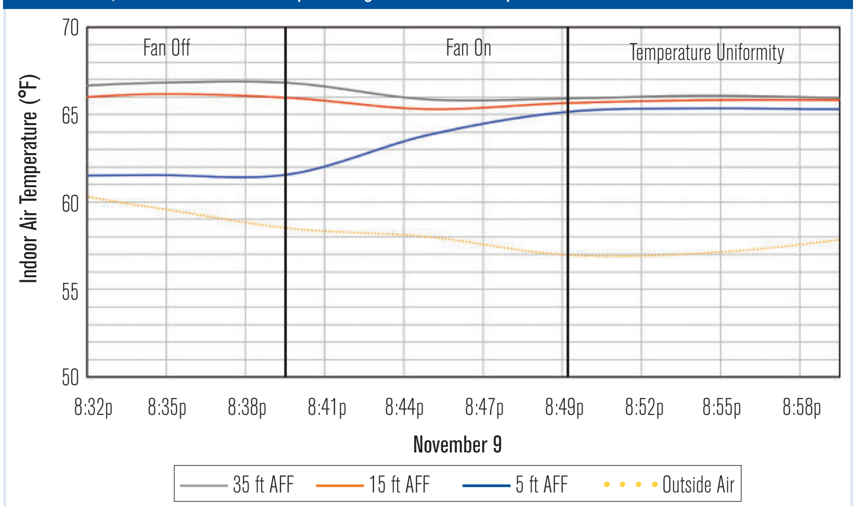
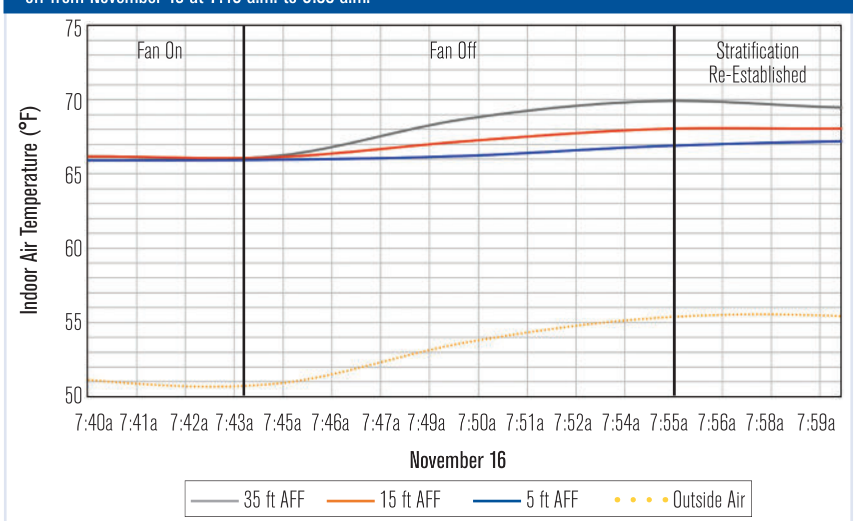


FIGURE 7 Indoor temperature conditions showing thermal air stratification over time after the fan was turned off from November 16 at 7:45 a.m. to 8:00 a.m.



heating degree days[4] for Frankfort, Ky., gas savings during the heating season would be approximately $4,150, while the energy cost for operating the fan would be $50. Simple payback on the project would occur in approximately two years.

CFD Models

Computational fluid dynamics models were used to simulate the stratification of air caused by the gas heating units. The hangar facility was modeled based on the actual dimensions and heat sources that matched the manufacturer's published performance data for the unit heaters added to the space.

Using software, a steady-state analysis was set up and run until convergence was attained. The fan geometry was meshed to an acceptable resolution and quality (maximum element size was #, and maximum skewness values were less than 0.95), and the fan fluid zone was assigned an angular velocity of 17.5 rpm. A realizable k-epsilon turbulence model was used, as was a coupled pressure equation solver model.

The hangar temperature was set at 40°F (4.4°C) to start the simulation, and the heaters were run for a period of three minutes without the HVLS fan to allow air to stratify within the space. This is shown in the left image of *Figure 8*. The fan was then turned on to 25% of maximum speed. After 11 minutes of fan operation, the air within the space was fully destratified (as seen in the right image of *Figure 8*); this closely aligned with the measured, collected data at the hangar via installed loggers.

Conclusion

Evaluating the impact of HVLS fans in an airplane hangar proved air stratification can be minimized from floor to ceiling while also providing significant winter heating savings. During the first week, when the HVLS fan was not in use, the average recorded temperature gradient from floor to ceiling was 6.0°F (3.3°C). The following week, while the fan was in use, an average floor-to-ceiling temperature difference of 0.7°F (0.4°C) was observed. The HVLS fan effectively mixed the stratified air to produce more uniform temperature conditions despite the size of the hangar. The fan reduced stratification, and achieved near uniform temperature conditions within 10 minutes of operation. Once the fan turned off, stratification of the air started to reappear in as little as 15 minutes, which indicates that continuous or nearly continuous operation of the fan may be required to minimize heat loss through the envelope. The HVLS fan also reduced the normalized gas use by 29%, which consequently translated to significantly lower winter heating costs. Using HVLS fans in airplane hangars is an energy-efficient method of creating a more uniform thermal environment due to the fan's low power requirements and high potential for utility savings in the cold weather season.

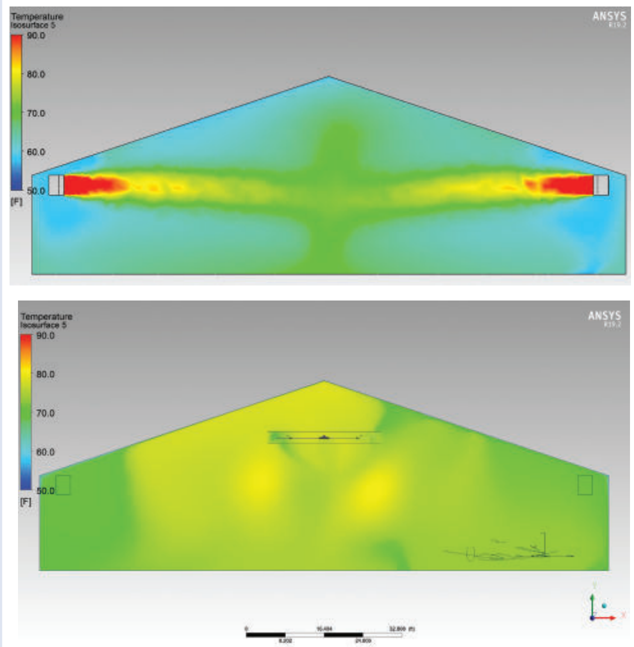
TABLE 3 Summary of gas heater use while fan was off.

HEATER USE TOTALS-FAN OFF	
Total Use	35,958 ft³
Total Cost	$276.52
Normalized Use	465 ft³/HDD

TABLE 4 Summary of gas heater use while fan was on.

HEATER USE TOTALS-FAN ON	
Total Use	24,881 ft³
Total Cost	$191.33
Normalized Use	330 ft³/HDD

FIGURE 8 Cross section through space showing temperature with heaters on and fan off (Top) versus fan on (Bottom).



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