BLOWING HOT AIR: THE USE OF CEILING FANS IN AN ATRIUM SPACE

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ABSTRACT

This study examines the use of ceiling fans as a strategy to de-stratify air and provide a diminished vertical thermal gradient in an atrium space. The hypothesis was that the use of the ceiling fans in the Hedco atrium space diminished the vertical sensible temperature difference between floors to within 2 ° F versus without the use of the ceiling fans. Data collection was accomplished in one evening during the winter season over a period of two hours in five minute intervals beginning with the ceiling fans on, then with the fans switched off while the other thermal control measures, radiant heat and HVAC remained active for a period of one hour. After one hour, the fans were turned on again and data collected for an additional hour. Variable sources of heat exchange, including insolation and external air ingress through the front doors were controlled by collecting data after sunset when minimal users were accessing the building. The hypothesis was proven, in that the vertical temperature gradient of the atrium was within 1 degree Fahrenheit with the ceiling fans on and 5 ° F with the fans off.

1. INTRODUCTION

Building atria contain a high ratio of air to floor surface area and, therefore, present a design challenge when providing consistent thermal comfort to occupants. The Hedco Education Building, completed in spring 2009 on the southwest edge of the University of Oregon campus, has been heralded with recent design awards, including the People's Choice Award in the International Interior Design Association Contest. The 100,000 ft^2 facility, designed by Czopek & Erdenberger Inc., and THA Architecture employs many energy conscious environmental control strategies, which diminish the energy requirements of the building while providing occupant comfort.

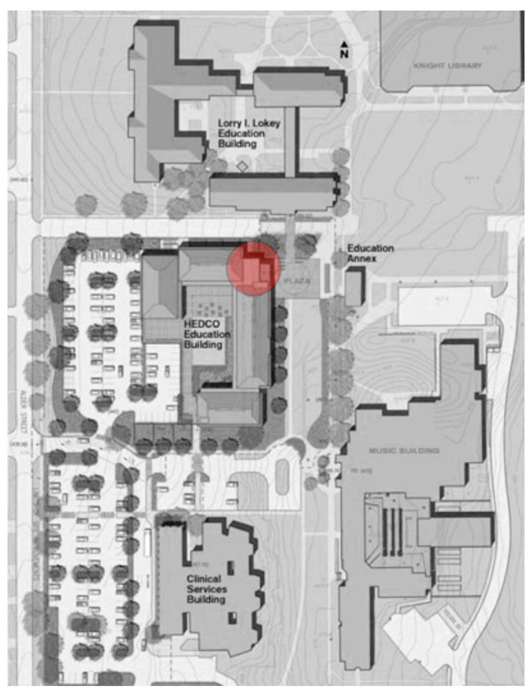


Fig 1: Site Plan of Hedco Education Building

The northeast entrance of the building has a monumental brick clock tower which bisects a wall of glazing and protrudes into a double height atrium space. At the base of the tower a hearth provides an enjoyable place to sit within the atrium. THA Architects utilized several environmental control systems to maintain thermal comfort within the large volume, including radiant heating from the subfloor and brick tower, HVAC and ceiling fans at the height of the atrium. The fans are zoned and run at variable speeds to help mitigate air stratification and subsequent temperature gradients. However, when descending the stairs within the space, one can perceive a change in temperature. ASHRAE standard 55 addresses "thermal environmental conditions for human occupancy."

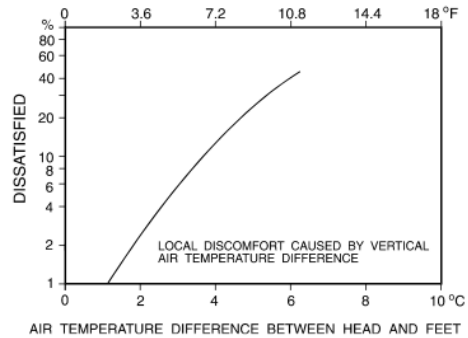


Fig 2: ASHRAE Local thermal discomfort caused by vertical temperature differnecs

Fig. 3: Interior view of Hedco atrium

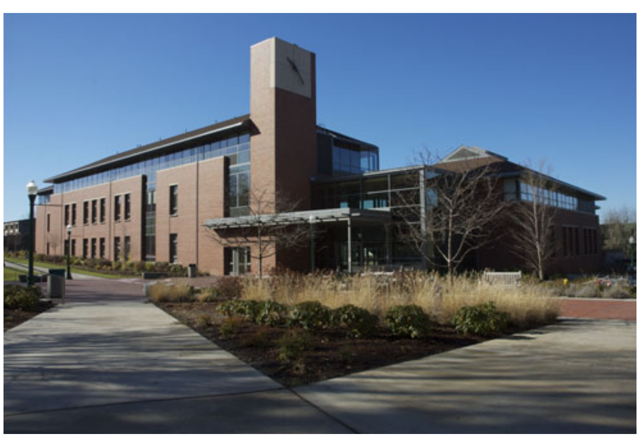


Fig. 4: Exterior view of atrium with brick tower

Fig. 5: Ceiling fans in Hedco atrium

Fig. 6: Hearth in brick tower

While there are many factors that influence thermal comfort within a space, including personal factors: health, psychology, sociology; situational factors: insulative clothing (Clo value), activity levels (Met Rate); air temperature, mean radiant temperature, relative humidity, air movement/velocity, asymmetrical temperature, floor surface temperature and air temperature stratification, this analysis will only address subsection 5.2.4 "local thermal discomfort caused by a vertical air temperature difference between the feet and the head." Fig. 2 illustrates the relationship between vertical temperature difference and percent dissatisfaction of occupants. (1) At 2 ° F difference, occupants report no thermal discomfort.

As part of a course assignment for the 2011 Winter Term Environmental Control Systems I class, the efficacy of fans to de-stratify air and maintain a more even temperature gradient will be investigated. The authors believe that the energy expended for the fans results in a more even thermal environment within the high volume space and, therefore, reduced heating demands with overall energy savings for conditioning the space.

While there are multiple strategies employed for thermal conditioning of the atrium, the scope of this project will address only the use of the fans as a tool for conditioning the atrium space. Due to the nature of the term project, testing will be limited to one evening of data collection in the winter.

2. THE PROBLEM & HYPOTHESIS

The large volume of an atrium space presents a design challenge to create even thermal comfort. In the Hedco Education Building on the campus of the University of Oregon, there are several strategies employed to provide optimum thermal comfort. This study hypothesizes that the ceiling fans in the atrium of the Hedco Education Building (Fig. 5) reduce the sensible heat temperature difference between floors to 2° F.

3.METHODOLOGY & EQUIPMENT

Data collection assumed only sensible heat gradients and attempted to control for the many thermal variables affecting the space. The northeast corner of the building has heavy circulation and frequent opening of exterior doors resulting in a high air exchange rate. Additionally, the north and east walls of the atrium are glazed and insolation was controlled by collecting data after sunset. This had the added benefit of fewer users accessing the space with fewer air exchanges through the main entrance. The data was collected on one afternoon to minimize external climatic differences.

Data collection was accomplished using Hobo U12 data loggers placed at five feet vertical intervals between the floors of the atrium. Measurements were taken from two locations within the atrium (Fig. 7) while maintaining normal operating conditions, including the radiant heating system, HVAC, hearth and ceiling fans. Facility management was asked to switch off the fans and measurement recordings were continued at five minute intervals for one hour to allow the air to fully stratify.
A Raytek temperature gun was used to gauge surface temperatures of the wall of glazing, masonry tower and account for any aberrant surface temperatures.

Step 1. Retrieve all the necessary equipment.

- Hobo U12 data Loggers (Fig. 8)
- 2 20 feet pieces of Rope
- Watch/Timer
- Infrared Heat Scope (FLIR)
- Raytek Surface Temperature Gun (Fig. 9)

Step 2. Attach the Hobo U12 data Loggers to each rope at 5 foot intervals

Step 3. Using the infrared heat scope take images of the atrium, entryway, and surrounding areas to identify significant thermal differences in the space.

Step 4. Go up to the second floor and have each team member drop one of the rope pieces down from 2 different locations.

Step 5. Allow for one hour to pass.

Step 6. Turn off the fans in the atrium space.

Step 7. Repeat step 5 with fans off.

Step 8. Detach Hobo U12 data Loggers and connect them to a computer to retrieve data.

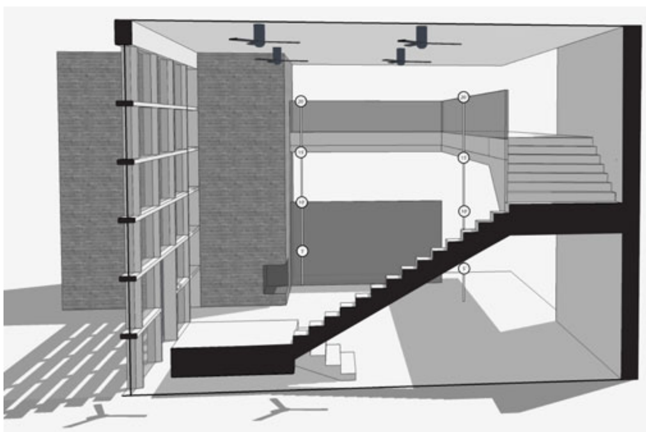
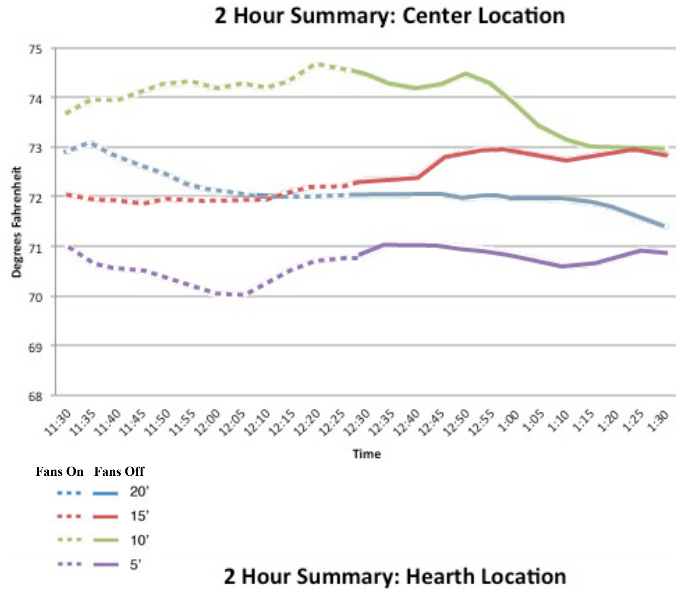


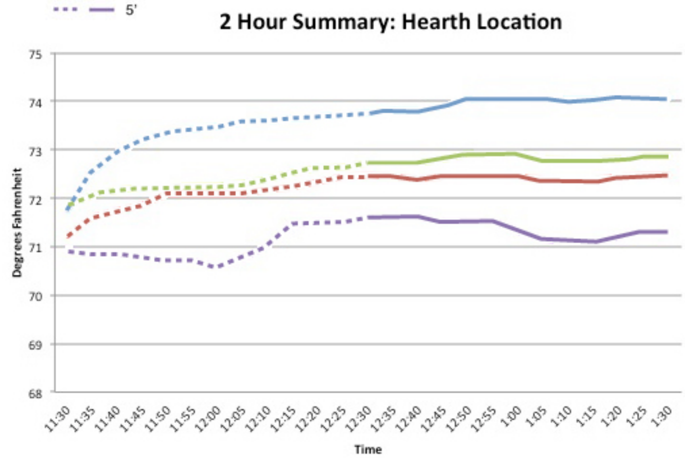
Fig. 7: Hobo U12 data logger placement in atrium

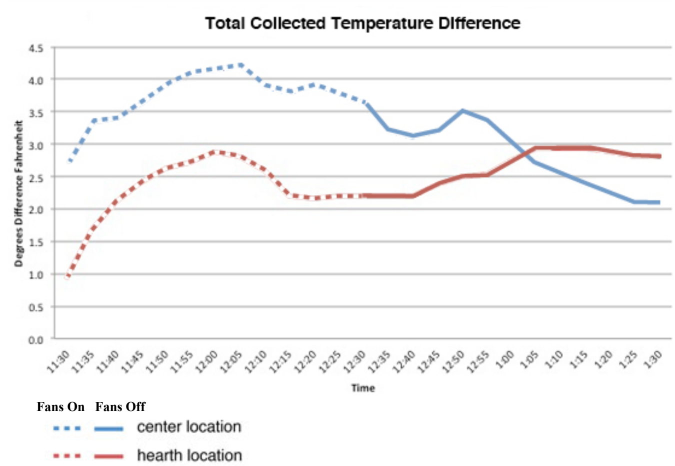
Fig.8 HOBO U12 Data Logger

Fig. 9 Raytek PM Temperature Gun

4. <u>RESULTS</u>



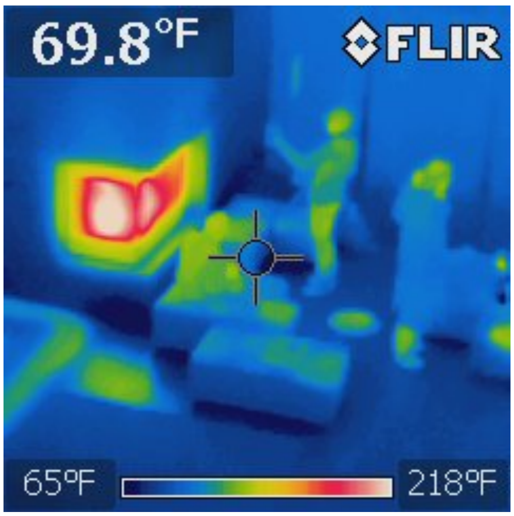


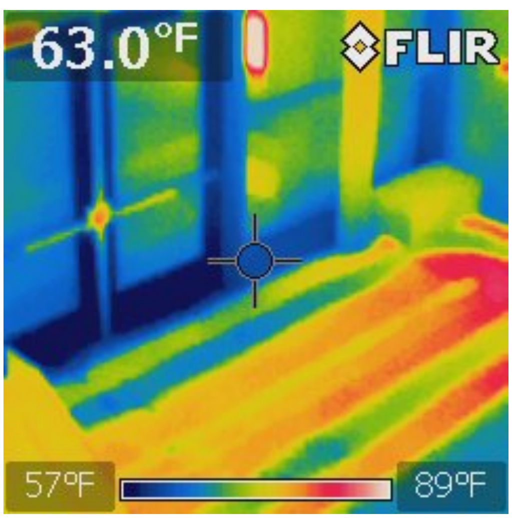


Figs. 10, 11, 12: HOBO U12 Data Logger Output

Table 1: Maximum Vertical Temperature Difference

Vertical Location	Fans On	Fans Off
Center	4.134° F	3.621° F
Hearth	2.885° F	2.931° F





Figs. 13, 14: Surface temperatures of hearth and brick tower, and entryway

These images show thermal ranges on a cold day when the hearth is on and the air temperature outside is significantly colder than inside. In figure 14 you can clearly see the radiant heat floor coils.

5. <u>ANALYSIS</u>

The IR camera and Raytek temperature gun used to map the heat sources within the space revealed radiant floor coils by the front entry, a forced air supply vent in the northwest corner and the hearth as heat sources (Fig.15). The data shows that the greatest vertical difference in temperature of the atrium space is more than 2 ° F with the fans on. The temperature difference was lower with the fans off, and after an hour of equilibration, even converged to 1.163° F.

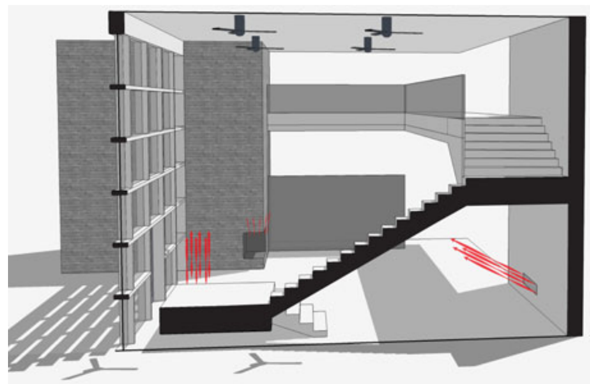
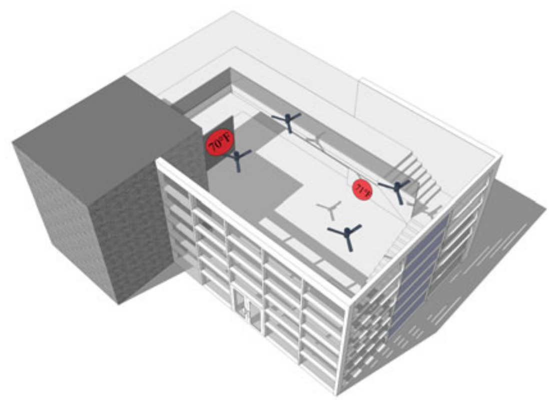
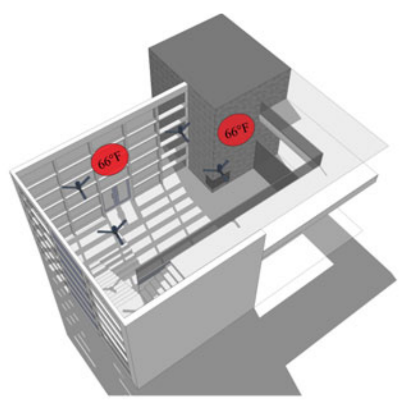


Fig. 15: Major heat sources in the atrium space





Figs. 16, 17: Raytek surface temperature readings

Surface temperature readings with the Raytek Temperature gun are mapped in Figs.16 and 17. While the hearth is itself a heat source, the infrared photos suggest that the heat of combustion isn't transferred to the brick tower for storage and protracted radiation into the environment, but rather exhausted with the combustion gases. The hearth brick tower is actually a colder mass than the other internal walls in the room, and the same temperature as the wall of glazing. However, temperature differences between the internal walls and external walls of glazing and brick are all within 5° F. The temperature readings were taken when there was no direct solar gain on the northeast windows.

The temperature data collected from the Hobo U12 data loggers revealed a consistent heat stratification in the hearth location, where the 5' placement had the lowest temperature readings and temperatures were consecutively higher to the 20' placement, which had the highest. The readings in this area were consistent with the fans on or off. The center location exhibited a different stratification with the fan on. The concentration of temperatures at the 10' placement was significantly the highest. The 5' location was the lowest and consistent. The 15' and 20' locations were similar temperatures with a mean difference of 0.34° F, while the 15' and 10' had a mean temperature difference of 2.19° F.

The hypothesis that the vertical temperature differences would be diminished to within 2° F when the fans were on was disproved based on this small sample of data. In fact, temperature differences were within 2° F when the fans were off, but reached a maximum difference of 4.22° F when the fans were on and the highest temperatures were centered around the 10' Hobo placement. While this was counterintuitive, a possible explanation for this result could be that the fans are directing the air downward, but only with sufficient velocity to move the hottest air midway into the space; therefore, the hottest temperatures are directed into the middle of the volume. This is why the air begins to stratify and temperatures become more predictable when the fans are off. In addition, there are upper and lower hallways which intersect the space on the southwest side and are adjacent to the exterior doors on the east side. The two areas of air movement could produce a shearing effect on the air about the 10' midpoint, which could also account for some stasis of the air at this level.

6. CONCLUSIONS

When examining the data, there were certain variables that could have been further minimized to obtain more conclusive data. It would be impossible to control all the thermal variables affecting the space since the external environment is dynamic. Having longer time periods of data collection with the fans on and off would have allowed a more substantial set of data to recognize trends or aberrations. This data could also be overlaid on meteorological data for the collection periods to trend it in correlation with the external conditions. Although we minimized the insolation by taking late morning measurements, being able to fully control all other variables, such as ingress and egress of air through the main entrance would have provided a more conclusive correlation of the fans impact on the vertical temperature differences. However, the use of the space is dynamic and in this context, studying the ceiling fans with dynamic conditions still yields valuable results.

Based on the initial data, several conclusions were formed. There is a vertical temperature gradient in the space which is readily identifiable; however, with the use of the fans, the maximum vertical temperature differences were greater than 2 ° F. In fact, with the fans on, the middle zone was greater than 4° F. According to ASHRAE Standard 55, this local thermal control would dissatisfy 3-4% of occupants (1). The 4° F zone would explain the initial recognized temperature change when descending the stairs, which prompted this case study.

We believe that the fans are affecting the downward movement of warmer air; however, this does not appear to contribute to a diminished vertical temperature difference, but rather a concentration of warmer air in the center of the atrium space. Furthermore, the observed effect is primarily statistical, but not practical, since the temperatures at the 5' placement, the occupant level, stay consistent whether the fans are on or off.

The hearth location yielded consistent temperature results during testing. Our initial assumption was the thermal mass of the vertical masonry tower stabilizes the temperature gradient due to its radiation of stored hearth heat. However, after analyzing the radiant surface temperatures with the infrared camera, it is clear that the tower does not share the same heat strata as the air (Fig. 13). The corner hearth location is likely providing a shelter or air pocket from the primary air movement within the space. This protection from turbulence allows the usual and customary heat stratification.

The initial hypothesis was that the use of the ceiling fans in the Hedco atrium space diminished the vertical sensible temperature difference between floors to within 2 ° F versus without the use of the ceiling fans. In conclusion, this hypothesis was proven incorrect, in that the vertical temperature gradient of the atrium was greater than 2° F with the ceiling fans off and even greater than 4° F with the fans on. Further investigation is warranted to be able to trend this more conclusively, as well as determine the movement of the air within the space. If these trends are corroborated, then the energy expenditure for the use of the fans may not be warranted.

7. ACKNOWLEDGEMENTS

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