THE SOLAR CORRIDOR:
THERMAL COMFORT IN THE SUNSPACE IN GERLINGER HALL

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ABSTRACT

This case study looks at the temperature influxes within a south-facing corridor of Gerlinger Hall, a gymnasium for the University of Oregon in Eugene, Oregon. This space is a popular place for students, even when the temperature is out of the ASHRAE thermal comfort range.

In this study, we were interested in investigating sources of heat loss and movement of heat within the corridor. Through our investigation, we discovered that solar heat gain is as much of a problem as heat loss. Temperatures underwent extreme fluctuations and ended up spending time above the comfort zone as well as below.

We have proposed several strategies that may improve the thermal qualities of the sunspace, which include replacing the windows with high-performance glazing, shading the windows, and designating the corridor as unconditioned space.

1. INTRODUCTION

Gerlinger Hall was constructed in 1921 as a gymnasium at the University of Oregon, and is still used for this purpose today. The building is wood frame construction clad in masonry.

During our initial walk-through, we observed several interesting things about the corridor in Gerlinger Hall. The temperature seemed cooler than would be comfortable for a prolonged period of time without outdoor clothing. Although the sky was cloudy, the area was quite bright and pleasant. The space consists of a long corridor with many windows along the south side of Gerlinger Hall, wide enough to accommodate seating opposite the windows. The ceiling is slanted so that the highest point is on the window side and the lowest over the chairs on the other side.

Fig.1: South exterior view of Gerlinger Hall

The windows are old, single-glazed and operable, with numerous gaps around the framing and opening mechanisms. Radiators along the window side run on steam heat and are individually controlled by a valve on each radiator. There is no thermostat associated with these radiators, but the valves are customarily set on one (out of five), and are left on at all times. The average surface temperature of the radiators (measured with a Raytek temperature gun) was determined to be 163˚F.

Fig. 2: South-facing corridor

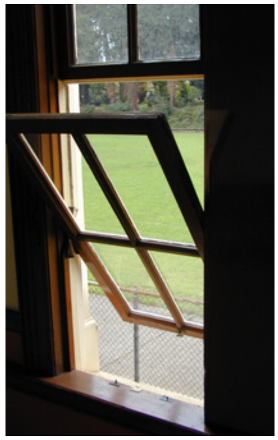

Fig. 3: Operable window

2. HYPOTHESIS

Some questions we considered:

How much heat is lost through the windows?
Are people thermally comfortable when sitting here for prolonged periods?
How much solar heat gain is there on a sunny day vs. a cloudy day?
Does the high ceiling near the windows trap heat?
How does the air flow in each bay?
What other sources of heat loss are there?

The height of the ceilings near the windows made us wonder if all the heat gained from the radiators and the sun was rising and escaping. We observed two major causes of heat loss: the large, single-glazed windows and the numerous cracks in the window framing. This led to a hypothesis: *In November, the temperature in the sunspace in Gerlinger Hall will not reach the temperature comfort zone dictated by ASHRAE (68-77°F) due to heat loss through the glazing assembly.*

3. METHODOLOGY

In order to determine the sources of heat loss in the corridor, we placed temperature data loggers along the estimated air flow path to measure the dry bulb temperature differences at various points along the cross-section of the hallway, emphasizing the ceilings and the windows. We also calculated infiltration losses by measuring air flow through representative gaps and determining the area of opening.

3.1 Equipment used

Seven HOBO XT data-loggers were used along with their thermistors, each set to record the dry bulb temperature at a 5-minute interval from 7 PM on November 7th until 10 AM on November 10th. The HOBOs were placed in the following locations:

- on the wall just below the window
- directly on the window at midpoint
- directly on the window at the top
- on the exterior of the window
- on the ceiling close to the window
- on the ceiling in the center
- on the ceiling above the seating area

We also used a Solomat hot wire anemometer to record air velocity through the gaps in the window framing. The anemometer readings were taken at the visible gaps in the window assembly and compared to readings where no cracks were evident. Direction and air speed were noted.

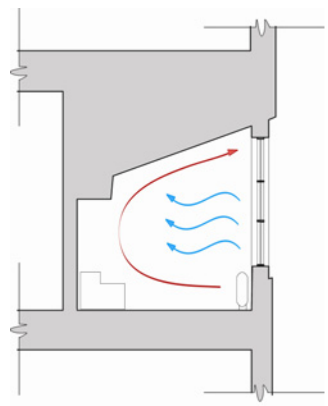

Fig.4: Estimated air flow

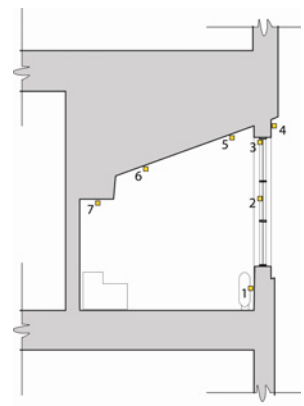

Fig. 5: Hobo locations in section

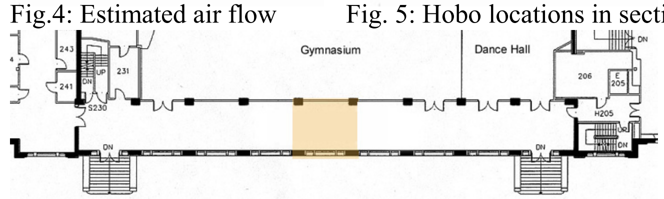

Fig. 6: All measurements were taken in the middle bay of the hallway.

4. RESULTS AND ANALYSIS

Temperatures taken at the ceiling remained relatively stable, but temperatures taken at the window fluctuated almost as much as the outdoor temperature, with the temperature taken at the wall under the window remaining in between. We assumed that the spikes encountered when graphing temperatures recorded by the data loggers outside and on the window were due to changing amounts of direct sunlight at these locations.

As expected, there was a lot of air movement by the gaps around the windows, but not much movement where there were no visible gaps. It is clear that heat is being lost through infiltration.

Temperatures inside the sunspace changed drastically with the sunlight, but were not consistently below or above ASHRAE comfort levels. However, it is evident that heat is being lost and gained through the glazing assembly. As observed, the inside surface temperature of the windows changed at nearly the same rate as the outdoor temperature, implying that the glazing assembly is not providing much of a barrier to exterior conditions. However, the temperature at the ceiling fluctuated less. We determined that the heat differential between inside and outside temperatures at the windows is caused by several components: the amount of solar radiation the window is receiving, infiltration through cracks in the framing of the windows, and conduction through the exterior walls and glazing assembly. We also determined that the sheer amount of glazing in this area of the building has a major effect on temperatures within this space.

The temperatures measured at the ceiling remained much more stable than those near the windows and were similar to one another. It is evident that warm air was rising to the ceiling and staying there throughout the day. At night temperatures at the ceiling fell, but not as drastically as those near the window.

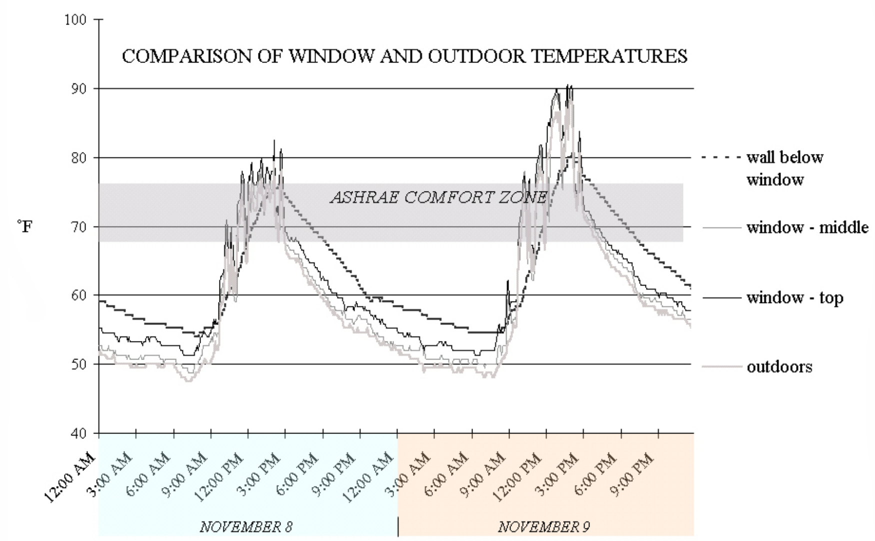

Fig. 7: Comparison of window and outdoor temperatures

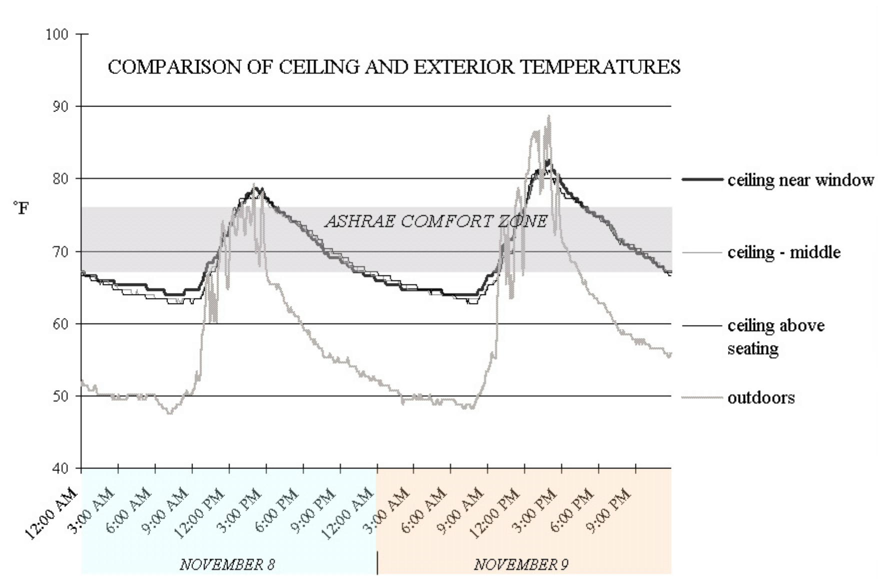

Fig. 8: Comparison of ceiling and outdoor temperatures

Fig. 9: Window bay

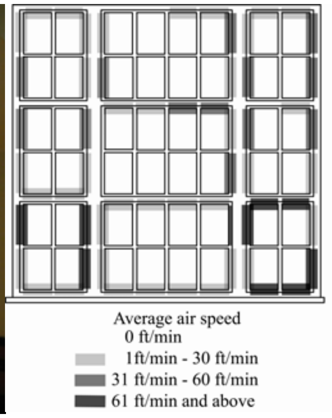

Fig. 10: Air velocity readings across the window bay

4.1 <u>Solar radiation</u>

Solar radiation had a significant effect on the temperatures within the corridor, particularly at the windows.

Spikes (Fig. 11) were observed only on the temperature graphs for data-loggers at the middle of the window, top of the window, and outside. Although weather for these midday and afternoon hours was reportedly clear[1], we concluded that the sunshine at those times was intermittent and local weather conditions were partially cloudy. This shows the dependence of the window temperature on the amount of sun it is receiving.

Trees and other buildings around Gerlinger Hall block the sun in the early morning and late afternoon. Sunrise at this location is at 9AM, and sunset is at 3PM. Temperatures rose sharply after the building began receiving solar radiation and dropped once the sun sank below the trees.
The recommended ratio of solar glazing to floor area for Salem, Oregon, is between 0.12 and 0.24, with the assumption that the building is insulated and windows are at least double-glazed.[2] Even if the windows were upgraded to a high-performance type, the ratio of glazing to floor area would still exceed the recommended ratio.

$A_{glazing} = 702 \text{ ft}^2$

$A_{floor} = 1940 \text{ ft}^2$

$A_{glazing}/A_{floor} = 0.36$

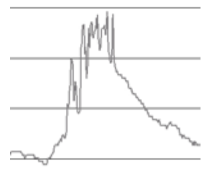

Fig. 11: Solar spikes

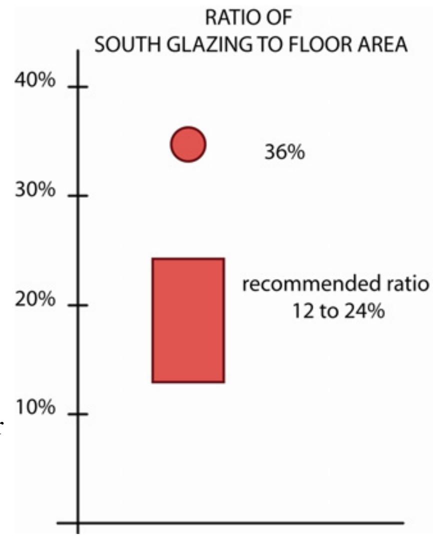

Fig. 12: Ratio of south glazing to floor area

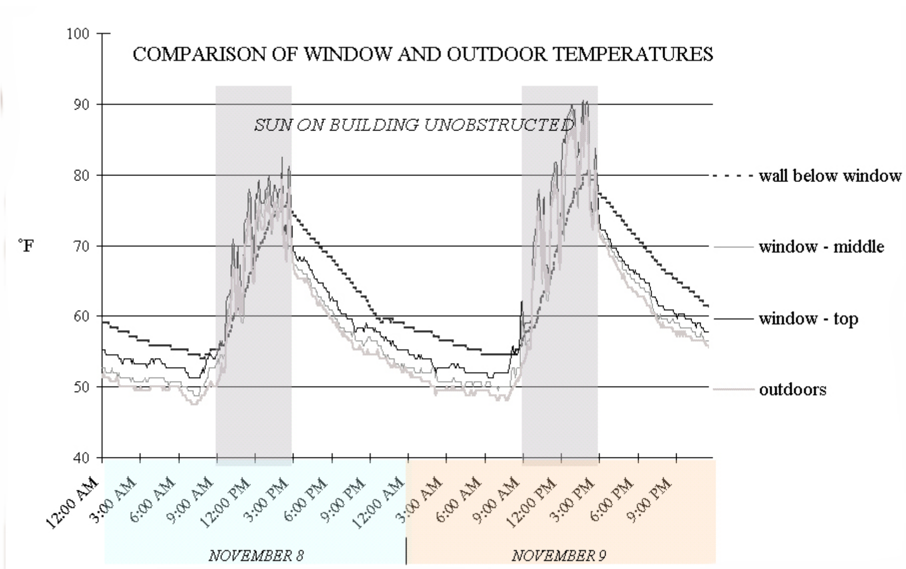

Fig. 13: Comparison of window and outdoor temperatures

4.2 Infiltration

The calculation for the sensible heat loss or gain by the flow of outdoor air into spaces is as follows[3]:

$Q_{infil} = V \times 1.08 \times \Delta t$

Where

Q_{infil} = sensible heat exchange due to infiltration (Btu/h)

V = volume flow rate, in cubic feet per minute (cfm) of outdoor air introduced

1.08 = a constant derived from the density of air at 0.075 lb/ft3 under average conditions, multiplied by the specific heat of air (heat required to raise one lb of air 1˚F), which is 0.24 Btu/lb3h and by 60 min. The units of this constant are Btu-min/ft^3h˚F.

Δt = the average difference between temperatures along the south wall and the outdoor temperatures

To obtain V, the average air speed through the gaps in the windows was multiplied by the area of the gaps. (The average air speed was determined by anemometer readings at the gaps.) To obtain the area of opening, the gaps on the bottom row of the window bay were measured by tape measure while the windows were closed. Because the two windows above are the same type and size, the area of gaps in the bottom window is multiplied by three to obtain the total area of gaps in one window bay.

$V = A \times v$

A = area of gaps in the window = 0.817 ft^2

v = average velocity of air at gaps = 46.5 ft/min

$V = (0.817\ ft^2)\ (46.5\ ft/min) = 38$ cfm

Heat loss during time studied:

$\Delta t = 3.23$˚F

$Q_{infil} = V \times 1.08 \times \Delta t$

$Q_{infil} = (38\ cfm)\ (1.08)\ (3.23˚F)$

Q_{infil} = 133 Btu/h

The heat exchange due to infiltration for one bay of the corridor is 83 Btu/h. Since there are 7 bays in the corridor, the total heat exchange due to infiltration (for the entire corridor) is:

Total Q_{infil} = (133 Btu/h) 7 = 931 Btu/h

4.3 Conduction

Since the windows in Gerlinger Hall are single-glazed, conduction through the glazing assembly is significant cause of heat exchange between the interior and exterior. The U-value for a single-glazed window assembly is 1.30 Btu/ h ft^2°F[4].

$A_{glazing} = 702\ ft^2$

$Q_{conduct} = UA\ (\Delta t)$

$= (1.30\ Btu/h\ \cancel{ft^2 °F})\ (702\ \cancel{ft^2})\ (3.23\cancel{°F})$

= 2948 Btu/h

$Q_{conduct}$ = 2948 Btu/h

The total heat exchange through the glazing assembly during the time studied, accounting for both conduction and infiltration, is as follows:

$Q_{total} = Q_{infil} + Q_{conduct}$

Q_{total} = 931 Btu/h + 2948 Btu/h = 3879 Btu/h

Q_{total} = 3879 Btu/h

From this comparison, it is clear that in this space more heat is exchanged through conduction than through infiltration. There is a significant amount of heat exchange through the glazing assembly which causes the Gerlinger Hall sunspace to be thermally uncomfortable. Because of the drastic temperature changes caused by solar radiation, conduction, and (to a lesser degree) infiltration, there is no effective radiator setting that could be used to combat these temperature swings. An HVAC system would have to both heat and cool every day to create a thermally comfortable space in the present situation. Since this would be inefficient energy use, other solutions must be considered.

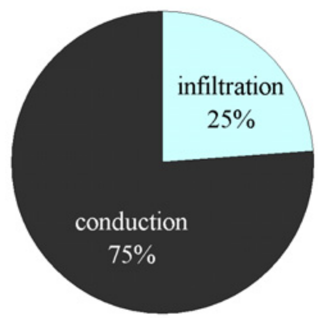

Fig. 14: Contributions to heat exchange

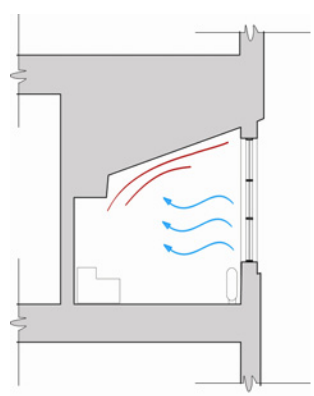

Fig. 15: Air flow in one bay

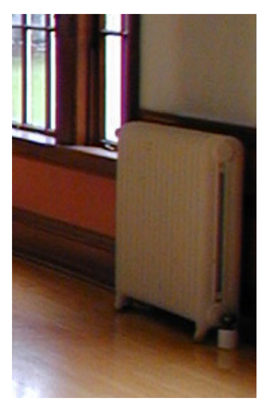

Fig. 16: Radiator

5. CONCLUSIONS

It is evident that the temperature in the Gerlinger Hall sunspace is often either above or below the ASHRAE comfort zone due to solar radiation and heat exchange through the glazing assembly by way of infiltration and conduction. Of these factors, the most significant is conduction through the windows themselves. Therefore, the most effective method of stabilizing temperatures in the sunspace would be to replace the old, single-glazed windows with high-performance windows. The original window framing could remain, especially since it adds to the ambience of the space, but it should be weather-stripped and detailed for maximum insulating effectiveness. However, since the ratio of glazing to floor area would still be significantly over the maximum recommended, there might still be problems with both heat gain and loss in this space.

A less expensive solution is to turn off the radiators in the corridor completely and designate it as unconditioned space. It would continue to be warmed by the sun during the day, and would be a buffer zone between the interior practice spaces and the outdoors. This would solve the problem of making the space comfortable: as unconditioned space, it would not need to comply with standards of comfort. Since there is no optimum setting for the radiators because of the extreme temperature fluctuations, this would be a cost-effective and simple solution, and might not actually change temperatures in the space very much from what they are now. People would continue to idle in the corridor between classes or use it as a study or meeting place despite extreme temperatures, just as they do now.

Other solutions which could be combined with either of the above options to help stabilize temperatures include:

- repairing cracks in the window framing
- adding thermal mass to the floor or ceiling of the space
- planting trees to block summer sun
- shading the windows

However, since heat exchange through conduction was by far the most significant factor determining the thermal quality of the corridor, these solutions would have little impact by themselves.

This case study was limited to the study of the temperatures within one area of this building. Further studies could be done regarding how heat from the rest of the building interacts with this space, airflow within each bay and along the corridor, and how temperatures change during the summer and when the radiators are turned off. Social aspects of the space could also be investigated: why people are willing to tolerate extreme temperatures in order to experience this space and under what conditions (time of day, sky conditions, season, etc.) they prefer to experience it.

6. REFERENCES

[1] The Weather Underground, http://www.wunderground.com/

[2] Reynolds, John, and Benjamin Stein, Mechanical and Electrical Equipment for Buildings, Ninth Edition, 2000, p. 145.

[3] Reynolds, John, and Benjamin Stein, Mechanical and Electrical Equipment for Buildings, Ninth Edition, 2000, Table 5.6, p. 212-216.

[4] Reynolds, John, and Benjamin Stein, Mechanical and Electrical Equipment for Buildings, Ninth Edition, 2000, Table 4.13, pp. 171-172.