COMFORT AND THERMAL PERFORMANCE OF PASSIVE SOLAR TEST ROOMS IN MUNCIE, INDIANA.

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ABSTRACT

This article presents a summary of the thermal conditions (in terms of operative temperature) found during the 2002-2003 heating season in five different passive solar test rooms (Direct Gain, Trombé-Wall, Water-Wall, Sunspace, and Roofpond) plus a control room located in Muncie, Indiana.

In addition, this article discusses particular characteristics of the thermal environments produced by each of the strategies studied in this research project, placing an emphasis on their implications for comfort. Recommendations to improve thermal comfort in each of the strategies are also made and future research is discussed.

1. EXPERIMENT SETUP

This project was setup to be a side-by-side comparison between a well insulated control room (walls R-26; floor R-22; roof R-35) without any source of heating, and five passive solar test rooms with the same type of insulation: Direct Gain (DG), Trombé-Wall (TW), Water-Wall (WW), Sunspace (SS), and Roofpond (RP). All the test rooms have a floor area of 128 ft^2 (8 ft by 16ft) with the smaller sides facing north and south.

2. TEST ROOM INSTRUMENTATION

The test cells were instrumented using a four point grid (see Figures 1-6) in which each of the nodes had four sensors (two internal and two external) connected to a HOBO H-8 RH/Temperature 2x data logger (see Figure 7). The two internal sensors were used to measure the air temperature and the relative humidity respectively, and the two external sensors were used to measure the mean radiant temperature (with a black globe) and the air temperature with a thermistor placed above the globe thermometer and shielded from solar radiation (see Figure 7).

3. RESULTS

The results presented in this article include only the data measured during the 2002-2003 heating season (December 2, 2002 through May 3, 2003).

3.1. Roofpond (RP)

The Roofpond used in this study was based on the Skytherm North system developed by Harold Hay and tested in St. Paul, Minnesota. The system consists of a “ceiling pond” with eight inches of water under a pitched roof conventionally insulated on the north side and with glazing on the south slope. Interior movable insulation is provided by a Thermacore® garage door (R-9.31) that moves between the north and south slopes. The movable insulation was automated and during the heating season it opened 45 minutes after sunrise and closed 45 minutes before sunset. The movable insulation, however, could be programmed to open or close at any desired time.

The RP was the most thermally stable among the strategies investigated both in time (measured as a percentage of operative temperature occurrence in the time studied) and throughout the space (simultaneous comparison of the four points instrumented within each cell), having little daily operative temperature variations during the heating season (see Fig. 8). In addition, the RP had, along with the WW test room, the highest nighttime temperatures (compare

Fig. 1. Roofpond (RP) Interior View

Fig. 2. Sunspace (SS) Interior View

Fig. 3. Water-Wall (WW) Interior View

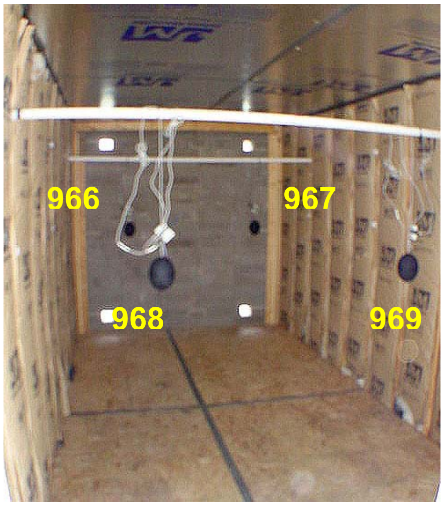

Fig. 4. Trombé-Wall (TW) Interior View

Fig. 5. Direct Gain (DG) Interior View

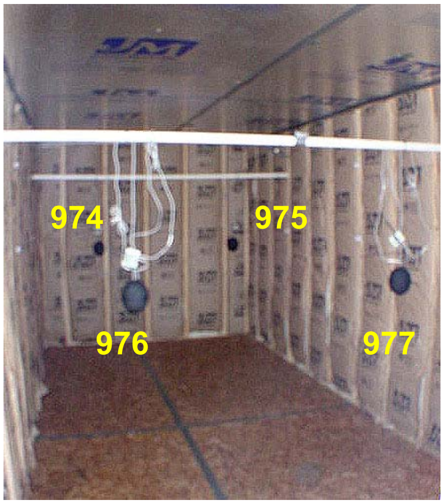

Fig. 6. Control Cell (CC) Interior View

Figs. 8 and 10). The RP strategy also had the best performance during the extended periods of overcast sky conditions, which were quite frequent during the 2002-2003 heating season. Though its performance during the daytime was not as good as the performance of the DG and WW rooms, the RP strategy still has great room for performance improvements as it can be easily coupled with any of the other strategies investigated in this project.

For the 2003-2004 heating season additional insulation (1" of foil faced rigid insulation) has been placed on the inner side of the test room door to minimize heat losses. In addition, the exterior access door to the attic (thermospace) was replaced with double doors with better insulation. Lastly, the interior batt insulation was doubled to cover the spots where bracing interrupted the continuity of the original batt installation (see Fig. 1).

3.2. Sunspace (SS)

The SS type investigated in this study (vertical glazing facing south, sloped glazed roof, and glazed side-walls) was attached to the test room. The SS had the smallest heat capacity of all the strategies studied (84 exposed standard concrete blocks) and the largest solar collector area if the side walls of the Sunspace are included. This arrangement produced large operative temperature swings between day and night with perceivable variations during the daytime between the sensors placed on the south side and those placed on the north side of the test room (see Figs. 2 and 9).

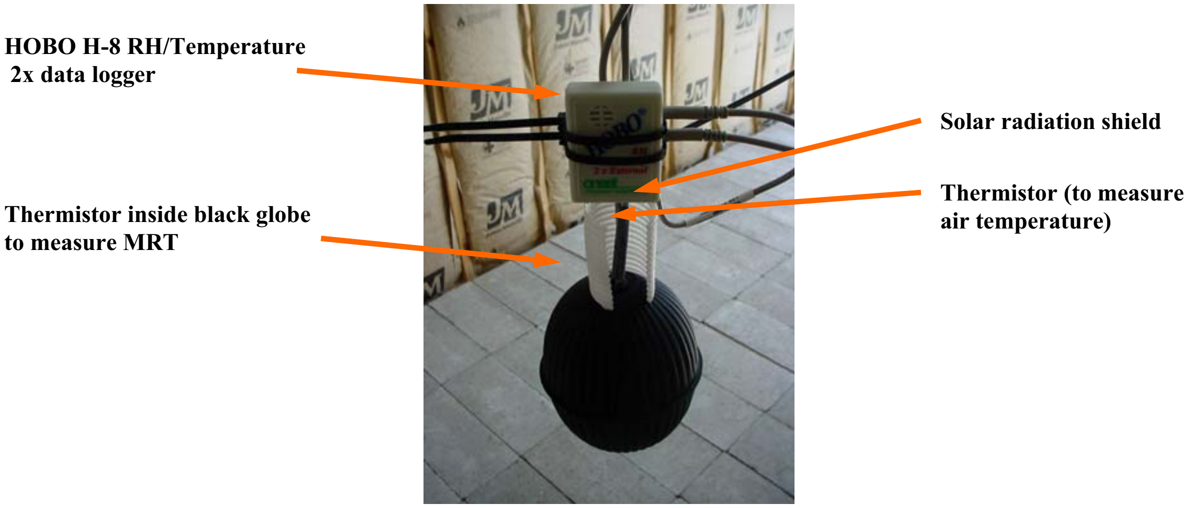

Fig. 7. Equipment Bundle Placed 43.3” (1.1 mts.) Above the Finished Floor

In many ways the SS strategy was the worst performer of this study, but with additional thermal storage and less glazing it could perform better. For the 2003-2004 heating season the test room was reconfigured to be a roofpond with direct gain below.

3.3. Water-Wall (WW)

The WW used in this study consisted of four translucent Sun-Lite® thermal storage tubes, each holding 66 gallons of water when full. The results presented in Fig. 10 show that the high thermal storage capacity of the WW room along with a ratio of south glass (clear double glass) to floor area of roughly 1:2 were able to provide less variations of operative temperature on both time and space when compared to the DG room (Fig. 12). The WW daytime conditions fell somewhere in between those found in the DG and TW rooms, but with higher operative temperatures at night than those found in the DG and TW rooms (compare Figs. 10, 11, and 12). In fact, the nighttime performance of this strategy is comparable to that of the RP (compare Figs. 8 and 10). For the 2003-2004 heating season the only change proposed is the addition of 1” of foil faced rigid insulation on the inner side of the door to reduce heat losses.

3.4. Trombé-Wall (TW)

The TW type investigated in this project was the vented one. The results shown in Fig. 11 demonstrate that even though the TW room had less thermal storage capacity than the DG room (the TW room had 109 solid concrete blocks versus 115 in the DG room), but with the same area of glazing, its operative temperature had less variations in time and space making it in some ways more acceptable than Direct Gain (compare Figs. 11 and 12). It is important to note that during the heating season reported in this article the vents were open at all times. For the 2003-2004 heating season the vents will be open two hours after sunrise and closed one and a half hours before sunset. In addition, 1” of foil faced rigid insulation on the inner side of the door will be installed to reduce heat losses.

3.5. Direct Gain (DG)

The DG test room had a ratio of south glass (clear double glass) to floor area of roughly 1:2. The ratio of south glass to exposed thermal mass (solid concrete block placed on the floor) was also close to 1:2. With this setup the DG room had significant variations of operative temperature on both time and space. The results shown in Fig. 12 suggest that a lower ratio of south glass to exposed thermal mass (perhaps 1:6 as suggested by Balcomb et al [1984]) would reduce the operative temperature variations between day and night. The operative temperature variations across the room are caused primarily by the incidence of direct solar radiation on the south side of the cell during the daytime and the high heat losses due to the large glazed area at night (see Fig. 5). This problem could be solved by lowering the ratio of south glass to floor area. However, this would make it more difficult to achieve 100% heating. The changes for the 2003-2004 heating season were the addition of 1” of foil faced rigid insulation on the inner side of the door and an increase thermal capacity from 115 solid concrete blocks to a total of 230 blocks. This modification also changes the ratio of south glass to exposed thermal mass to approximately 1:4.

3.6. Control Cell (CC)

Since the CC doesn’t have a source of heating nor significant thermal storage, it represents the conditions that

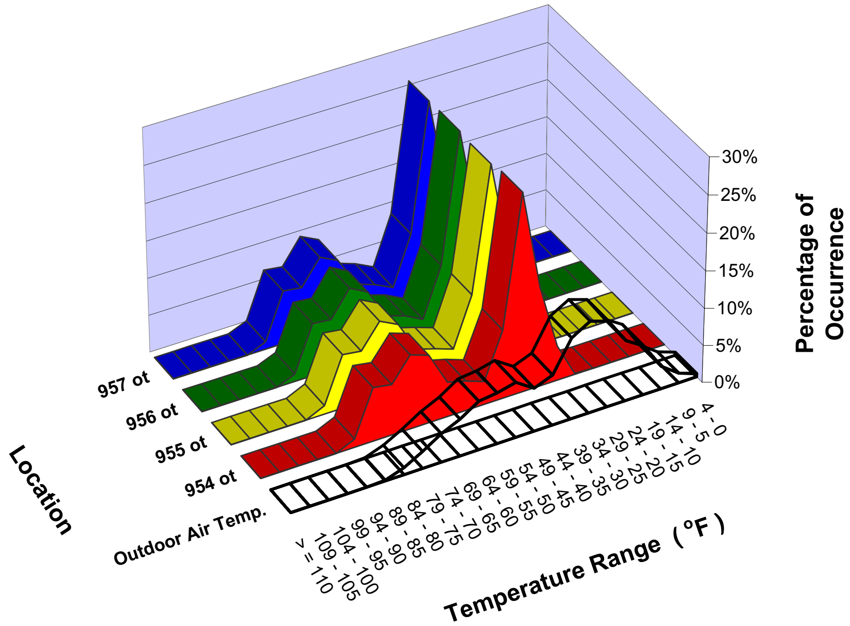

Fig. 8. Operative Temperature Frequency (Heating Season Only) inside Roofpond Test Room.

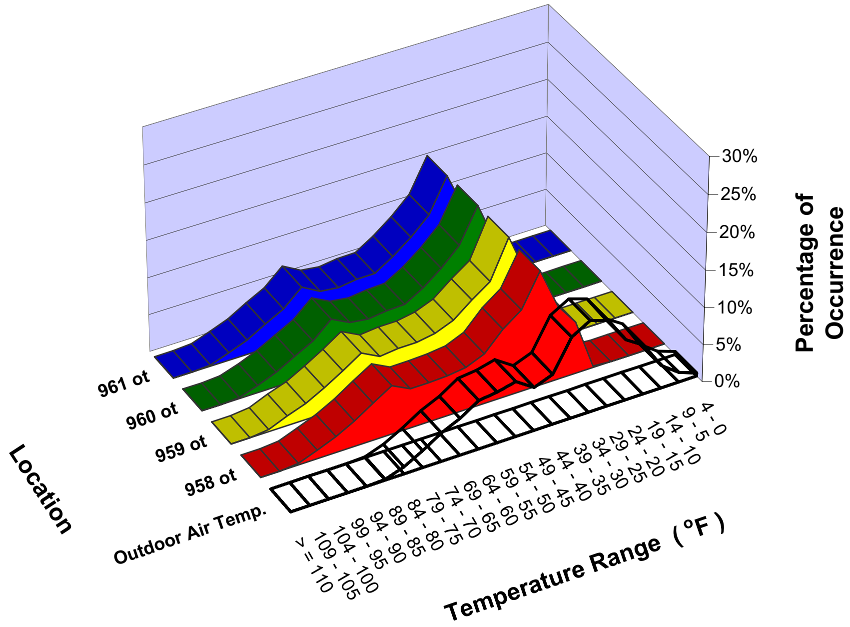

Fig. 9. Operative Temperature Frequency (Heating Season Only) inside Sunspace Test Room.

would be found in well insulated light frame construction without internal gains and when the heating system is not in use. Figure 13 shows the frequency of operative temperature occurrences in the four points instrumented inside the test room (see Fig. 6). As expected, the CC closely follows the outdoor conditions without reaching the outdoor temperature extremes. It is important to note that the measurements at point 976 (see Fig. 6) had the lowest temperatures due to its proximity to the door, the building component with the highest heat losses. To correct this situation, additional insulation (1” of foil faced rigid insulation) was placed on the inner side of the door for the 2003-2004 heating season.

4. CONCLUSIONS

After evaluating the results of the first heating season it became clear that the only way to obtain 100% Solar Savings Fraction in a Midwestern climate like that of Muncie would be to combine a direct or indirect gain strategy with a roofpond. This combination is likely to achieve both the heat gains to raise the interior operative temperature to an acceptable level and to achieve the thermal stability that characterizes comfortable buildings. In addition, and partly because these test cells didn't have any internal gains, it is necessary to increase insulation levels above what is recommended by Balcomb et al (1984).

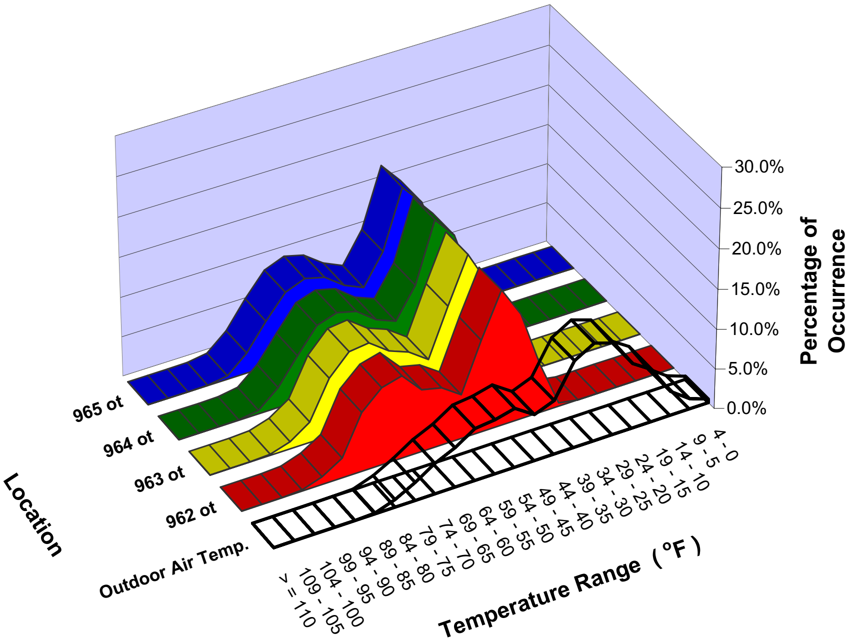

Fig. 10. Operative Temperature Frequency (Heating Season Only) inside Water-Wall Test Room.

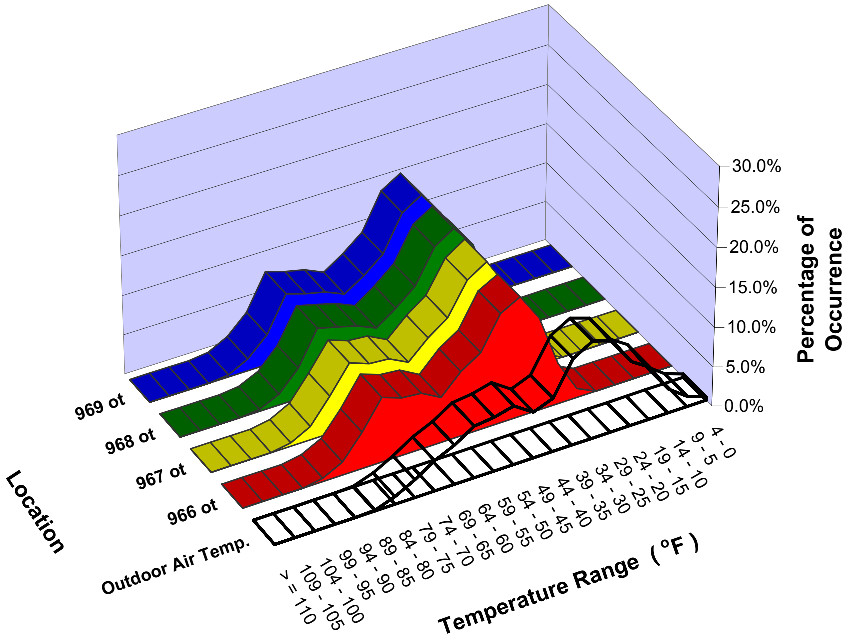

Fig. 11. Operative Temperature Frequency (Heating Season Only) inside Trombé-Wall Test Room.

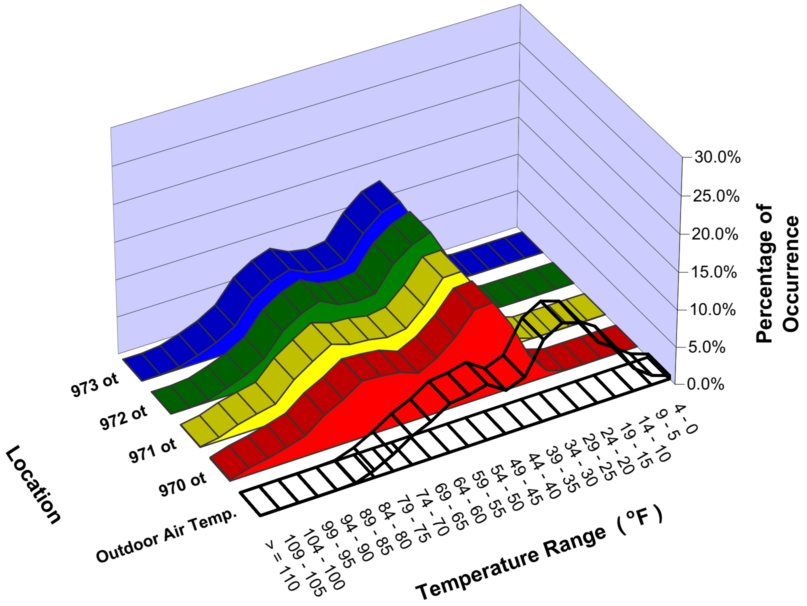

Fig. 12. Operative Temperature Frequency (Heating Season Only) inside Direct Gain Test Room.

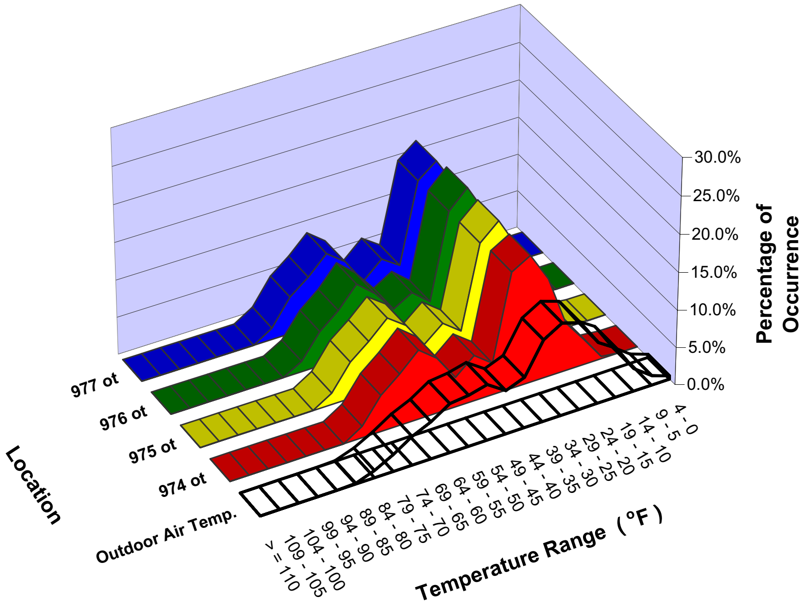

Fig. 13. Operative Temperature Frequency (Heating Season Only) inside Control Test Room.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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