Retrofit Passive and Active Solar with Thermal Storage for Emergencies

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Abstract: A retrofit passive solar system for emergencies (Smallen) was evaluated using a Trombe water wall, which was both the solar collector and thermal storage unit. One concern with a water wall is the loading on wood floors with a perimeter foundation. A strategy to separate the water containers from the collector and distribute the containers around a room could alleviate this concern. To test this hypothesis, one active and two passive solar configurations with distributed containers were tested in the same room. The results found that the weight of the water containers did not sag or damage the floors. Also, there is statistically no significant difference among the three configurations in terms of both room temperature or stored heat but there is between the room temperature of the three configurations as a group and the lower outside temperature.

Key Words: Active, Passive, Thermal Storage, Retrofit, Emergencies

1. Introduction

A paper on retrofit passive solar for emergencies (Smallen) was presented at the ASES Solar 2024 Conference. The passive solar structure was a wall of individual water-filled containers (Trombe water wall) sitting on a shelf next to an equator facing window. The structure is both the collector of solar energy and the thermal storage unit. This idea is intended to be used in times of war or natural disasters, when the heating infrastructure of a nation is damaged or destroyed.

One concern with a water wall is the loading on wood floors with a perimeter foundation where the minimum residential live load requirement is 146 kg/m^2 (30 psf) for sleeping areas and 195 kg/m^2 (40 psf) for non-sleeping areas (2019 California Residential Code). There is no such concern for slab on grade foundations. A water wall could weigh 227 to 454 kg (500 to 1000 lbs), and the footprint pressure could be as high as 610 kg/m^2 (125 psf). However, the load is distributed over a larger area by the floor structure, and the pressure is likely lower.

2. Methods and Approach

Nevertheless, a strategy to separate the water containers from the collector and distribute the containers around a room could alleviate the concern for floor loading. Therefore, an experiment was designed with separate active collectors and storage components. This configuration was compared to two passive approaches. So, the experiment consists of a comparison of three configurations for emergency heating. Configuration 1 consists of three active hot air heaters (Figure 1), separate and

 https://doi.org/10.52202/083252-0020

dispersed thermal storage in water (Figure 1) and nighttime window insulation. The water containers provided about 35% of the room's thermal mass. The rest of the thermal mass is provided by a Gypcrete floor (26.8%), sheetrock (21.1%) and furniture (16.6%). The hot air heaters consist of a flat black plate/space/ insulation sandwich. A fan and a photovoltaic panel circulate the air through the collectors and into the room. Configuration 2 is a passive solar approach with thermal storage in water and nighttime window insulation. Configuration 3 is the same as configuration 2 but without nighttime window insulation. Configuration 3 is the control. The term "direct passive" is not used here because the sun did not directly illuminate the thermal storage containers. All three configurations were tested in the same room with a perimeter foundation. A floor plan shows the location of the hot air heaters and thermal storage (Figure 2). The order of testing was random. The room temperatures and solar radiation were measured over the 2024 to 2025 heating season using calibrated instruments. The data was evaluated using analysis of variance (ANOVA) with α = 0.05. Also, the measured and calculated room temperatures were compared to each other.

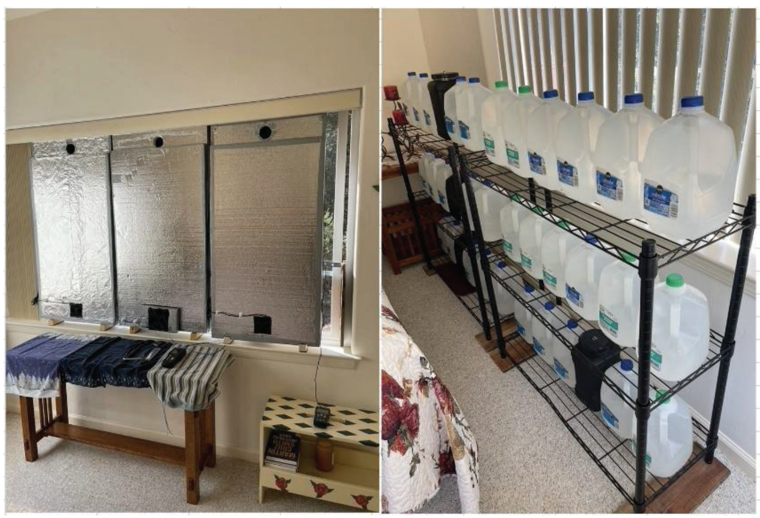

Figure 1. Hot air solar collectors (L) and water thermal storage (R).

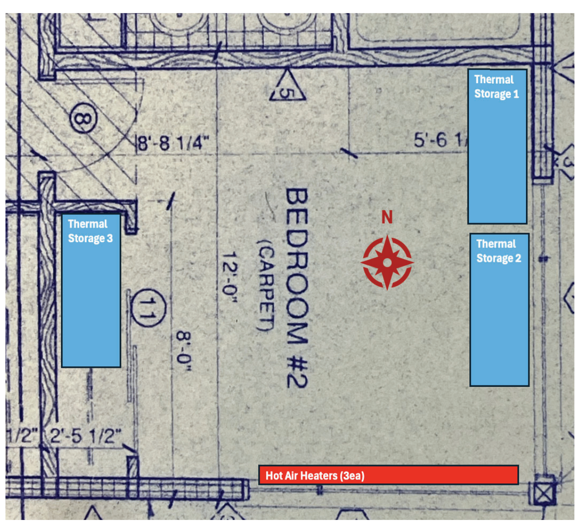

Figure 2. Location of hot air heaters and thermal storage.

3. Theory

Below describes the theory for determining the solar energy stored in the room and the calculated room temperatures. The solar energy is stored in the thermal mass of the room as described above. The equations below pertain to these materials.

3.1 The heat stored in each material is $Q_U = mC\Delta T$ (eq. 1), where *m* is mass, *C* is the specific heat capacity, and *ΔT* is the temperature increase.

3.2 The main heat loss mechanism is radiation. Heat loss via radiation is: $Q_L = \frac{t_1 \varepsilon_1 A_1 \sigma \left(T_2^4 - T_1^4\right)}{1000}$ (eq. 2), where t_1 is the time of energy collection, ε_1 is emissivity, A_1 is the surface area, σ is the Stefan-Boltzmann constant, T_1 is the average room temperature, T_2 is the average material temperature and *1000* converts *W* to *kW*

3.3 The total heat stored at the end of the day is: $H_b = \frac{Q_U + Q_L}{A}$ (eq. 3), where A = the window area. Radiation heat loss is added to heat stored to account for the total heat collected.

3.4 The predicted average daily indoor temperature (Mazria) is: $t_i = \frac{HG_{sp}}{U_{sp}} + t_0$ (eq. 4), where HG_{sp} is the solar heat gain, U_{sp} is the overall coefficient of heat transfer of the room, and t_0 is the average daily outdoor temperature.

4. Results

The weight of the water storage did not sag or damage the floors. There is statistically no significant difference (95% confidence level, P-value = 0.22 to 0.96) among the average room temperature of the three configurations but there is between the three configurations as a group and the lower outside temperature (95% confidence level, P-value = 0.00). Similar results were found by Thangam et. al. (2022) when comparing passive and active solar heaters. The average air temperature of the room was about 7 to 12°C higher than the outside air temperature over the heating season (Figure 3). The measured and calculated average room air temperatures are similar. The minimum and maximum room air temperatures are close to the comfort zone limits of 19°C to 26°C. There is statistically no significant difference (95% confidence, P-values = 0.12 to 0.59) among the three configurations in terms of the heat stored in the room. The average efficiency of heat collection from solar radiation to stored heat in the room is 48.1%. Two of the 54 water bottles leaked so drip pans should be installed under the bottles. Alternatively, one could use more substantial bottles than drinking water bottles.

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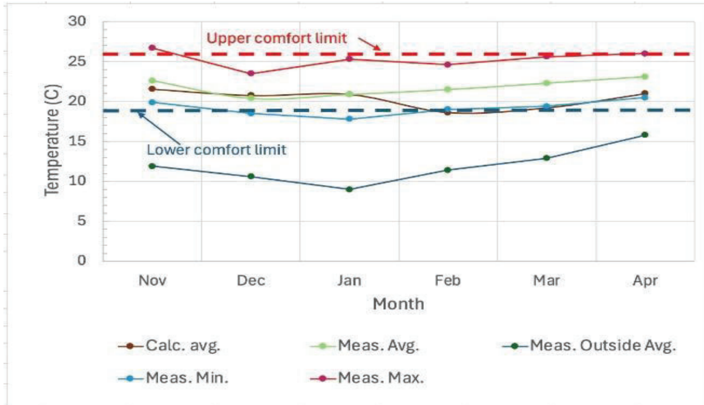

Figure 3. Room and outside air temperatures.

5. Conclusion

When the water containers were distributed around the room, there were no adverse effects on the room floor from their weight. This statement is based on a qualitative observation. Future work could be to perform structural calculations of weight additions on existing floor framing. Based on ANOVA of the data, there is statistically no significant difference between passive and active solar heating. Since the passive system is simpler, it would be the preferred choice for emergency heating. In milder climates, no nighttime window insulation would be needed, if the window had at least two glass panes. In colder climates, nighttime window insulation is recommended.

6. References

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