Evaluation of Retrofit Passive Solar for Emergencies

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Martin Smallen
Metallurgist, Retired

George Washington University
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1. Abstract

During war or natural disasters, the heating infrastructure of a nation can be damaged, and temporary heating is necessary. Emergency generators are often employed until infrastructure restoration. This project proposes to add a simple and inexpensive passive solar Trombe water wall consisting of individual containers to that emergency energy mix. An experiment determined that the conversion efficiency of solar radiation into stored heat was 60% for the water wall. The average yearly heating performance was then calculated at two locations: Morgan Hill, CA (37.1ºN latitude) and Bozeman, MT (45.6ºN latitude). The performances were predicted using two methods, which agreed with each other. The predictions show that the water wall can supply 98% of the yearly heating requirement for Morgan Hill and 85% for Bozeman. The heating performance can be improved if the containers are tilted so that the sun's rays are perpendicular to the absorbing surface on the winter solstice.

2. Introduction

- In times of war and natural disasters, the heating infrastructure of a nation can be damaged.
- There is a need for emergency heating of buildings. Solar or fossil fuel generators may only supply a few hours a day on a rotating basis.
- It is proposed to add retrofit passive solar, on a temporary basis, to that emergency energy mix.
  - To provide a warm room(s) in unheated buildings.
  - To reduce the load on power plants.
- The concept is to build a Trombe water wall out of inexpensive and easily available materials.
  - It would consist of flat black painted containers on a shelf, which is close to an equator facing (±30°) window.
  - Construction materials could be wood, plastic or metal containers, flat black paint, water, and polystyrene insulation
- During the day, the sun's rays warm the water in the containers. At night, insulation directs the heat into the room.
- The design is: 1) decentralized, 2) inexpensive, 3) constructed of common materials, 4) requires no electricity, 5) easy to assemble and disassemble and 6) a low carbon emitter.
- It would take a semiskilled person 1 to 2 days for assembly.

3. Theory

- **Duffie and Beckman (1974) method**
  - The Trombe water wall was analyzed as a flat plate collector: $A(\tau\alpha)S = Q_U + Q_L + Q_S$ (eq. 1):
  A is the solar collector area, $(\tau\alpha)$ is the transmittance-absorptance product of the clear cover, *S* is the rate of total solar radiation/unit area, Q_U is the rate of useful heat transfer to a working fluid, Q_L is the rate of energy loss, and Q_S is the rate of energy storage. But $Q_S = 0$ since the stored energy is the useful heat and $\boldsymbol{A(\tau\alpha)S = Q_U + Q_L}$ (eq. 2).
  - $\boldsymbol{Q_U = 2.78x10^{-7}(mC\Delta T)}$ (eq. 3):
  m is mass of containers' water, *C* is the specific heat capacity of water, ΔT is the water temperature increase and $2.78x10^{-7}$ *kWh/J* converts *J* to *kWh*.
  - The containers were isolated on pads, so the heat loss via radiation is: $\boldsymbol{Q_L = \frac{t_1 \varepsilon_1 A_1 \sigma(T_2^4 - T_1^4)}{1000}}$ (eq. 4).
  t_1 is time of energy collection, ε_1 is the emissivity of the flat black painted containers, A_1 is the total surface area of the containers, σ is the Stefan-Boltzmann constant, T_1 is the average room temperature, T_2 is the average container temperature and *1000* converts *W* to *kW*.
  - Heat stored at the end of the day is: $\boldsymbol{H_b = \frac{Q_U + Q_L}{A}}$ (eq. 5).
  - Solar performance is: $\boldsymbol{P = \frac{100SEA_W}{Q_r}}$ (eq.6).
  E is the conversion efficiency of solar radiation into heat in the containers, A_w is the total window area and Q_r is space heating requirement.
  - Predicted daily average indoor temperature is: $\boldsymbol{t_i = \frac{HG_{sp}}{U_{sp}} + t_0}$ (eq. 7).
  HG_{sp} is solar heat gain, U_{sp} is the overall coefficient of heat transfer and t_0 is the avg. daily outdoor temp.
- **In addition to the above method, the Trombe water wall was analyzed by the Mazria (1979) method.**

4. Methodology

- **Equipment**
  - The experimental setup is shown in Figure 1.
  - The containers on the lower shelf are tilted at 60° and those on the upper shelf are tilted at 90°.
  - The containers were painted with a flat black paint.
  - Calibrated thermocouple temperature meters measured the water, room air and outside air temperatures.
  - Calibrated solar power meters measured cumulative solar radiation at 60° and 90° tilts. The placement of the solar power meter sensors is shown in Figure 2.

Fig. 1 Experimental setup .

Fig 2. Solar sensor placement.

- **Procedure**
  - In the morning, the insulation was removed from the space between the water wall and the window.
  - The temperature and solar radiation measurements were recorded in the morning and afternoon.
  - The predicted heating performance of the water wall was calculated for two locations, one in Morgan Hill, CA (37.1°N latitude) and one in Bozeman, MT (45.6°N latitude).
  - To do this, E was obtained from Figure 3 and was used along with National Renewable Energy Laboratory historical solar data (Marian & Wilcox, 1990) plus historical heating data from Morgan Hill (23 years) and Bozeman (3 years).
  - In addition, the performance of the two locations was calculated using (Mazria, 1979) except that actual overall coefficient of heat transfer (U_{sp}) was used instead of the calculated U_{sp}
  - The predicted room temperatures were calculated per the Mazria method.
  - Finally, the cost was determined to build a water wall.

5. Results

- Figure 3 shows that approximately 60% of sunlight is stored as heat in the containers for both tilt angles and this curve is used to predict the performance of the Trombe water wall.
- Figure 4 shows the predicted heating performances in Morgan Hill, CA and Bozeman, MT.
  - The Trombe water wall supplied the following percentages of the heating requirement:
    - Morgan Hill, CA
      - 90° tilt
        - December - **66%;** January - **71%**
        - Total heating season - **98%**
      - 60° tilt
        - December - **97%;** January - **97%**
        - Total heating season - **162%**
    - Bozeman, MT
      - 90° tilt
        - December - **56%;** January - **50%**
        - Total heating season - **85%**
      - 69° tilt
        - December - **66%;** January - **61%**
        - Total heating season - **108%**
  - 60° and 69° tilts make the sun's rays perpendicular to the absorbing surface of the containers on December 21st.
- In Mazria's method, the solar contribution is truncated for those months when it exceeds the heating requirement. If that is done with the Duffie and Beckman method, then the percentage of the yearly heating requirement supplied by solar for Morgan Hill at a 90° tilt is **87%** for the Duffie and Beckman method and **79%** for the Mazria method. The difference is due to solar radiation literature source.
- The predicted average daily indoor room temperature for both locations is given in Table 1. An example of the water wall's heating capability can be seen for January. The water wall increases the Morgan Hill room temperature over the outdoor temperature by 9.4˚C for a 60˚ tilt and 8.2˚C for a 90˚ tilt. In Bozeman, the increase is 16.5˚C for a 60˚ tilt and 15.4˚C for a 90˚ tilt.
- The cost to construct a passive solar Trombe water wall is $221/m^2$, excluding labor (2023 prices). The price can be lowered by using second-hand or salvaged materials.

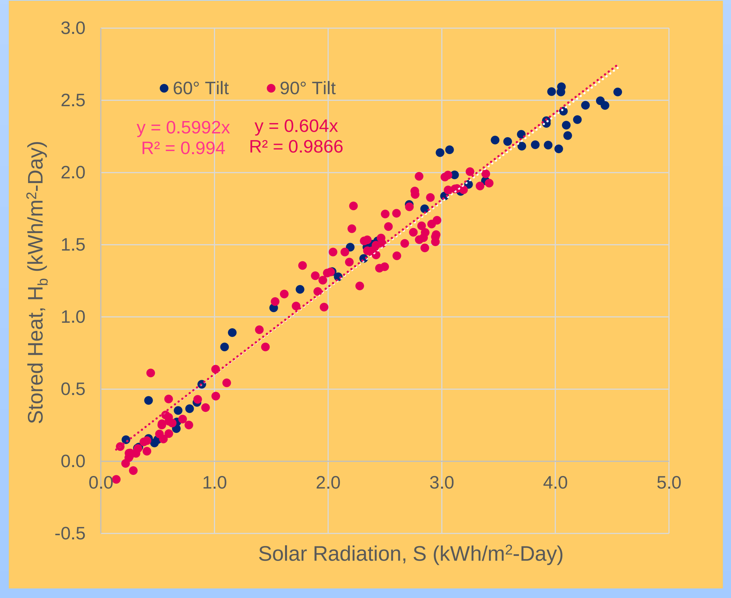

Figure 3. Heat stored as a function of solar radiation. S is shown in Eq. 1 and comes from solar energy meter measurements. H_b is shown in Eq. 5 and comes from temperature measurements. The slope gives E in Eq. 6.

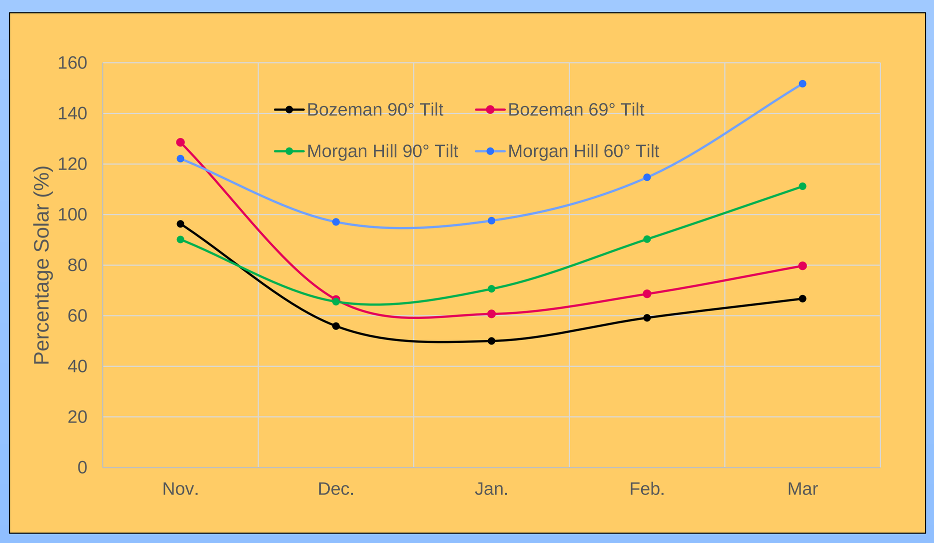

Figure 4. Predicted heating performance for Morgan Hill, CA, USA (37.1°N latitude and window area = 2.90 m^2) and Bozeman, MT, USA (45.6°N latitude and window area = 1.78 m^2).

Month	Room Temperature (°C)			
	Morgan Hill, CA		Bozeman, MT	
	60° Tilt	90° Tilt	69° Tilt	90° Tilt
Sept.	30.3	27.0	31.2	27.0
Oct.	27.7	25.6	25.1	22.8
Nov.	22.3	21.1	16.1	15.0
Dec.	19.0	18.1	9.4	8.7
Jan.	19.7	18.5	12.3	11.2
Feb.	21.7	19.5	16.2	13.8
Mar.	22.9	19.4	20.6	16.3
Apr.	23.8	19.4	22.3	16.4

Table 1. Predicted daily average indoor temperatures for each month.

6. Conclusion

- Approximately 60% of sunlight can be stored as heat in a retrofit, passive solar Trombe water wall.
- Two methods predict that a water wall could supply a substantial portion of the heating requirement in rooms with equator facing windows.
- The predictions show better results at lower latitudes.
- Nevertheless, enhancements can be made to improve the performance at higher latitudes such as by adding windows, reflectors, or selective surfaces.
- It is proposed that this retrofit be used in countries where their heating infrastructure has been damaged by war or nature to supplement other emergency energy sources.
- Government policies could aid in the implementation of such a system. Those policies could include tax incentives and storage facilities with water wall kits available for emergencies.

7. References

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Marian, W. and Wilcox, S. (1990) *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors,* NREL, P. 38.

Mazria, E. (1979) *The Passive Solar Energy Book,* Emmaus, Pa: Rodale Press, pp. 28–62, 152–179.

8. Acknowledgements

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