POST-OCCUPANCY ANALYSIS OF THE REAL GOODS SOLAR LIVING CENTER

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ABSTRACT

This paper is a report on the post-occupancy passive and active solar performance of the Retail Showroom at Real Goods' Solar Living Center. The 5000 s.f. showroom features straw-bale walls with a sprayed soil-cement (a.k.a. PISE) finish, which are integral parts of the passive solar design. Conclusions include:

- The thermal mass of the straw-bale walls provides a 12-hour lag from the outdoor ambient temperature.
- Interior temperatures remained below 82°F (28°C) despite outdoor temperatures of 91°F (33°C) and high occupant densities.
- Evaporative Coolers have proved unnecessary due to the radiant cooling provided by the straw-bale walls, flushed nightly with cool nighttime air temperatures.
- Daylighting meets roughly 90% of the showroom lighting needs, with electric lighting provided to highlight merchandise at the rear of the space.
- Indoor air quality assessments have detected high levels of dust generated by the PISE (stabilized earth) coatings on the straw-bale walls.
- Approximately 70 to 80 kWh are produced with on-site photovoltaic and wind-powered generation. Recently a separate 132kW solar plant was installed at the site, selling energy to the utility grid.

Particular attention is paid to the passive cooling and straw-bale thermal mass wall performance.

DISCUSSION

The Real Goods Solar Living Center in Hopland, California was opened at the inaugural Sol*Fest of June 1996. Since then it has been lauded as one of the premier solar buildings, and recognized by the AIA Committee on the Environment as one of the AIA's "Earth Day Top Ten". Van der Ryn Architects of Sausalito, California designed the project. The author of this paper is the Project Architect, and Adam Jackaway (now at the University of Colorado) served as Climate Responsive Design Specialist.

The project is a showcase of both passive solar design and renewable energy. The design process has been well documented, in Solar Today (May/June 1996), the book A Place in the Sun (Chelsea Green, 1997, authored by the members of the design team), and a 1998 Project Report supplement to the AIA Environmental Resource Guide.

Like almost all projects, little has been published regarding the actual performance of the showroom building. For this paper, empirical data as well as results of two research projects (primarily a paper by students of Professor Gail Brager of UC Berkeley, and also a Vital Signs workshop) are utilized.

The section diagrams on the following page illustrate the modes of operation of the building, depending on the time of day and year. The store staff is responsible for the operation of the simple functions (i.e. opening or closing clerestory and other windows, wood stoves for supplemental heat, light shelves). They are reportedly quite pleased to perform these tasks, and do so religiously, as if their comfort depended upon it!

TESTING PASSIVE COOLING PERFORMANCE

A UC Berkeley Architecture class on Natural Cooling & Ventilation taught by Professor Gail Brager studied the Real Goods showroom three months after it opened in June 1996. The team of Graham Carter, Jeff Hou and the co-author studied the physical performance of the building beginning with an interest in studying the natural ventilation strategies in the building and the thermal performance of the strawbale walls.

The specific questions investigated by the team study were:

How are the natural ventilation strategies (operable windows, stack effect, and night time ventilation) being used to cool the space? Which of these appear to be the most effective?

Why are the evaporative coolers not being used when it is warm inside the showroom?

What are the thermal characteristics of the straw bale / pise wall? Do the Real Goods Showroom walls have appropriate thermal mass?

Instrumentation was placed for a 10 day period and measurements were taken during the site visit to study various design features of the building. During the monitoring, Hopland had a hot spell of weather which tested the passive cooling strategies. This data was supplemented with phone conversations and surveys performed by another team.

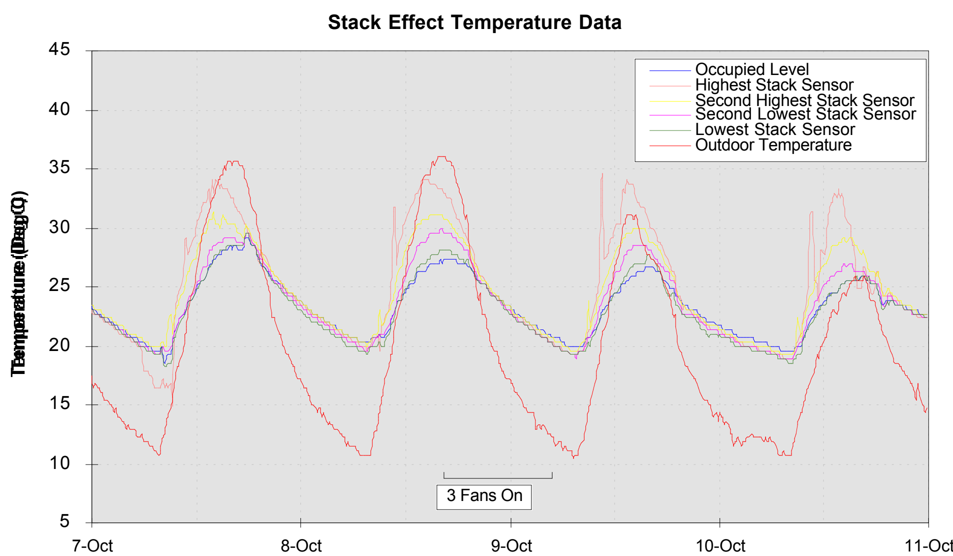
VENTILATION

A key cooling strategy in the design of the Real Goods Solar Living Center was the natural ventilation strategies. The numerous operable windows, doors, and clerestory windows allow the employees to create air movement in the space when desirable outdoor conditions are present. The openings and the evaporative cooling fans, which can be run with only the fan on, also serve in the night time flushing strategy which not only removes warm interior air, but assists in cooling the thermal mass of the building. High ceilings in the Showroom promote a stack effect enhancing comfort and ventilation. The operator's log showed that employees were very active in opening and closing the windows, doors and clerestory windows. In general, employees would open the doors and the windows upon arrival at work and would close these along with the clerestory windows by 11:00am when the outdoor air became warmer than the indoor air. When outdoor temperatures begin to drop in the afternoon, the building would be opened up again until closing time allowing outdoor air to move through the space. At this time the clerestory windows would be re-opened and left open through the night allowing the cool night air to flush the building.

The stepped roof and the clerestory windows between the roofs were important design features. The designers were very conscious of trying to create a negative pressure area outside these windows with the prevailing wind from the north west. The difference in pressure across the openings draws the warm inside air out of the showroom. The data suggest that this is another successful design feature. The temperature sensors were placed at different heights allowing the vertical temperature gradient to be examined above the cash register area.

Firstly, the stack temperatures approach each other at times when the clerestory windows are open while the temperatures stratify in the day time when windows and doors are closed. This suggests that there is relatively little air movement mid-day when everything is closed. Conversely, when the clerestory windows are open at night, the data suggests significant air movement since stack temperatures approach each other.

The result shows that the stack-effect cooling appears to be working quite well in the Real Goods Showroom. During afternoons when the outside ambient temperature



Graph 1 – Stack Effect Temperature Data of Real Goods is highest, the temperature difference between the highest and lowest sensors ranges between 3°C to 8 °C (5.4°F to 14.4 °F). The graph shows clear temperature stratification during that time. On the average during the 10-day period, the temperatures at the occupied level (≈ 4' above the floor) are 2 °C (3.6 °F) lower than the average stack temperatures. Without the high ceilings this temperature difference would be smaller and the occupied space temperatures warmer. Furthermore, this stack effect promotes air movement from the occupied space upwards.

Indicated on the chart is the period during which the evaporative fans were on. The fans were only used during one night. Observing the relationship between the interior temperatures to the exterior temperatures suggests that the fans are not providing much of a flushing effect. It is possible that the clerestory windows are so effective at bringing in cool night time air that they become the dominant effect and that the additional air provided by the fans is not noticeable in the data collected.

Supporting the data are employee comments that during very hot days doors and windows will be opened as a last resort to create air movement. Furthermore, the fact that the windows and doors were operated consistently throughout the study period suggests that the ventilation created by these openings is significant and that the ventilation strategies have been successful.

The stack effect and clerestory window ventilation strategies appear effective in the Real Goods Showroom. The combination of opening windows and doors while having the clerestory windows open is particularly effective at increasing air movement and thus ventilation.

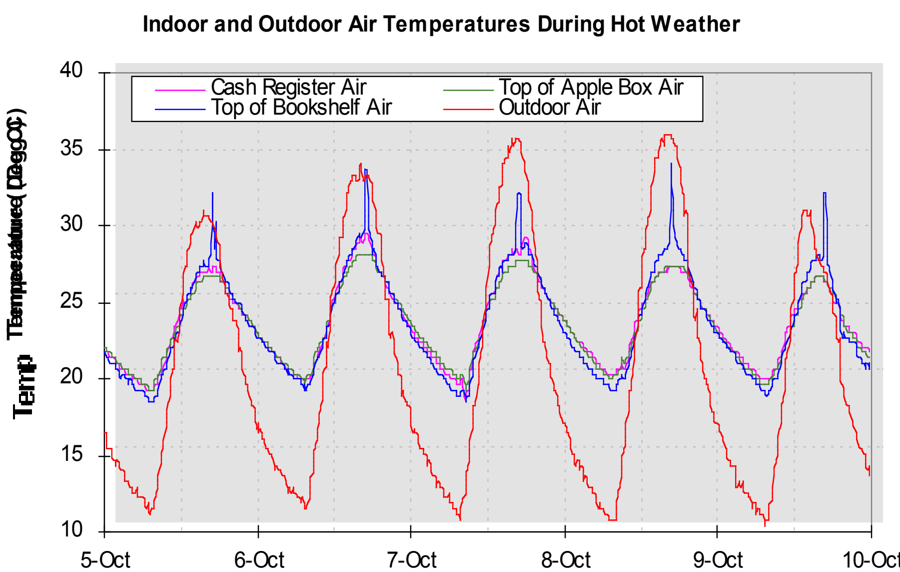
EVAPORATIVE COOLING

The Real Goods Solar Living Centre Showroom is equipped with evaporative coolers for those periods when the thermal mass cannot be cooled sufficiently at night to provide comfortable space temperatures in the day time. A five day period with day time temperatures exceeding 86°F (30°C) coincided with the monitoring period. However, the evaporative coolers were not used at all during this period despite interior temperatures reaching 81°F (27°C) in the afternoons.

A discussion with Real Goods employees verified that the operator logs were correct. These same people indicated that though the interior temperatures were bearable they would have preferred cooler temperatures. Asked why the evaporative coolers were not being used, the employees indicated that the humidity added by the evaporative coolers creates an uncomfortable space.

The building bio-climatic chart suggests that for this site, evaporative cooling is a good strategy for cooling. The chart also assumes occupancy similar to a residence. Weekend afternoons tend to be the busiest times for Real Goods with 30-40 customers in the store at one time. Such high densities make the moisture exhaled by customers a significant quantity.
Making reasonable assumptions suggests that a fully occupied store on a typical summer day could produce an indoor relative humidity on the order of 50% given a typical summer afternoon relative humidity of 30%. Evaporative cooling on top of this would elevate indoor humidity levels to 80% or higher! Thus the employees decision not to use the evaporative cooling appears to be an understandable one.

In the future, consideration should be given to the increase in moisture expected from occupants when considering evaporative cooling as a design option. The analysis here is limited, but does suggest that in certain situations, evaporative cooling may not be the most appropriate response. The critical factors to consider are the climate, ventilation rates, occupant densities and occupant activity.



Graph 2 – Outdoor & Indoor temperature data of Real Goods

STRAW BALE WALLS

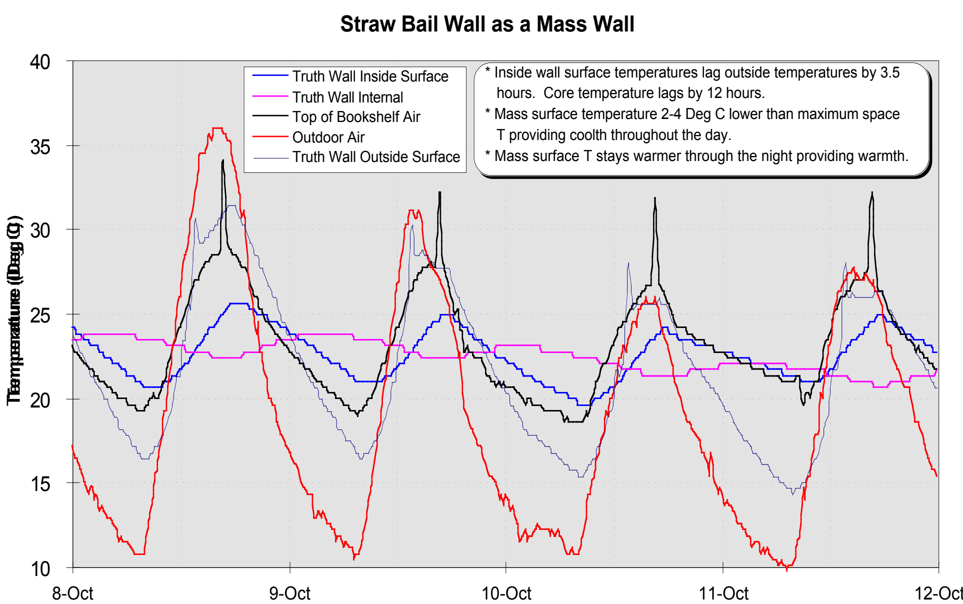
The straw bale walls are one of the more interesting design features of the Real Goods Solar Living Center. Constructed of 2’ thick rice straw bales covered with a 3” thick layer of pise, the construction provides a wall with a high thermal resistance and thermal mass - ideal for passive cooling. Outside surface temperatures compared between walls were found to track each other closely; the inside surface temperatures tracked each other as well. A total of seven temperature sensors were placed in or on the surface of the walls. Shown below are the three temperature sensors placed on the truth wall along with inside and outside air temperatures. The steps particularly noticeable in the internal wall temperature line are due to the 0.3°C resolution of the data loggers.

All the characteristics of a thermally massive wall can be seen in the data. The diurnal variations in the mass temperature are smaller than those of the indoor air temperature which in turn are smaller than those of the outdoor air temperatures. The core temperature of the wall varies less than the surface temperatures which is in line with the high insulation value of the straw. The cooler mass temperature in the afternoon provides cooling while the warmer mass temperature in the evening allows the wall to release heat built up during the day into the cool outside and to a lesser extent into the indoor air. The core of the straw wall has a 12 hour lag with the inside air temperature resulting in a warm wall at night and a cool wall during the day when cooling is needed. The fact that the inside wall surface temperature tracks the inside air temperature closely suggests that the mass is thermally coupled to the indoor air - a prerequisite for thermal mass to be successful.

The data suggests that the straw bale wall is working as thermal mass. An estimate of the amount of cooling is not possible given the limitations of the field methods. There were several unsolicited comments from the employee surveys suggesting that they felt the walls created a pleasant cooling effect. This combined with the data suggests that the straw bale wall as a thermal mass design feature was successful.

Though 2’ thick straw bale walls are advertised to provide a thermal insulation value of R65, the heat capacity of straw bales is not as well publicized. The data collected presented the opportunity to estimate this value. Using a spreadsheet model of the mass wall, the pise was assumed to have thermal properties similar to lightweight concrete. Assuming R65 for the composite wall, the thermal insulation of the straw bale alone could be estimated. The model fitted to the measured data suggests that the volumetric heat capacity of the straw bales is on the order of 0.0093 Btu/ft^3°F. This value will vary depending on moisture levels, the type of straw, and how densely the straw is baled. Another variable is the surface roughness of the pise which will affect the heat transfer to the air. This value can be used in lieu of better information, but there is a high degree of uncertainty associated with the estimate, perhaps ±40%.

The relatively high heat capacity and low thermal resistance of the pise and the low heat capacity and high thermal resistance of the straw bales suggest that the thermal characteristics of a straw bale wall can be tuned. Within the significant design constraints, the thickness of the pise and straw bales could be varied to change the amount of mass and its lag time.



Graph 3 – Straw Bale / Pise Wall as a Mass

DAYLIGHTING

The store staff reports that customers have shopped for three hours, which is relatively unheard of in the retail industry. Sales in the first year of operation exceeded the optimistic projections by over 50%.

Daylighting meets roughly 90% of the showroom lighting needs, with supplemental electric light provided to highlight merchandise only at the very rear of the space. Fluorescent fixtures have dimmable ballasts on automatic light sensors, providing supplemental light under cloudy or evening conditions. Light scoops designed to reflect direct sunlight onto the ceiling of the space were eliminated due to cost, and have yet to be installed. These would further reduce the need for electric light.

RENEWABLE ENERGY SYSTEMS

On average the facility uses around 100 kWh of electrical power each day. Approximately 70 to 80 kWh are produced with on-site photovoltaic and wind-powered generation. The system is grid-intertied with a small battery back-up, installed to offset inequitable buyback rates before the State of California adopted net metering for commercial customers. Active tracking arrays have proven quite problematic, and only recently have they been rectified, setting a record of two weeks with all of the arrays tracking together.

Real Goods has recently installed a 132kW solar plant, a joint venture between AstroPower, Inc., GPU International, Real Goods and Green Mountain Energy. On a clear day in March, this array produced 694.5 kW of energy, sold to Green Mountain Customers as part of a clean energy blend.

INDOOR AIR QUALITY

Indoor air quality assessments by the Vital Signs workshop, sponsored by the Pacific Gas & Electric Energy Center detected high levels of dust generated by the PISE (stabilized earth) coatings on the straw-bale walls. Studies of ventilation reveal that the building flushes well and air quality is rectified when clerestory windows are opened.

CONCLUSIONS

Other aspects of the project worthy of further analysis include the integration of passive and active solar systems with other elements of ecological design, most notably the artfully regenerated landscape by Stephanie Kotin and Christopher Tebbutt, and artwork by Baile Oakes and Peter Erskine. One goal of this project is to illustrate that solar design is the basis of high-quality, ecological design. Through careful site and climate analysis, and multi-disciplinary collaboration, Real Goods stands as a model for mainstreaming solar design.

Fig. 5: Solar Plant Output on Spring Equinox (data courtesy of PowerLight Corp.)

Fig. 6: Aerial View of Solar Oasis & Retail Showroom (photo by Chris Benten)

ACKNOWLEDGMENTS

The Real Goods Showroom case study by the architecture class of UC Berkeley was an all-class effort and as such credit goes to all my class mates for this worthwhile effort part of which is presented in this paper. I wish to thank my team members Graham Carter and Jeff Hou for doing a tremendous amount of work. Without their work our report and hence this paper would not have been possible.

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