Report on the Physical Performance of the Real Goods Solar Living Centre Retail Showroom

submitted by:
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Arch 243 Natural Cooling and Ventilation
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Summary

As a showcase for environmental consciousness and ecological design, the Showroom at the Real Goods Solar Living Center has incorporated various energy-conserving passive environmental control strategies, such as night time ventilation, thermal mass, evaporative cooling, stack effect and passive solar heating. Three months after the June 1996 opening of the showroom, located in Hopland California, the showroom was visited by a group of UC Berkeley architecture students.

One of the teams looked at physical performance of the showroom. Temperature data collected over a 10 day period combined with occupant surveys, phone interviews, and energy simulation provided insight into the questions of interest. In summary, the findings of the study were:

- The evaporative coolers were not used during overheated periods due to discomfort created by high humidities. The high humidity is largely a result of moisture exhaled by the showroom's occupants.
- The straw bale walls are working as thermal mass. The core of the wall has approximately a 12 hour lag with the outdoor ambient temperature. The inside surface temperature of the wall, had a 2 hour lag in relation to the peak interior space temperature. Furthermore, the inside surface temperature of the wall was on average 3°C (5.4°F) lower than the interior air temperature thus providing some radiant cooling. The straw bale wall mass is provided by the pise while the insulation is provided by the straw bales.
- The operable windows, clerestory windows, and doors are very effective at ventilating the showroom. The high ceilings in the showroom create a stack effect which drives the natural ventilation. The temperature stratification created by the stack effect was between 3°C (5.4°F) and 8°C (14.4°F). When the windows and doors were opened, the stack temperatures approached each other suggesting air movement through the showroom. The building occupants were very active in adjusting the doors and windows suggesting that these devices are successful for ventilation control. The effectiveness of the nigh time ventilation fans is unclear. The limited data on their operation suggests that the clerestory windows and stack effect are the dominant ventilation mechanisms.
- The simulation of Real Goods Showroom done in CALPAS3 predicted that the showroom would use about 1/6 th of the energy of a conventional commercial building in the state of California. Most of that energy would be used during winter months. The simulation predicted the maximum indoor air - dry bulb temperature on the worst day in December to be around 13°C (55°F) and the minimum outdoor temperature on the same day to be around 8°C (47°F). Some thermal comfort strategies using simulation as a design tool were tested. Our aim by trying these strategies is to suggest ways to improve the thermal comfort of the occupants with minimum use of energy and cost. We didn't find any one strategy which could cost effectively improve the comfort during the winter months. A few relatively inexpensive options are suggested to improve thermal comfort by reducing radiative heat loss from the human body to the exposed cool slab or glass (especially during cloudy days). Covering the slab with rugs and the glass with curtains are an option. Cutting the vines in the winter months to let in more sun may help as our simple sun angle studies showed that solar access was low. Even then some supplemental heating from wood stove might still be needed to maintain comfort.

Though daylighting is not addressed in this study, light level measurements were taken on the day of the site visit. This data and observation of the lights at the time of the visit suggest that the daylighting strategies are effective.

Overall the passive cooling strategies are effective as the peak interior temperatures remained below 28°C (82°F) despite 33°C+ (91°F+) outdoor temperatures and high occupant densities. The simulations performed suggest that the Real Goods Solar Living Center's Showroom uses a fraction, 1/6, of the energy of a comparable market building.

Introduction

As a showcase for environmental consciousness and ecological design, the Showroom at the Real Goods Solar Living Center has incorporated various energy-conserving passive environmental control strategies, such as night time ventilation, thermal mass, evaporative cooling, stack effect and passive solar heating. These strategies are anticipated to significantly reduce the peak cooling and heating loads while requiring little supplemental cooling and heating. Showing how buildings can be designed to conserve energy without sacrificing occupant comfort was a design intent.

Three months after the June 1996 opening of the showroom, located in Hopland California, the showroom was visited by a group of UC Berkeley architecture students. Breaking into smaller teams we developed ideas for case studies. The material in this report presents some of the findings of our team of three studying the physical performance of the showroom. Instrumentation was placed for a 10 day period and measurements 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.

Initially, in broad terms, we were interested in the thermal mass of the straw bale walls, the role of the clerestory windows in the natural ventilation strategies, the thermal comfort near the glazing, and the effectiveness of the daylighting strategies. From there our questioning and analysis evolved into some more specific questions addressed in the remainder of the report.

> *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?*
>
> *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?*
>
> *Given the focus on passive cooling strategies in the design, how well can the showroom expect to perform in cooler winter months?*

The following sections describe what methods and instruments were used and the results of how each strategy performed in the 10-day period meets the design intent. In addition, energy simulation shows estimated cost and savings compared with a typical mechanically conditioned space with the same size and use.

At the time of the study in October 1996, the Real Goods showroom had not experienced a full year of occupancy. Hence, the occupants did not know the actual thermal performance of the passive solar building in winters. Simulation helped us in understanding the buildings performance in winter months. As a design tool, simulation helped us in testing different passive design retrofit strategies on the building which could further improve the performance of the building (i.e. thermal comfort and energy savings).

We would like to thank the Real Goods staff and in particular Mark Winkler and Jeff Oldham for enthusiastically assisting us in this case study. We also thank Adam Jackaway for his insights and suggestions into the performance of this building.

Methods

Three sources of data were used in this study.

Temperature Logging:

A total of eighteen Hobo XT Temperature Sensors were used to monitor temperature for the Real Goods Showroom for a period of 10 days between - October 4 through October 14, 1996. One of the sensors monitored the outdoor air - dry bulb temperature for the whole period. A number of sensors in the showroom at different locations and heights monitored indoor air - dry bulb temperature. Some sensors monitored indoor and outdoor straw bale wall surface temperatures on the north and west orientations. A set of Hobo XT's also measured the straw bale wall core temperatures by placing them in the 'truth wall' of the showroom.

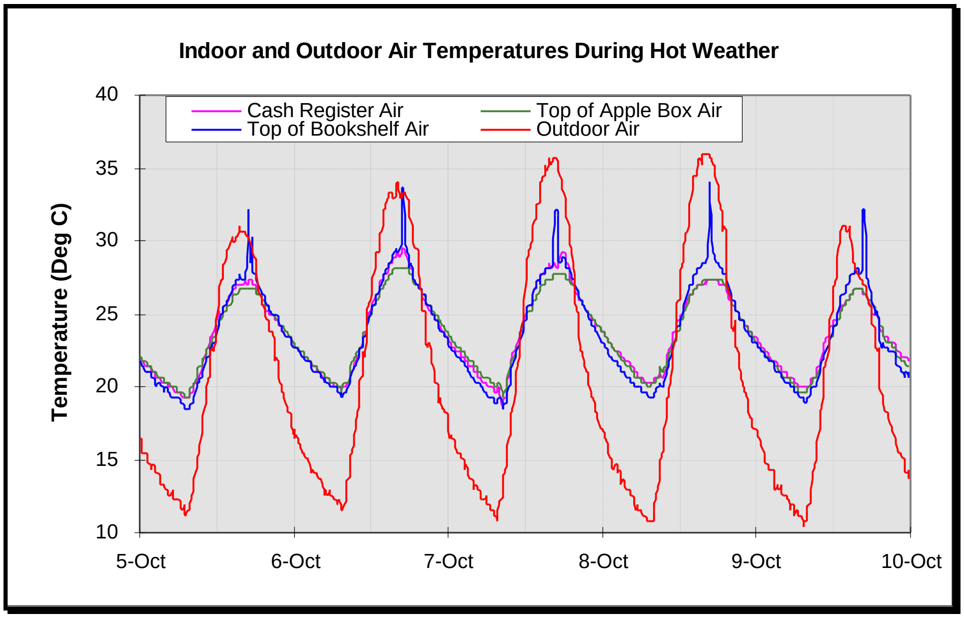
Operator's Log:

A log was kept by the Real Goods staff identifying the times at which windows and doors were opened or closed and the times when the fans or evaporative coolers were used.

Phone Interview:

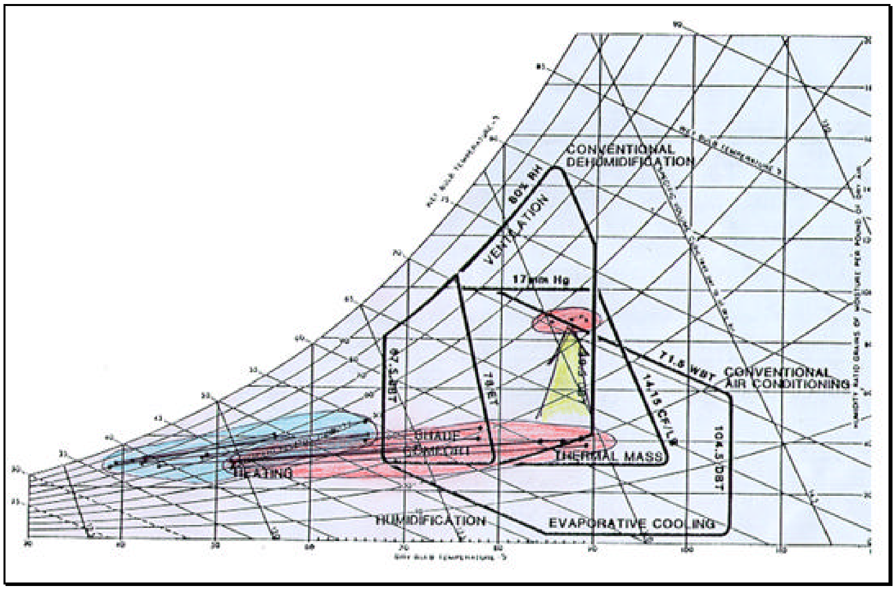
To provide insight into the data collected two phone interviews with real Goods staff were conducted.

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.



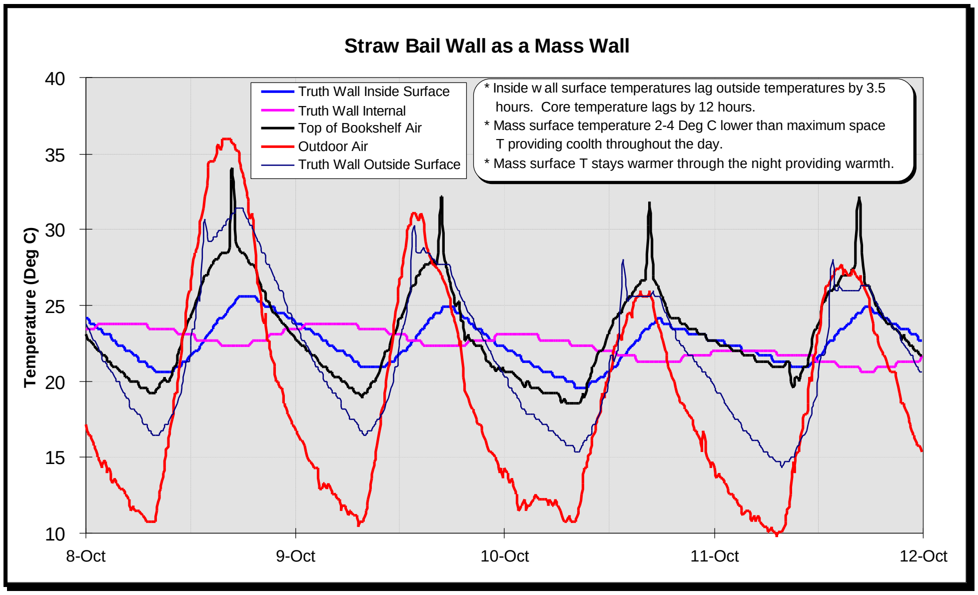
Making reasonable assumptions suggests that a fully occupied store on a typical summer day could produce an indoor relative humidity on the order of 50% given a typical summer afternoon relative humidity of 30%. Evaporative cooling on top of this would elevate indoor humidity levels to 80% or higher! 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.

Straw Bale Walls

The straw bale walls are one of the more interesting design features of the Real Goods Solar Living Centre. 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 is on the order of 1/2 the heat capacity of air and more than three orders of magnitude less than that of lightweight concrete. It is not immediately obvious how the straw bale could have a lower heat capacity than air. 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%.

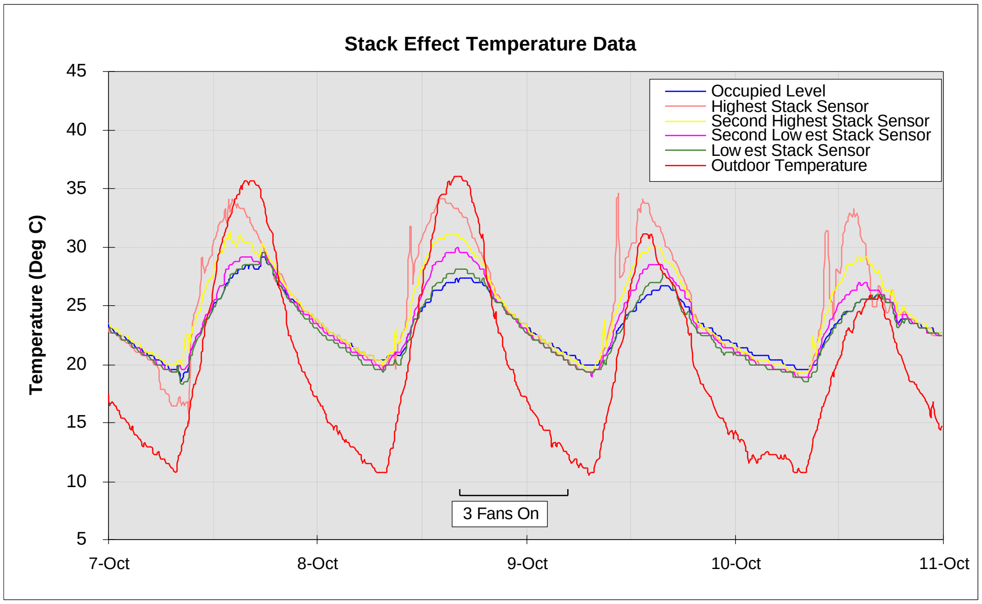
The relatively high heat capacity and low thermal resistance of the pise and the low heat capacity and high thermal resistance of the straw bales suggest that the thermal characteristics of a straw bale wall can be tuned. Within the significant design constraints, the thickness of the pise and straw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

Ventilation

A key cooling strategy in the design of the Real Goods Solar Living Centre 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.

Stack-effect cooling is a passive strategy that takes advantage of the phenomenon in which hot air tends to rise above the cool air due to the difference in density. In spaces promoting a stack effect, the hot air rises to the ceiling thereby lowering or maintaining the temperature at floor level. The stack effect will occur in spaces with tall ceilings and where internal loads increase the temperature at the occupied level.

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 is highest, the temperature difference between the highest and lowest sensors ranges between 3°C to 8 ^{o}C (5.4°F to 14.4 ^{o}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 ^{o}C (3.6 ^{o}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. However, it is puzzling why the interior air temperature sensors do not approach the outdoor air temperature more. The interior temperatures remain 8°C above the outdoor temperature at night. The air is being warmed by the mass of the building and its contents while being sensed. How much of the 8°C (14.4°F) temperature difference between indoor and outdoor temperatures is due to this heat pick up is not known.

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.

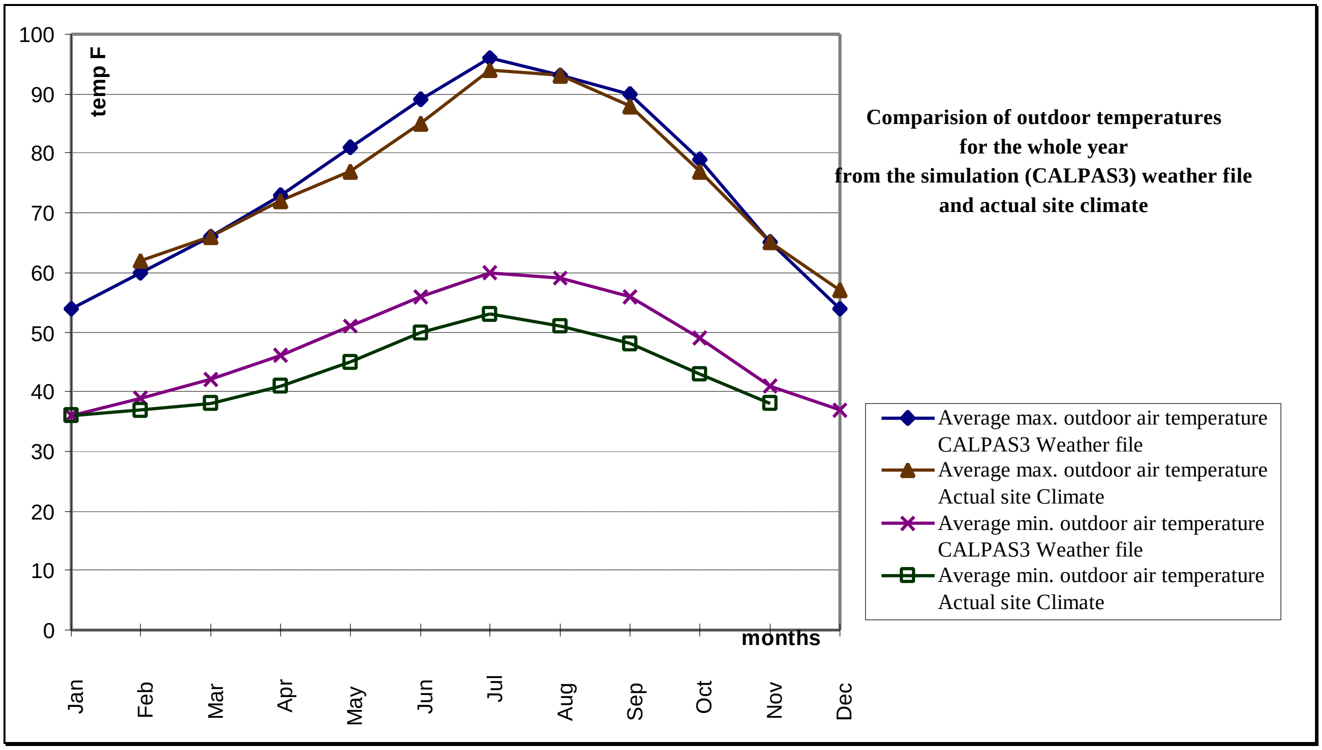
The stack effect and clerestory window ventilation strategies appear effective in the Real Goods Showroom. The combination of opening windows and doors while having the clerestory windows open is particularly effective at increasing air movement and thus ventilation.

Simulation

The purpose of doing a computer Simulation of the Real Goods showroom was primarily to study the thermal performance of this building during winter. Having opened in the month of June 1996, the building had not experienced a winter season when we did the case study i.e. in the month of October and the real performance of this passive solar building during winter was not known. Simulation was also done for the purpose of predicting the annual energy consumption in the showroom assuming the building had Air-Conditioning or mechanical heating to supplement during any uncomfortable period. The uncomfortable period (the higher limit of temperature) was defined by the Real Goods staff comfort zone derived from the temperatures they were able to be comfortable in during 1996 summers without any mechanical cooling. This comfort zone was different from the ASHRAE comfort zone and higher in the upper limit. As a design tool, simulation helped us in testing different design retrofit strategies which could further improve the performance of the building (i.e. thermal comfort and energy savings).

The graph below shows the comparison of the site's weather data with the CALPAS3 CA valley weather file used for simulation.

Graph 1

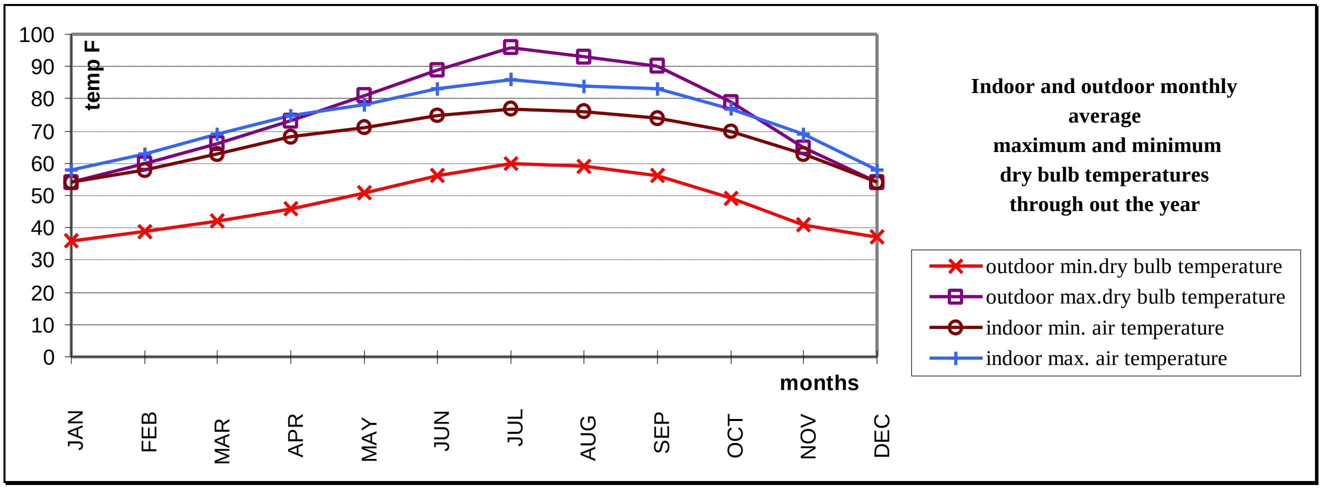


The 'as designed' model of Real Goods is simulated as a basecase in CALPAS3. The simulation predicted that the showroom as designed and constructed would use about 1/6 th of the energy used by a conventional commercial building in the state of California. The simulation model assumed supplemental use of any Air-Conditioning or mechanical heating during any uncomfortable period. This prediction categorises the Real Goods showroom to be an extremely low energy consuming building. And in reality since the building has coasted through the hot period without even using evaporative coolers because of the high tolerance of its occupants, it uses virtually no energy for cooling. The simulation results showed that most of the energy would be used for heating in the winter months.

Table 1

Strategy	Space Conditioning Loads						Source Consumption			Operating Cost $/Yr.				
	Cooling		Heating		Total		kBTU/sq.ft.							
	KBTU	% Sav.	KBTU	% Sav.	KBTU	% Sav.	Cool	Heat	Total	Cool	Heat	Total	$/sq.ft.	% Sav.
RealGood BaseCase	6416	---	63591	---	70007	---	1.8	17.7	19.4	66	806	873	0.24	---

Graph 2

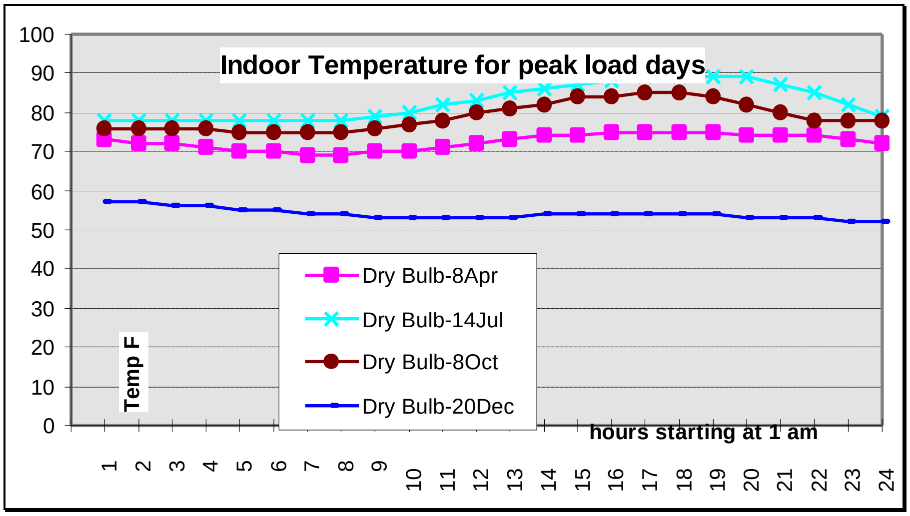


The indoor air temperature scenario during the whole year derived from simulation showed that under NO active heating or cooling, the average max. temperatures (day time) in the building would range from high 50s F in December to approximately. 85 F in July. Actually the indoor temperatures would be slightly lower due to a slightly different that is CA valley weather file used for simulation instead of Hopland's weather data which was not available. (see graph 1) The average min. temperatures (night time) would range from low 50s F in December to high 70s F in July. (see graph 2) It is important to note here that these temperatures from the simulation output represent a uniform temperature in the whole indoor space although in reality the temperature at different heights would be different due to stack effect as seen from actual monitoring. This is because this simulation tool (CALPAS3) can only simulate a single node in a space/building and therefore the advantage of stack effect in summers due to higher ceiling heights in the Real Goods Showroom (revealed in our monitoring as a temperature difference of approximately. 10 F between the occupied level and the ceiling height) is not reflected in the simulation output temperatures.

Similarly the simulation output temperatures in the space during winter show much higher temperature then would actually be in the space due to the same stack effect reason.

The building is using virtually zero energy specially in summer as we have found out from the staff of the showroom. But our simulation model shows that there are some very hot periods in the building when the staff still does not use any active cooling. This brings the use of simulation as a design tool which was our next step. How can we retrofit some strategy which would improve the comfort in the building during both summer and winter seasons without using any active systems since the real Goods staff do not use them.

Graph 3



A look at the temperature profile for peak load or worst condition day in December shows that on the coldest day in December, the building would be between 50 F and 60 F during the whole 24 hours. (see graph 2) And these temperatures would actually be lower than shown here due to two reasons- 1) the stack effect as cited earlier 2) due to a slightly different that is CA valley weather file used for simulation instead of Hopland's weather data which was not available.
(see graph 1)

To improve the comfort in the building in winter, we tried to understand the gains and losses and heat storage in the building envelope on a peak December day. (see figure 1 & 2) It shows that although there is a lot of storage possible there is basically very little solar gain. A sun angle study of the large glass area to the south showed that a lot of solar gain is obstructed by the trellis and overhangs. In order to find out which element of the envelope that is glass, slab or mass wall if insulated has the biggest potential of improving comfort for winters, some strategies were tried via simulation. The strategies were tried on two basecases. Basecase 1 in which Air-Conditioning and mechanical heating was assumed (the one tabulated in Table 1 and 2) was used to predict energy savings and hence pay back period. Basecase 2, (Graphs 2 & 3) was used to test the different strategies by predicting improvement of comfort in terms of temperature.

Figure 1

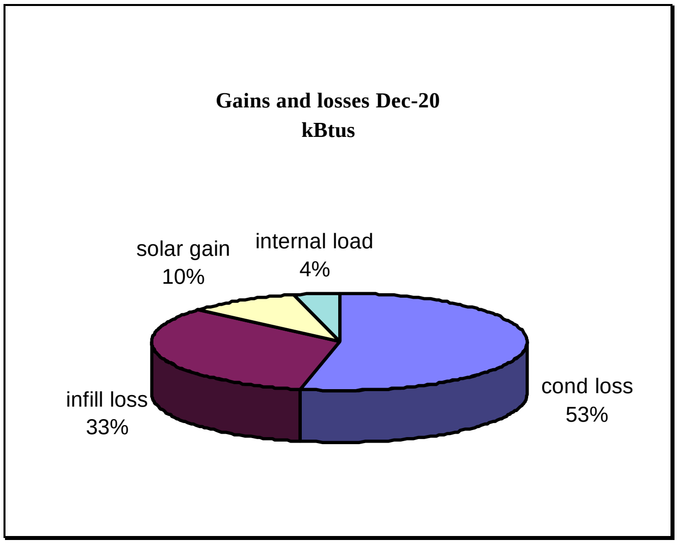
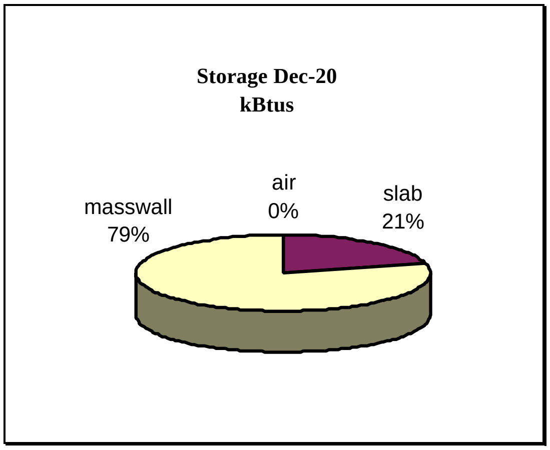


Figure 2



Strategy 1 - Using quilted tightly fit night insulation in winters on all glazing improves the temperatures on a peak December day. This strategy reduced the heat loss during that night by a delta T of only 4-5 F which was still lower than 60 F. The simulation predicted this strategy to actually reduce the annual heating energy load by approximately 35%.(see table 2) Pay Back period for this strategy can be more than 10 years.

We observed during our field study of the showroom that the light shelves which also serve as night insulation on mid-level glazing did not tightly fit the glazing when shut. Hence they are not very good insulators. Making them tightly fit the glass at night may prevent some of the heat loss, and hence improve comfort. Energy simulation shows that this might not bring great energy savings.

Table 2 - strategies

Strategy	Space Conditioning Loads						Source Consumption			Operating Cost $/Yr.				
	Cooling		Heating		Total		kBTU/sq.ft.							
	KBTU	% Sav.	KBTU	% Sav.	KBTU	% Sav.	Cool	Heat	Total	Cool	Heat	Total	$/sq.ft.	% Sav.
Basecase (Real goods as original design)	6416	---	63591	---	70007	---	1.8	17.7	19.4	66	806	873	0.24	---
night insulation on all glazings	6417	0.0	39037	38.6	45454	35.1	1.8	10.8	12.6	66	495	561	0.16	35.1
Improved night insulation on mid-level glazing	6416	0.0	61026	4.0	67442	3.7	1.8	17.0	18.7	66	774	840	0.23	2.8
Caulking and weather stripping	5801	9.6	48305	24.0	54106	22.7	1.6	13.4	15.0	60	612	672	0.19	22.2
slab with carpetting	13677	-113.0	46203	27.3	59880	14.5	3.8	12.8	16.6	141	586	727	0.20	15.9

Strategy 2 - Caulking and weather stripping. I assumed that Real Goods was an average construction and if they caulk the holes and weather strip the leaks, the annual heating load by could be reduced by about 24% with a pay back of about 2 years. There would be about 3-4 F relative improvement in indoor temperatures on a peak December day.

Strategy 3 - Insulating the slab with carpet improves the annual heating load by 27%. It is not a good strategy since it reverses the savings for summer when the slab acts as a heat sink.

Summarising our analysis of strategies, some very simple and inexpensive strategies might bring maximum comfort improvement to the occupants. we would suggest cutting the vines in winters to let in as much sun as possible. Use of some rugs on exposed area of the floor slab in the winters could provide greater comfort to the occupants by preventing the radiation loss of heat from the human body to the cold floor. A similar simple solution could be using some curtains on the cold glass at night and during continuous cloudy days. Applying quilted panels as night insulation or caulking will improve the winter comfort but at a cost and even then some ancillary heating might be required to keep comfort. Moreover, there is no other option during continuous cloudy winter days.

Our aim by trying these strategies has been to improve the thermal comfort of the occupants. It has not been to say that this building is uncomfortable, in fact it is one of the very few buildings in this country which has been designed with a commitment to provide human comfort by natural means at very low energy cost. Our attempt has not been to declare that there could have been more energy savings which can hardly be the case since this building already uses very low energy. This building is a superb example of a low energy use and highly comfortable and delightful building compared to other conventional buildings. This should be our aim when designing buildings because achieving zero energy use for space conditioning is not a realistic goal in most climates.

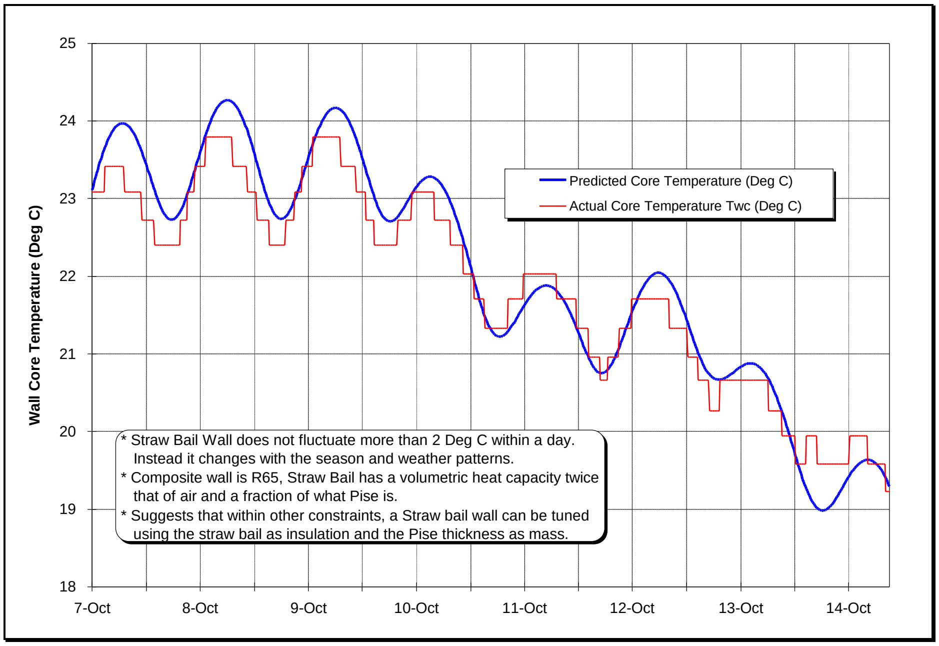
Appendix I: Method For Estimating Thermal Heat Capacity of Straw Bale Walls

In creating an energy simulation model of the Real Goods Solar Living Centre, the question arose, "what is the heat capacity of a straw bale wall?". Architects and contractors involved in the design and construction of straw bale walls did not know what the answer was. Since inside surface, outside surface, and internal temperatures of the straw bale/pise wall had been taken it was possible to estimate the volumetric heat capacity of the construction.

It was assumed that the wall consisted of 3" of pise on both inside and outside surfaces and that the pise had properties similar to lightweight concrete. Furthermore, we assumed that the composite wall was R65 as professed by the designers. Using typical air film resistance's we back calculated a resistance for the straw bale of R63 (63 ft^{2}*hr*°F/Btu) - virtually all of the wall's thermal resistance comes from the straw bale.

Layer	R-Value (ft^{2}*hr*°F/Btu)
Inside Air Film Resistance	0.68
Inside 3" Pise	0.58
24" Straw Bale	62.89
Outside 3" Pise	0.58
Outside Air Film Resistance	0.17
Composite Wall	65.00

Using the method described in Reading 12 of the Spring '96 ARCH 140 Reader, a spreadsheet was developed to model temperatures through the wall as a function of surface temperatures. A 12 minute time step was used. We assumed that the 3" pise was made up of three 1" elements and that the straw bale was made up of five 4.8" straw elements. The inner pise element was set to the inside wall surface temperature we had recorded while the outer pise element was set to the outside wall surface temperature recorded. The middle straw bale element temperature was then compared to the measured core temperature. The best estimate of the straw bale heat capacity could then be found by minimising the error between these two temperatures.



* Straw Bail Wall does not fluctuate more than 2 Deg C within a day. Instead it changes with the season and weather patterns.
* Composite wall is R65, Straw Bail has a volumetric heat capacity twice that of air and a fraction of what Pise is.
* Suggests that within other constraints, a Straw bail wall can be tuned using the straw bail as insulation and the Pise thickness as mass.

Since, our initial guess at the temperature profile through the wall would be off, we threw out the first three days of data. A sum of squares error was used as the cost function to be minimised in this optimisation problem. Through trial and error the volumetric heat capacity which minimised the error was found to be 0.0093 Btu/ft^{3}°F for the straw bales. The graph at left shows how well the predicted and actual temperatures track each other. This estimated heat capacity is puzzling in that it is ½ that of air and over three orders of magnitude smaller than that of lightweight concrete.

Uncertainties in this analysis include the fact that the wall core temperature may not have been physically in the middle of the wall. If the sensor is located closer to the inside or outside the results would be affected. Also the resistance between the pise and straw bales was assumed to be non-existent and we assumed an R65 composite wall. Variations in these assumptions will affect the heat capacity and thermal resistance estimated here.

The estimates suggest that all the thermal resistance is provided by the straw bales while all the thermal mass is provided by the pise. This dichotomy suggests that this type of composite wall could be tuned for a needed thermal performance. Of course the structural limitations (the size of bales which can be used) are a serious limitation on this tuning. The spreadsheet used to estimate the heat capacity can be obtained on request.

Appendix II: Method For Estimating Space Humidity

Despite high indoor and outdoor temperatures the evaporative coolers were not used at all during the monitored period. After discussions with Real Goods staff the logical answer was revealed to be: occupant generated humidity was significant and for this reason humidity added by evaporative coolers was intolerable from a comfort point of view. A first glance at a bio-climatic chart suggests that evaporative cooling is a good strategy for the Hopland climate; however, a humidity balance on the showroom using reasonable assumptions validates the occupants feelings of discomfort.

Using average daily maximum and minimum dry bulb temperatures and humidities for a typical August day in Healdsburg, a profile was generated. We assumed that maximum humidity occurs at the daily low - one hour before sunrise. Similarly the minimum humidity level was assumed to coincide with the daily high temperature four hours prior to sunset. A sinusoidal interpolation was made to generate an hourly profile for an August day.

Real Goods has their peak times on weekend afternoons when upwards of 40 people are in the showroom. Typically there are 15 customers in the store throughout the day. The following assumptions were made in the analysis:

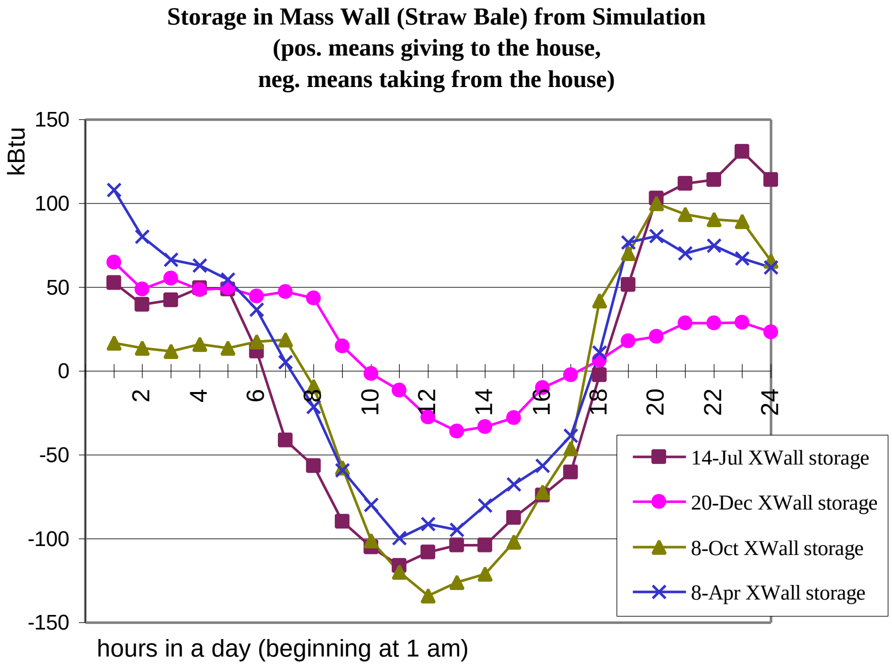
- A peak of 35 occupants in the building (this includes staff)
- A latent heat gain of 239 Btu/hr which translates into 0.25 lb/hr of moisture generated by each occupant.
- An occupancy profile with a peak period from noon until 4:00pm. Peak occupancy is only reached for 1 hour at 3:00pm.
- An infiltration profile that is representative of employees opening and closing doors and windows.
- A peak infiltration which corresponds to 1 air change per hour in the showroom.

A mass balance of moisture was found for each hour of the day. There are two moisture flows across the control volume - infiltration with a humidity equal to that of the outdoor air and exfiltration with a humidity equal to that of the indoor air in the previous hour. The air flow rate of infiltration and exfiltration were assumed equal - i.e. neutral pressure in the building. The only source of humidity in the building was assumed to be the occupants.

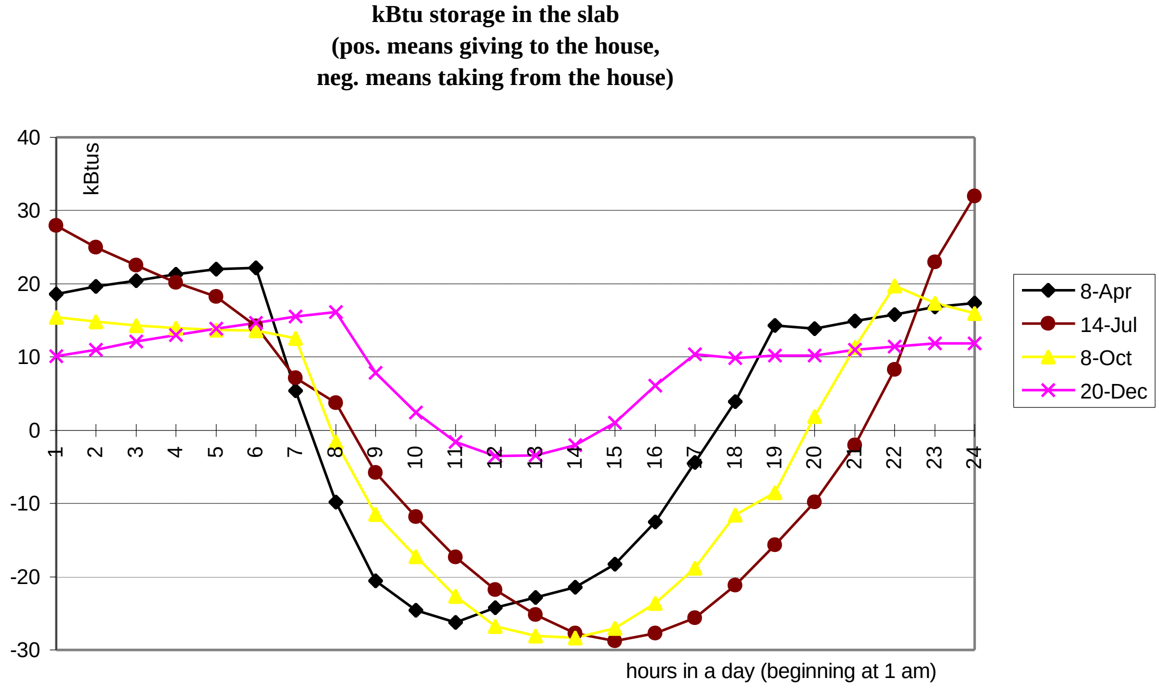
The model suggests that whereas the outdoor humidity ratio peaks at 0.0055 lb_m/lb_{air}, the indoor can climb as high as 0.0139 lb_m/lb_{air}. This could produce indoor relative humidities of 80%+! Once occupants begin leaving the building and windows are opened up, the humidity level drops quickly. A hard copy of the spreadsheet is attached. Soft copy is available on request.

This model is highly sensitive to the assumed outside air infiltration and the number of occupants. Though reasonable assumptions were made, actual conditions may be such that humidities are much lower or slightly higher than estimated here.

Appendix III: Mass wall(straw bale) & Slab storage from simulation



Storage in Mass Wall (Straw Bale) from Simulation
(pos. means giving to the house,
neg. means taking from the house)



kBtu storage in the slab
(pos. means giving to the house,
neg. means taking from the house)