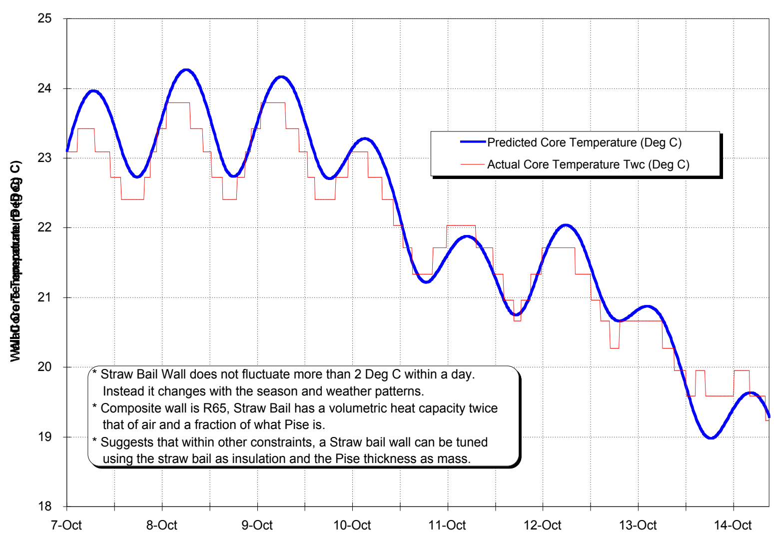
Appendix I: Method For Estimating Thermal Heat Capacity of Straw Bale Walls

In creating an energy simulation model of the Real Goods Solar Living Center, 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



Graph 4 – Predicted versus Actual Straw Bale Wall Temperature

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 minimizing the error between these two temperatures.

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 minimized in this optimization problem. Through trial and error the volumetric heat capacity which minimized 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.

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.