Appendices

1. Earthen Wall Monitoring Test Plan

Engineering Test Plan – Earthen Wall Moisture and Humidity Measurements

Specification plan for what is to be done and how it will be accomplished, indicating why each task will be done and may anticipate use of resources such as time, money, equipment, facilities, and people.

Objective

The objective of this test is to monitor the indoor and outdoor environment variables of:

- Relative Humidity,
- Temperature and Dew Point ;
- And Wall assembly variables of:
    - inner (interior) wall assembly temperature,
    - outer (exterior) wall assembly temperature,
    - inner wall assembly water content and
    - outer wall assembly water content.

This monitoring process will be done over one year. From this data collection, observations of performance will be discussed: how it pertains to common metrics where applicable, and how it performs under specific conditions experienced within the period.

Expected Observations

In building codes the requirement for vapour barriers is defined by the relationship between Relative Humidity, temperature, and the point at which vapour condenses into water. In earthen walls historical performance shows this has not been an issue, thus allowing buildings to last for centuries without moisture damage, but this relationship between RH, temperature, and dew point, is not well understood, nor has been observed in real-life/real-time conditions. The monitoring of these variables will show how water content in the earthen walls responds to changes in temperature, RH, and dew point, and provide information on whether water content stays within a safe realm, or whether it moves into dangerous levels (>14%),[Minke].

In building codes there is the requirement for mechanical systems to control Relative Humidity, to maintain RH around 35%, to stop issues of excessive condensation inside wall assemblies and lending to dangerous levels. Historically earthen buildings have had RH levels around the 55%

mark. The monitoring of indoor and outdoor RH will show whether this anecdotal observation truly exists. It should also show the range of fluctuation of daily RH inside should stay within a narrow range, and demonstrate what this looks like in comparison to outdoor RH levels and fluctuation.

The Building codes use insulation to moderate temperature differentials between indoor and outdoor environments, trying to ensure that the vapour barriers do not drop to the dew point wherein condensation from the warmest side will occur. In cob walls, not previously known for their insulative value, there is the unknown as to how the earth wall reacts when a portion of the wall assembly drops below the dew point. With the monitoring we will be able to monitor and document when these periods occur and what changes occur.

As earthen walls are considered mass walls, a measured actual density of 1653 kg/m3, there is the potential for the mass to absorb excess heat and then provide it back as surround air cools, similar to a rock wall in the sun. Though this is generally accepted, our research monitoring system should be able to show this action repeatedly. We expect to see inside temperature be moderated and have a shallower amplitude in it diurnal swings than the outside, and we expect to see correlational swings on the interior wall, though time shifted wherein the maximum daily temperature of the inner wall occurs several hours after the peak of the outer wall.

Type of test:

Performance tests of Earthen Mass Wall:

Earthen cob mass walls regulate humidity to prevent moisture condensation and mold growth. No HVAC systems are required to regulate this effect, and no vapor barriers are required. Four moisture sensors installed respectively in the north and south earthen mass walls will be used to provide annual data to back up anecdotal evidence of mass wall performance.

Earthen cob mass walls, insulated with ~30% pumice, have increased the R value of the wall from R-10 (regular cob mass wall without pumice) to ~R-20, contributing significantly to a passive solar design by regulating interior temperatures. Anecdotal evidence is to be confirmed with the use of temperature sensors installed in the north and south earthen mass walls and monitored over an annual period. From this data an energy model will be developed to estimate heat loss load calculations, determine heating requirements for similar structures, and determine an Energuide rating.

Equipment needed:

HOBO U30 Datalogger, 15 channels, with Internet interface.

4x M005 Soil Moisture and Humidity Sensors.

2x M008 Air Temperature & Humidity Sensors.

4x Soil Temperature Sensors.

Laptop computer

Location(s):

All tests performed on site at Eco-sense Earthen home, located in the Highlands district of Victoria, BC. Majority of installation work performed by the Bairds, owners and operators of the Eco-sense project. Data analysis and objectives performed and defined by C.Goodvin, project Test Engineer.

Date(s)/Total time:

Set-up of system:
- May 17 2010-June 10 2010

Initial data testing and calibration:
- June 10 2010 – June 14 2010

On-going data gathering:
- June 15 2010 – June 19 2011

Data analysis:
- June 22-2011 – August 17 2011

Report & Summary:
- August 2011

Test Objective:

Performance tests of Earthen Mass Wall:

The Performance Test will show validity of earthen cob wall structure at regulating moisture and air humidity. The humidity measurements will help determine how the earthen walls influence the interior environment. Measurements are taken at regular dated time intervals, of no less than 15 minutes.

The measured parameters include:

1x Temperature, dewpoint and humidity sensor for indoor environment (air)
1x Temperature, dewpoint and humidity sensor for outdoor environment (air)
2x Embedded soil temperature sensor readings of inside south and north wall, respectively: sensors located 5 cm into the wall.
2x Embedded soil temperature sensor readings of outside south and north wall, respectively: sensors located 5 cm into the wall
2x Embedded soil humidity sensor readings of inside south and north wall, respectively: sensors located 5 cm into the wall
2x Embedded soil humidity sensor readings of outside south and north wall, respectively: sensors located 5 cm into the wall
Sensors are connected to the HOBO U30 datalogger.

Comparison of Earth Home to Conventional

It is expected that the moisture content in the walls will not become greater than 6%, as many documents place the equilibrium water content of cob walls between 0.4%- 6% [Minke] moisture content. It is expected that the relative humidity within the Baird's home will maintain a level consistent to 55% RH. It is expected that the water content of the inner walls will be of similar value to that of the outer walls, or perhaps slightly greater than the outer walls due to higher vapor pressure attributed to indoor activities and heating loads.

Procedure

The Hobolink Datalogger will sample all sensors every 4 minutes and record a data set each half hour based on the averaged samples in that half hour. This will occur for each sensor, and will be recorded for the year period of research ending June 22 2011. Sensor details are provided in Table 1

Table 1-1

Sensor details

Series: Temp,¬†*C¬†(T/RH1 – Indoor Temp)
- Sensor Info
  - Serial Number: 9731301
  - Part Number: S-THB-XXXX
  - Label: T/RH1 – Indoor Temp

Series: RH,¬†%¬†(T/RH1 – Indoor RH)
- Sensor Info
  - Serial Number: 9731301
  - Part Number: S-THB-XXXX
  - Label: T/RH1 – Indoor RH

Series: Temp,¬†*C¬†(T/RH2 –Outdoor Temp)
- Sensor Info
  - Serial Number: 9731302
  - Part Number: S-THB-XXXX
  - Label: T/RH2 –Outdoor Temp

Series: RH,¬†%¬†(T/RH2 – Outdoor RH)
- Sensor Info
  - Serial Number: 9731302
  - Part Number: S-THB-XXXX
  - Label: T/RH2 – Outdoor RH

Series: Temp,¬†*C¬†(T7-North Wall OUTER)
- Sensor Info
  - Serial Number: 9738433
  - Part Number: S-TMB-XXXX
  - Label: T7-North Wall OUTER

Series: Temp,¬†*C¬†(T8-North Wall INNER)
- Sensor Info
  - Serial Number: 9738434
  - Part Number: S-TMB-XXXX
  - Label: T8-North Wall INNER

Series: Temp,¬†*C¬†(T9-Sth Wall OUTER)
- Sensor Info
  - Serial Number: 9738435
  - Part Number: S-TMB-XXXX
  - Label: T9-Sth Wall OUTER

Series: Temp,¬†*C¬†(T10-Sth Wall INNER)
- Sensor Info
  - Serial Number: 9738436
  - Part Number: S-TMB-XXXX
  - Label: T10-Sth Wall INNER

Series: Water Content,¬†m¬≥/m¬≥¬†(WC3- S. Wall OUTER)
- Sensor Info
  - Serial Number: 9741479
  - Part Number: S-SMC-M003
  - Label: WC3- S. Wall OUTER

Series: Water Content,¬†m¬≥/m¬≥¬†(WC4- S. Wall INNER)
- Sensor Info
  - Serial Number: 9741480
  - Part Number: S-SMC-M003
  - Label: WC4- S. Wall INNER

Series: Water Content,¬†m¬≥/m¬≥¬†(WC5- N. Wall OUTER)
- Sensor Info
  - Serial Number: 9741481
  - Part Number: S-SMC-M003
  - Label: WC5- N. Wall OUTER

Series: Water Content,¬†m¬≥/m¬≥¬†(WC6- N. Wall INNER)
- Sensor Info
  - Serial Number: 9741482
  - Part Number: S-SMC-M003
  - Label: WC6- N. Wall INNER

Device Info
- Product: HOBO U30 Station
- Serial Number: 9758096
- Version Number: 2.0.0
- Manufacturer: Onset Computer Corporation

General Deployment Info
- Launch Description: Eco Sense
- Launch Time: 06/15/10 05:25:54 GMT-07:00 AM
- Logging Interval: 00 Hr 30 Min 00 Sec
- Sampling Interval: 04 Min 00 Sec

First Sample Time: 06/15/10 05:30:00 GMT-07:00 AM
Last Sample Time: 06/19/11 03:00:00 GMT-07:00 PM

Criteria for success:

Based on observation of data.

Data Output/Intervals Sample Data Sets:

Table 1-2 – Indoor Environment Sample Data

#	Date Time, GMT-07:00	Indoor Temp, (°C)	Indoor RH, %	Indoor DewPt, °C)
1	06/15/10 5:30	20.627	54.3	11.1
2	06/15/10 6:00	21.533	54.6	12
3	06/15/10 6:30	20.889	53.8	11.2
4	06/15/10 7:00	20.793	53.9	11.1
5	06/15/10 7:30	20.722	54.3	11.2
6	06/15/10 8:00	21.342	54.9	11.9
7	06/15/10 8:30	21.008	54.7	11.6
8	06/15/10 9:00	20.841	54.8	11.4
9	06/15/10 9:30	20.722	54.7	11.3
10	06/15/10 10:00	20.65	54.5	11.2

Table 1-3 – Outdoor Environment Sample Data

Plot Title: Eco

#	Date Time, GMT-07:00	Outdoor Temp, (°C)	Outdoor RH, %	Outdoor DewPt, (°C)
1	06/15/10 5:30	8.095	76.3	4.2
2	06/15/10 6:00	7.444	74.9	3.3
3	06/15/10 6:30	8.045	74.2	3.7
4	06/15/10 7:00	7.67	77	3.9
5	06/15/10 7:30	8.27	78.5	4.8
6	06/15/10 8:00	9.435	78.7	5.9
7	06/15/10 8:30	9.952	79.9	6.7
8	06/15/10 9:00	11.151	75.1	6.9
9	06/15/10 9:30	12.147	66.2	6
10	06/15/10 10:00	12.001	65.6	5.8

Table 1-4 – Earthen Wall Temperature and Moisture Sample Data

Plot Title: Eco

#	Date Time, GMT-07:00	Temp - S. Wall INNER, (°C)	Water Content - S. Wall INNER, (m^3/m^3)
1	06/15/10 5:30	20.341	0.0228
2	06/15/10 6:00	20.341	0.0228
3	06/15/10 6:30	20.341	0.0228
4	06/15/10 7:00	20.341	0.0228
5	06/15/10 7:30	20.341	0.0228
6	06/15/10 8:00	20.317	0.0228
7	06/15/10 8:30	20.317	0.0228
8	06/15/10 9:00	20.317	0.0228
9	06/15/10 9:30	20.293	0.0228

Results:

Relative Humidity

The relative humidity inside the home responded as predicted, in that the mean RH was 54.81%, with minimal fluctuation from the mean, and no fluctuation into so called "dangerous levels" of below 20% or over 70%.. The extremes equally distributed throughout the year are of interest in that they show the maximum limits; maximum indoor RH reached 68.6%, and a minimum of 39%. For outdoors the extremes were 100% and 18.4%.

It is critical to note the average RH and how much the RH fluctuated on a daily basis. Indoor RH averaged 54.81 % with a daily fluctuation of only 4.7%, thus meaning that that daily average range was between 57.16% - 52.46%. In comparison, the outdoor RH was on average 78.95% with a daily fluctuation of 24.7% thus meaning the daily average fluctuation was between 91.3% - 66.6%.

The following graph shows the outdoor relative humidity variation in black for the year (min and max for each day), and shows the indoor RH (min and max) in blue. The key points of observation are the wide daily difference between the outside RH minimum and maximum and the corresponding very narrow range seen with the indoor RH. Also it is important to note the steady range of the indoor RH.

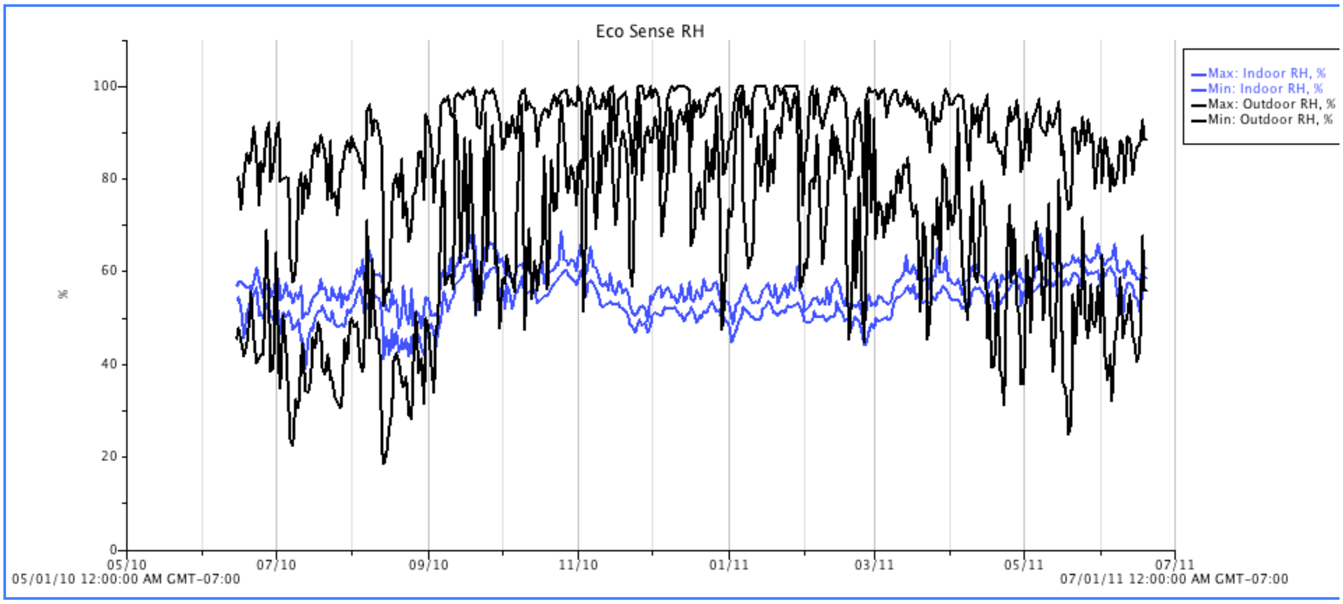


Figure 1-1 – Annual RH variation and Fluctuation

RH results summary:

Table 1-5 – Relative Humidity Results Summary

		Average Annual RH %	Daily Avg RH % Fluctuation	Daily RH% Range
Indoor Max RH	68.6%	54.81%	4.7%	57.16%-52.46%
Indoor Min RH	39 %			
Outdoor Max RH	100%	78.95%	24.7%	91.30%-66.60%
Outdoor Min RH	18.4%			

Humidity Control Observational Snapshot

The following graph (figure 2) shows the effective response of the walls to the sudden increase in temperature and RH indoors at a party wherein 60 people attended from 1pm to 4 pm.

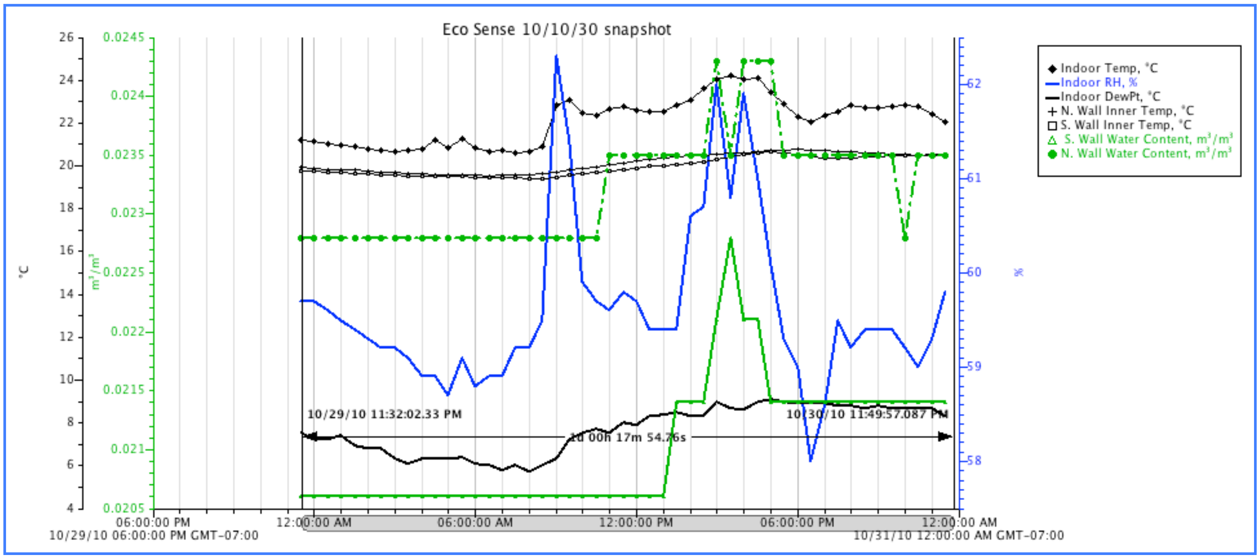


Figure 1-2 - Snapshot October 30 2010 – humidity control

As noted in Minke, most moisture adsorption and de-adsorption within earthen walls within the first 24 hrs occurs within 4 inches (10 cm). The moisture sensors are located 5 cm deep therefore we can calculate the amount of moisture adsorbed. The S. Inner wall moisture content increased from 0.0206 m3/m3 to 0.0228 m3/m3 for a change of 0.0022 m3/m3; The N. Inner wall had an overall increase of 0.0015 m3/m3. The average increase between the two was 0.0018 m3/m3. Over a wall area of 99.209 m2 with a depth of 10cm, the volume of wall mass implicated in adsorbtion is 9.9209 m3.

An increase of 0.0018 m3/m3 X wall volume of 9.9209 m3 = 0.017858 m3 of water adsorded. This converts to 17.858 litres or 17.858 kg. Over the four hour period this is a rate of adsorbtion of 4.46kg/hr.

Wall Water Content

The results of water content (m^3/m^3) in the walls demonstrates the ability of the walls to control humidity yet maintian a water content levels that is virtually static, and remains well below the levels required for insect life (> 14%), and fungal growth (>20%)., (table 6). The content responds remarkably similar to the result found by Minke and Straube, further supporting a moisture equilibrium between 0.4% to 6.0%. These moisture levels stayed static for the year, with minor fluctuations attributed to temperature changes.

Table 1-6 – Wall Water Content Summary

	Max & Min Moisture content	Average Annual Moisture Content	Daily Avg moisture content (m^3/m^3) fluctuation	Daily Moisture content range
S. Inner Wall	2.35%	1.88%	0.0012 or 0.12%	1.82%-1.94%
	1.41%			
N. Inner Wall	2.93%	2.18%	0.0010 or 0.10%	2.13%-2.23%
	1.70%			
S. Outer Wall	7.73%	5.21%	0.0079 or 0.79%	4.82%-5.6%
	3.81%			
N. Outer Wall	5.55%	3.20%	0.0045 or 0.45%	2.98%-3.42%
	2.21%			

The water content in the walls is within the moisture equilibrium range of 0.4%- 6%. Even with the average daily fluctuation the fluctuation range is very narrow. Moisture content is not considered unreasonable or dangerous until >14% (insect inhabitation) and >20% (molds and fungi).

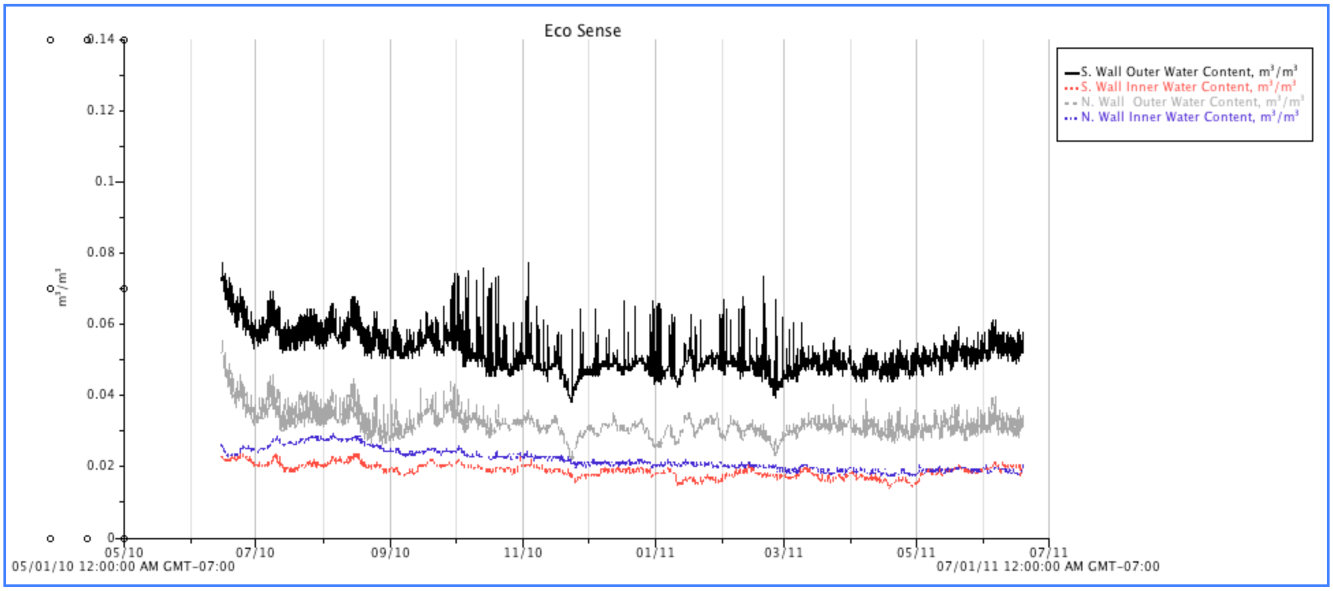


Figure 1-3 Yearly Wall Moisture Content

Figure 3 represents the water content for the year. The research data results on the walls clearly illustrates that on the inside of the home (the wall surface with the highest vapour pressures) the moisture level does not exceed 3%. This was unexpected, as we predicted it would be greater on the inside due to heating loads and living activities.

Table 1-7 Maximum wall water content measured over the year

	m^3/m^3	Percentage
Max S. Inner Wall Water Content	0.0235	2.35%
Max N. Inner Wall Water Content	0.0293	2.93%
Max S. Outer Wall Water Content	0.0773	7.73%
Max N. Outer Wall Water Content	0.0555	5.55%

Dewpoint Observation

The dewpoint is the temperature at which water vapor in the air condenses into a liquid. There was nothing discovered that indicated a relationship between wall water content and RH or Dewpoint. The following snapshots (figures 4, 5, and 6) are of the outer wall assembly performance in relation to outside dewpoint and relative humidity. Of particular note is where the wall temperatures drop below the dewpoint., (figure 4). It is at these times that we would expect drastic changes in the moisture content in the walls, wherein we would expect to see condensation and thus saturation.

Moisture levels stay well within the < 3% range. The expectation was that at some point in the day the dew point would be at its maximum, providing the best chance for the wall to come nearest the dewpoint. During this same period we know that a wall experiences its minimum temperature. The graphs below observe the maximum dewpoint in relation to the minimum wall temperature.

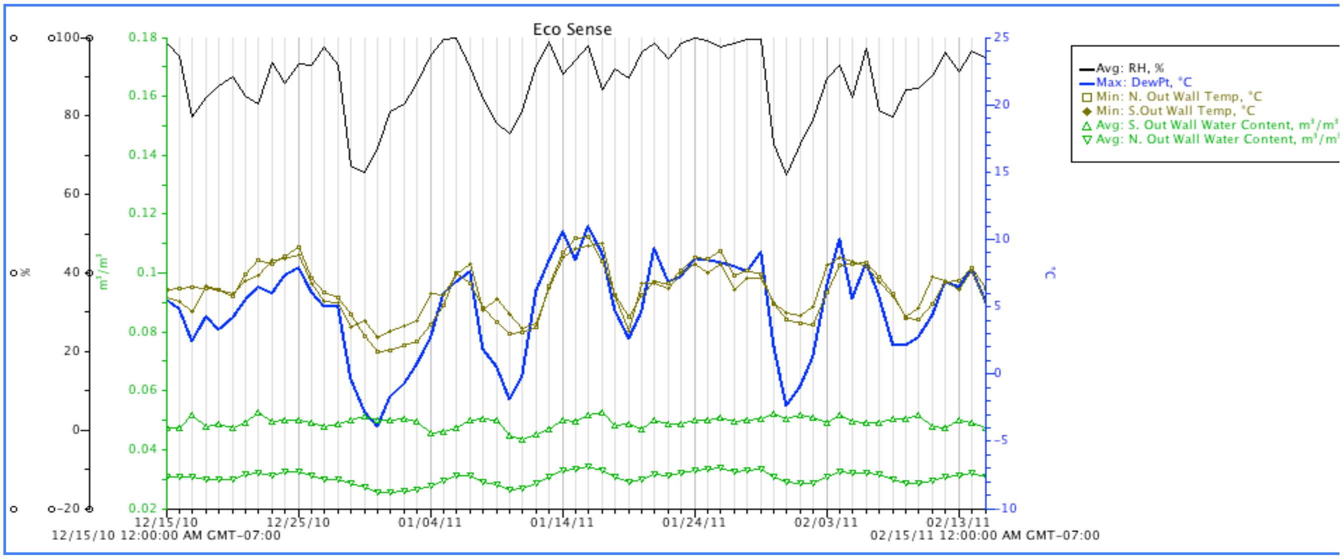


Figure 1-4 Winter Results

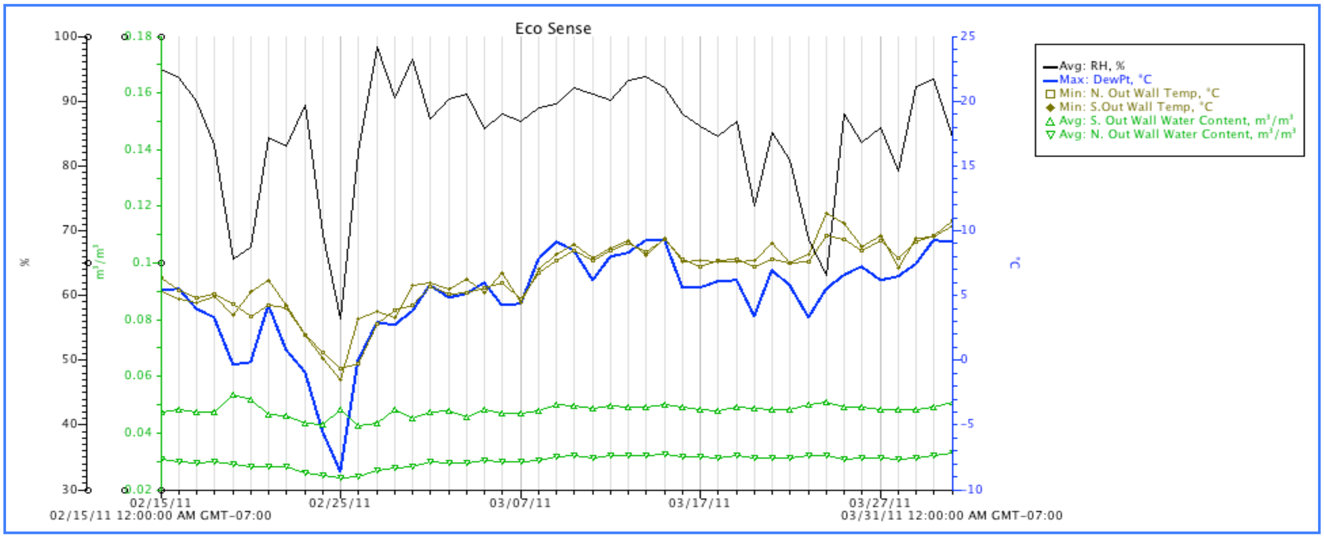


Figure 1-5 Spring Results

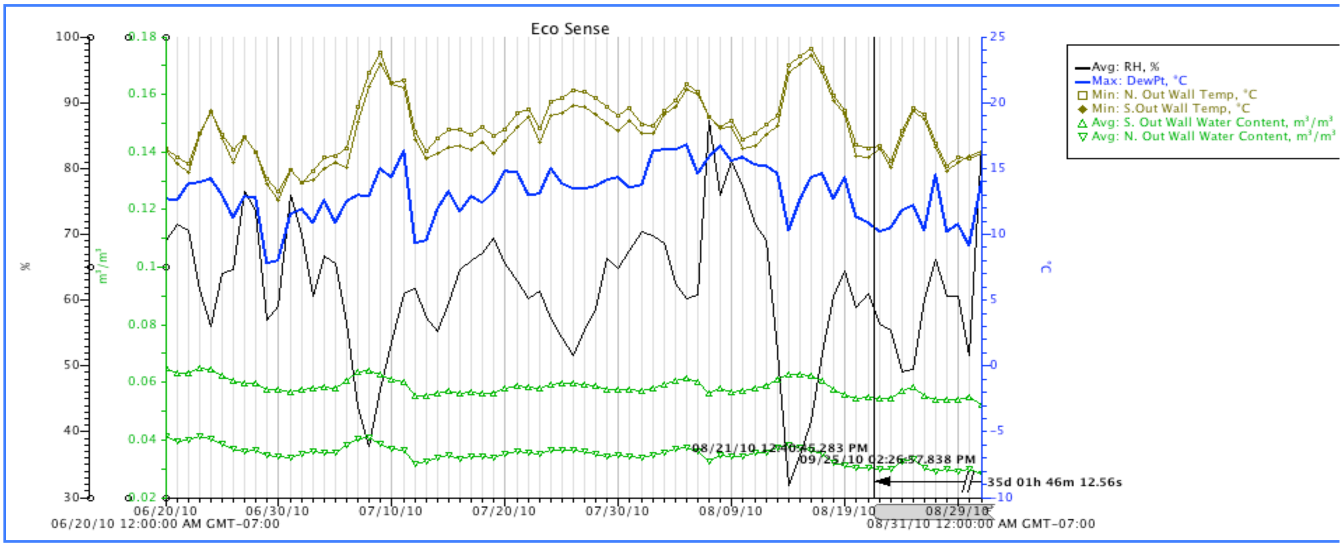


Figure 1-6 Summer Results

Wall Temperature and Moisture Content

A result that was not expected was the relationship with wall water content and temperature. We found that in periods where wall temperatures increased sharply from the normal range, such as when sun heated up the south outer wall, we witnessed a correlational increase in water content. The following graph (figure 7) compares the moisture and temperature of the North Outer Wall to that of the South Outer wall in November (winter), wherein the sun has shone on the south wall during a day where temperature is below 0^{o}C

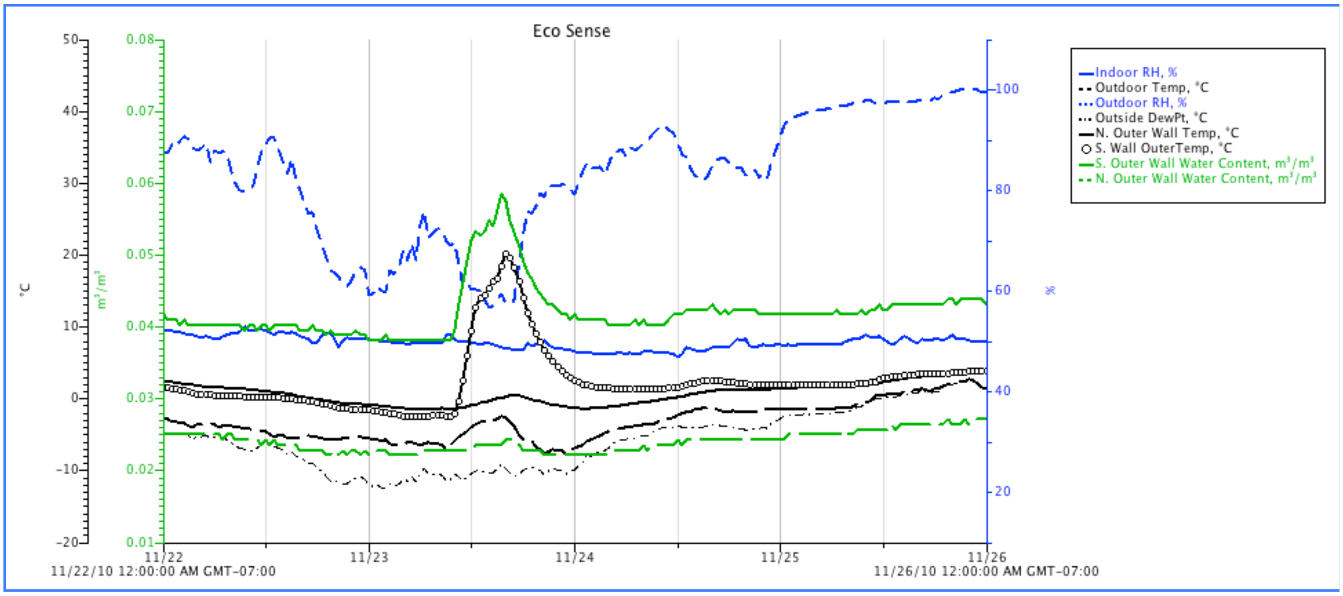


Figure 1-7 RH, Temp and Water content

Water is a polar molecule, meaning it has magnetic force due to two atoms that are negatively charged, and one that is positively charged. As the temperature increases the water molecules gain energy, vibrating and moving within the wall capillaries. In the case where the temperature of the wall increases we see greater moisture bonding with the clay as the activity of the water molecule provide more opportunity to contact clay molecules as a result of more freedom to move. As the moisture comes near the exterior surface of the wall, the pressures and temperature allow for evaporation.

Temperature Moderation

Results thus far have shown the temperature moderating effect of the cob wall wherein interior temperatures maintain a shallower amplitude between daily extremes, than those experienced outdoors. Below is a graph that denotes the South Wall over a 7 day period showing the heating and cooling exterior temperature cycles. Of importance in this observation is the time shift seen between S. Wall outdoor peak and the S. Wall indoor peak, which is several hours' difference. This also highlights the cycling pattern of the outer wall moisture and temperature swings.

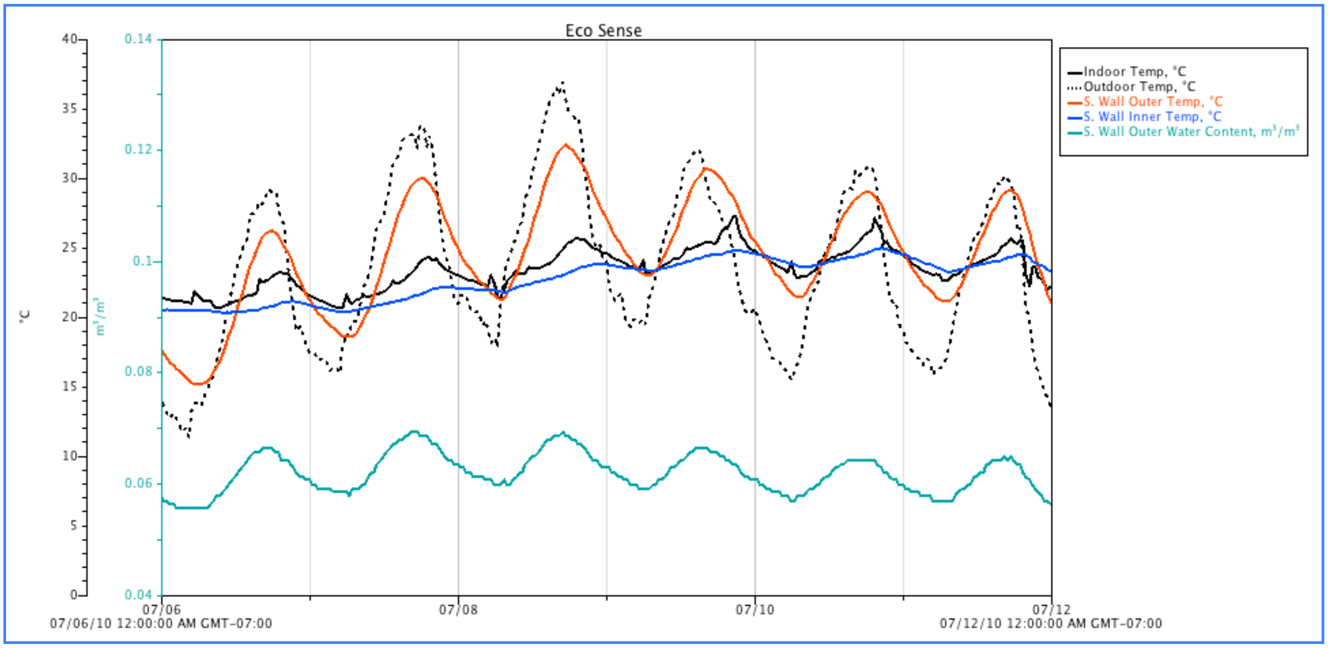


Figure 1-8 Temperature variation

Temperature control through Heat storage is a anecdotal observation in all mass wall systems. The ability for cob to absorb and store heat readily explains this anecdotal observation. Specific heat capacity is the measure of the amount of thermal energy that can be stored in a volume of material. Specific heat capacity measurement of the cob walls reflect similar findings found by Goodhew, Grindley, & Probert.

Table 1-8 Measured Specific Heat capacity and adjusted for 3% water content

	MJ/(m3 K)	J/(kg K) where m3 is 1685kg	kWhr/(m3 k)
KD2	1.482	879	0.41666
With 3% WC		975.34	0.45651

$$\frac{100*879 + 3*4186.8}{100+3} = 975.34 \text{ average}$$

For every degree C increase the clay walls serve as a battery and can store 0.45651 kWhrs/ m3 of heat.

Table 1-9 Common Specific Heat Capacity Table: Engineering toolbox.com

Substance	Specific Heat	
	(cal/gram°C)	(J/kg°C)
Air, dry (sea level)	0.24	1005
Asphalt	0.22	920
Bone	0.11	440

Ice (0°C)	0.50	2093
Granite	0.19	790
Sandy clay	0.33	1381
Quartz sand	0.19	830
Water, pure	1.00	4186
Wet mud	0.60	2512
Wood	0.41	1700

The absorbed energy from solar gain provides a significant construct in the functioning of the wall assembly. As the sun hits the wall surface the wall absorbs energy to a depth we estimate to be 10 cm. With a specific heat capacity based on an average water content of 3%, a 3m X 3m section can absorb 0.45651 kWhrs for every degree C increase. This absorbed heat is then released over a time delay, thus moderating the heat by absorbing excesses then releasing the energy as the external inputs are removed.

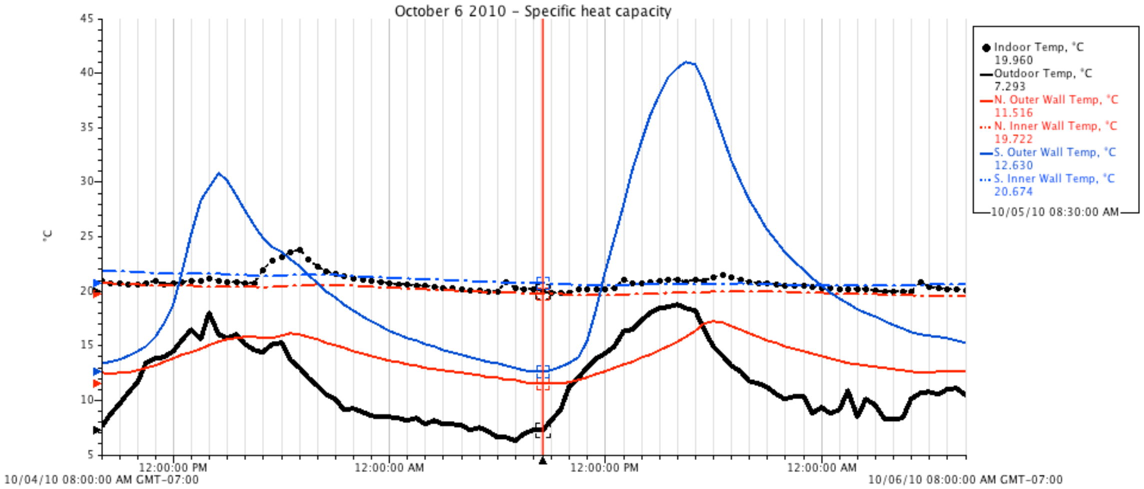


Figure 1-9 Time Lag (1) Minimum wall temperature @ 8:30 am

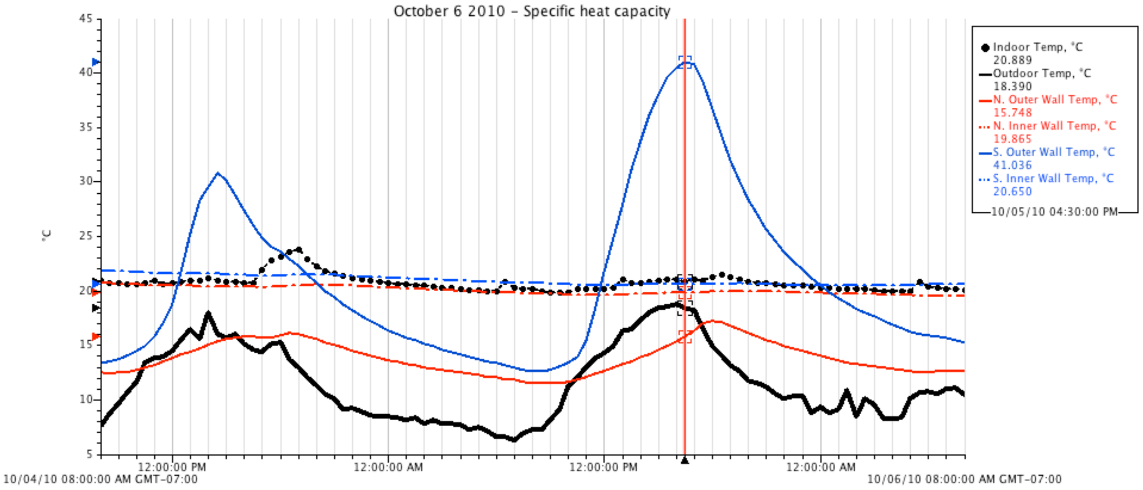


Figure 1-10 Time Lag (2) Peak temperature reached @ 4:30 pm lapse of 8 hrs

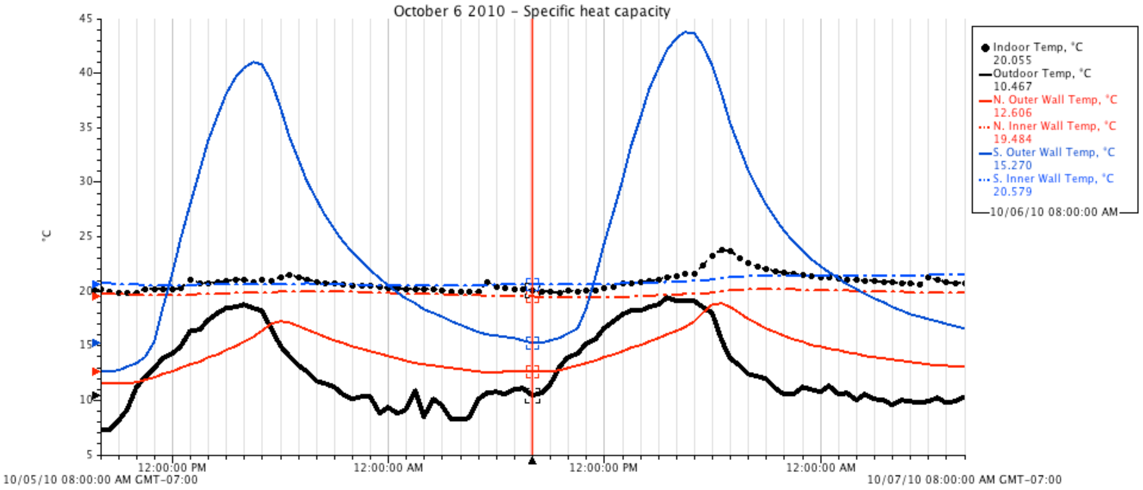


Figure 1-11 Time Lag (3) Minimum wall temp reach @ 8 am following day: lapse 15.5 hrs

In a day with good solar exposure we see the S. Outer wall temperature increase from 12.63 C to 41.04 c, a difference of 28.41C. This translates into an increase in stored thermal energy of 12.97 kWhrs. The time lag to reach this peak energy store was 8 hours. The corresponding time lag to give up the gains is 15.5 hours. All temperature profiles on the wall systems show the ability to quickly and readily absorb thermal energy, with a much extended tail as the energy dissipates.

The relevance of this in understanding the specific heat capacity, the time lags in releasing stored energy, and the thermal performance of the wall is that as the energy composition of the outer wall fluctuates with variations of temperature and moisture, it directly impacts the flow of thermal energy from the inside of the wall to the exterior, which means the functional RSI values vary greatly depending upon the state of the exterior wall.

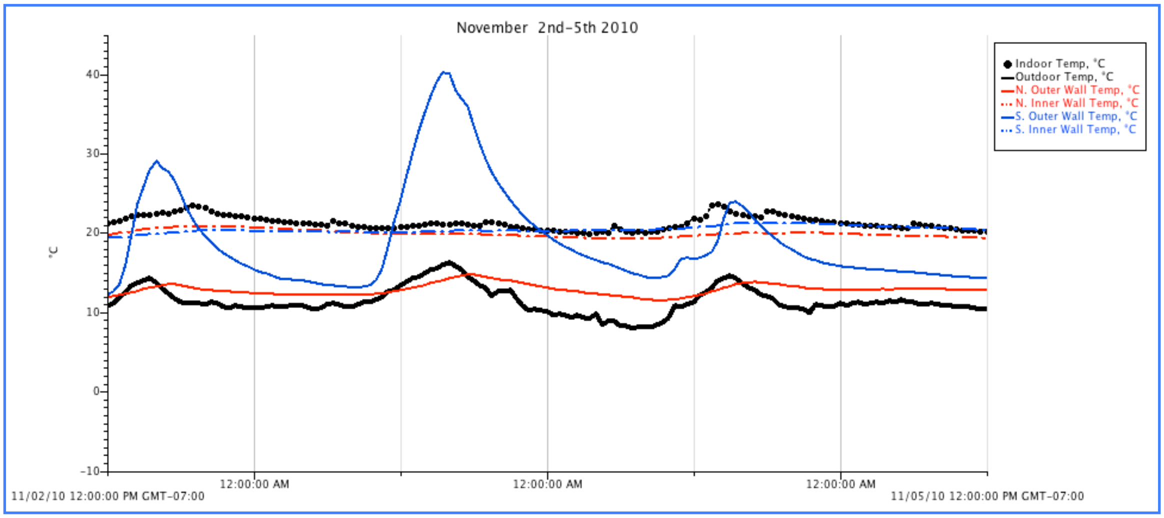


Figure 1-12 Snapshot November 2-5 2010

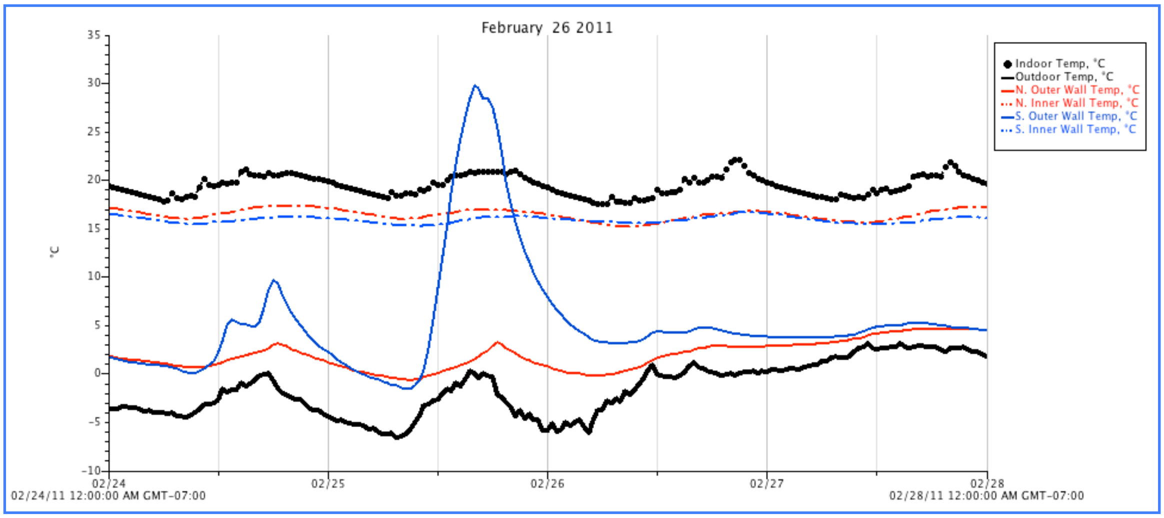


Figure 1-13 Snapshot February 26

In observations over the summer in particular July 8 2010, Outdoor Max temp was 33.8 C, indoor Max temp was 24.2 C with a lag time of 1.5 hours between peaks.

We find the inner wall temperatures respond primarily to indoor temp. As noted Max indoor temp was 24.2 C; the N. Inner Wall Max temp (22.8 C) occurred 3.5 hours after, and S. Inner Wall Max temp (22.13C) had a lag of 3.0 hours.

Winter:

Review of the diurnal (24 hr) temperature swing on the coldest day of the year November 23 2010, provides additional insight on the thermal lag of the cob wall. Min Temp -8 C @ 11:00 pm; Max Temp – 2.4 C @ 3:30 pm.

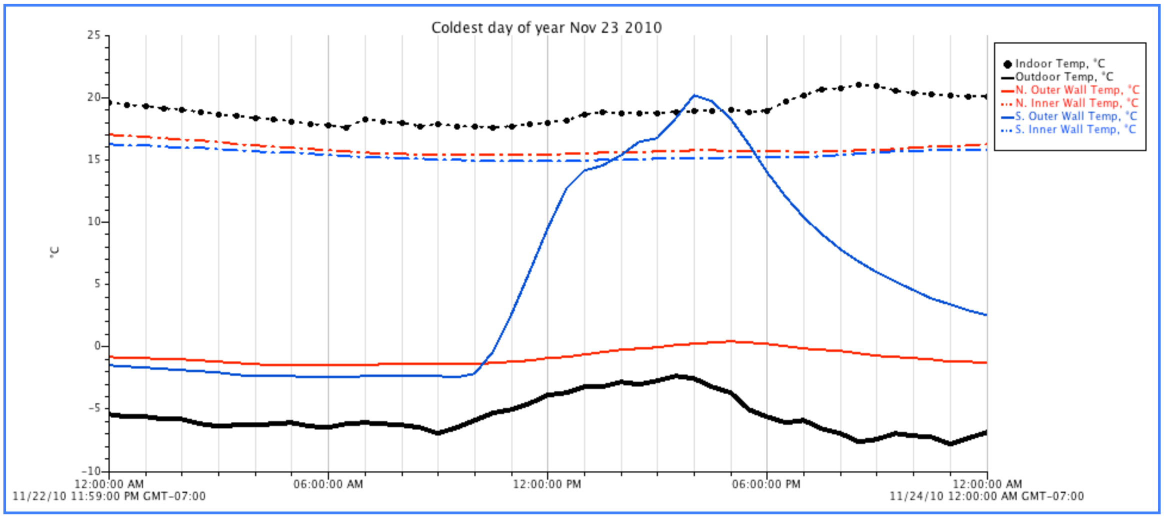


Figure 1-14 Snapshot of November 23 coldest day of the year

Thermal lag is not decipherable between inside and out, but the N. Outer wall that receives no solar gain shows a slight lag. The warmest outdoor temperature of the day -2.4 C was followed by the N.Outer Wall warmest temp of 0.4 C; the time lag was 1.5 hours

The plaster on the cob walls would be insignificant as it is virtually the same materials as the cob, though comprised of finer particles and highly compressed. The KD2 probe does not account for this as the measuring tip of the probe is buried about 10 cm into the wall

Conclusions:

To use the animal cell as an analogy, we see the cob wall acting like a cell membrane, selectively permeable, being able to exchange gasses on each surface layer in response to the changing environment. The interior wall surface layer is very responsive to the interior air of the home. The same can be said for the exterior surface layer and exterior air. The walls are responsive to thermal lag from heating, but only over a large time interval, suggesting a very effective thermal resistance. As the environment changes it can alter its performance to ensure the inside maintains constant and amenable conditions while not destabilizing its structure in the process.

Under normal conditions the wall does not experience condensation; extended to abnormal conditions where conventional wall assemblies are challenged, such as when dewpoints and wall temperature collide, there is also no sign of change in wall moisture content.

The walls show a remarkable ability to balance relative humidity, specifically as this building has no mechanical system to do so, and does it with elegance throughout the whole year. The walls respond quickly to the absorption and de-absorption of vapor. It also holds humidity at levels that are healthier for humans [Minke], without sacrificing the building structure life expectancy.

The moisture content in the walls is kept with a very low and narrow ranging margin, a margin that does not allow insects or fungus to live. This provides evidence as to why historical structures like these have such long lived life expectancies of 500-700 years.

The year worth of data collection has provided a huge resource that will continue to be drawn upon, analyzed outside the timeframe deadlines of this report, and dissected. There is opportunity to share and revisit this data as conditions allow.

What is of most value out of the monitoring of these walls is not the ability to observe and dissect a component of a wall assembly, but to observe it in its entirety, functioning within its ecosystem. In an era where we focus on small and more narrow criterion, we forget to stand back and see how earthen buildings can function as a whole. This has been an astounding opportunity to see the whole.

References:

Goodhew, S.M.R., Grindley, P.C., Probeif, S.D.: Composition, effective thermal conductivity and specific heat of cob earth-walling. Transactions on the Built Environment vol 15, © 1995 WIT Press, www.witpress.com, ISSN 1743-3509

Earthen Wall Schematic

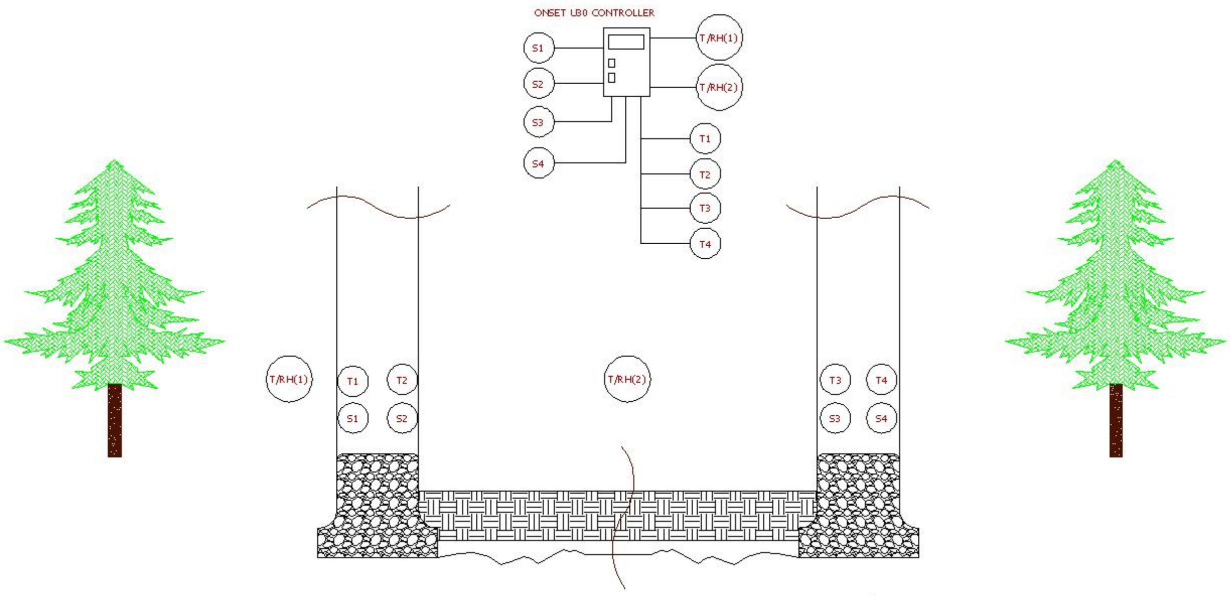


Figure 1-15 Earthen Wall Sensor Schematic

2. Solar Thermal Monitoring Test Plan

Engineering Test Plan – Solar Thermal Heating

Specification plan for what is to be done and how it will be accomplished, indicating why each task will be done and may anticipate use of resources such as time, money, equipment, facilities, and people.

Objective

The objective is to gather data on the performance of the solsr thermal system and see what role it plays in the energy mix of the home, when or if there are periods that it is more effective, what the comparisons are to wood and solar PV, and suggest improvements to the system design.

Expected Observations

It is expected that the system will function as the manufacturer specs. We expect that a considerable amount of heat is dumped in the summer, and that very little is used for space heating purposes between May and October. We expect that it the cost per kWhr of energy is a third of that for solar PV.

Type of test

1. Performance tests of Solar Collector Closed Loop:

Monitor existing closed loop between Thermomax collectors and off-grid double coil tank. The solar collectors feed into the bottom tank heat exchanger. Closed loop heat exchange fluid a mixture of water and glycol. Sensor data logging uses volumetric pump flow and temperatures of collector outlet, and collector inlet to calculate heat added to the system. Circulation pump controller by temperature difference between collector and tank.

2. Performance tests of Space Heating and Wood Boiler Loop:

Wood boiler acts as both heat source and heat dump. Space heating loop combined with wood boiler, feeding into off-grid tank upper heat exchange coil. In winter wood boiler adds heat directly to the space heating system and to the tank for DHW. In summer, when space heating demand low/non-existent the wood boiler flow reversed to cool off-grid tank.

Equipment needed

1. Performance tests of Solar Collector Closed Loop:
    - 12Volt iSolarPlus Controller with VBus capability.
    - VBus data logger to periodically download stored data on controller.

2. Performance tests of Space Heating and Wood Boiler Loop:
    - 12Volt iSolarPlus Controller with VBus capability.
    - VBus data logger to periodically download stored data on controller.

Location(s)

All tests performed on site at Eco-sense Earthen home, located in the Highlands district of Victoria, BC. Majority of installation work performed by the Bairds, owners and operators of the Eco-sense project. Data analysis and objectives performed and defined by C.Goodvin, project Test Engineer.

Date(s)/Total time

Set-up of system:
  - May 2010

Initial data testing and calibration :
  - June 5 2010

On-going data gathering:
  - June 17 2010 – June 20 2011

Data analysis:
  - June 23 2011- August 28 2011

Report:
  - August 28 2011

Summary – Installation of the Caleffi iSolar controllers went well, but there were flash problems with the DL Puck that delayed collection of data from the wood system.

Test Objective

1. Performance tests of Solar Collector Closed Loop:

To collect daily data on the heat input from the solar collectors, using the following formula defining heat transfer by fluid flow:

$$Q = V \times c \times \rho \times (T_b - T_a)$$

Where:

Q = heat transfer per unit time [W = J/s]
V = flow rate of fluid [m3/s]
c = specific heat capacity of fluid at constant pressure [J/kg C]
ρ = density of fluid [kg/m3]
ΔT = temperature rise across parallel collectors [C]

To set up the controller to capture and store the data collected, which includes collector outlet temperature, collector inlet temperature before circulation pump, and tank temperature at top of bottom solar loop heat exchange coil. The controller will also estimate the energy generated across the collectors in kWh.

Analyze data on a weekly, monthly and yearly basis.

Incorporate a Insolation data pyranometers of three surrounding University of Victoria weather stations (Eagle View, Cal Revelle, East Highlands) to measure actual available insolation levels, and average insolation levels. Knowledge of actual insulation levels (W/m2) can be used to compare with estimated collector capacity and used to calculate actual collector capacity.

$$Capacity = A_{ap} \times \left(\eta_0 G - a_1\left(T_m - T_a\right) - a_2\left(T_m - T_a\right)^2\right)$$

Where:

Capacity = Power [W]
Aap = aperture area of collectors [m2]
G = insolation [W/m2]
ηo = optical efficiency
a1 = heat loss coefficient
a2 = second order coefficient
Tm = mean temperature across collector, ΔT [C]
Ta = ambient temperature [C]

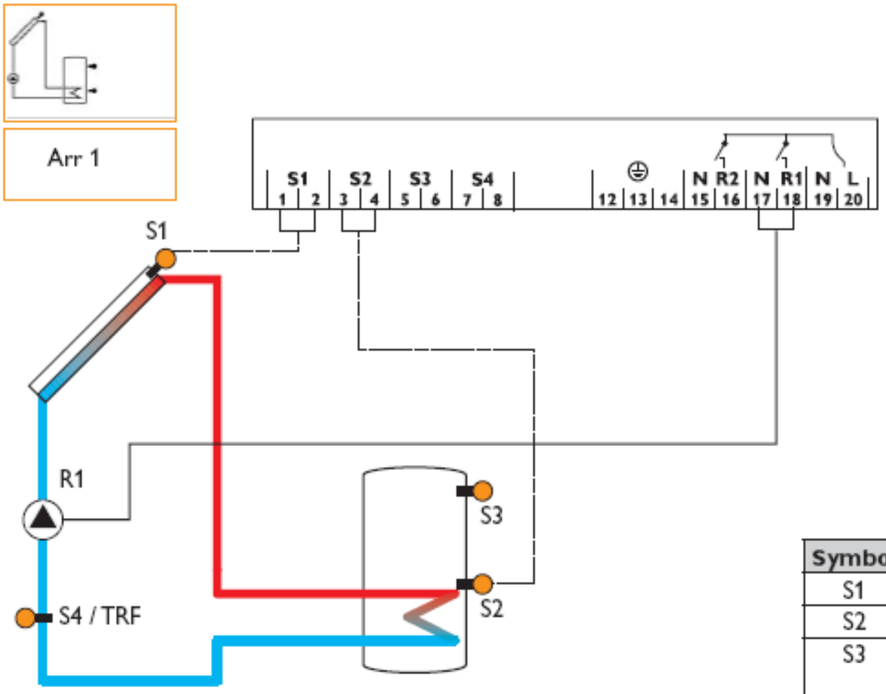
2. Performance tests of Space Heating and Wood Boiler Loop:

The actuator valve and pump in the space heat/boiler loops are connected and operated by the controller, defined under two conditions: when the boiler provides heat in the winter and when the water storage tank needs to dump heat in the summer. We intend to collect and log daily data on the heat input from and heat dump to the wood boiler for one year.

Procedure:

1. Performance tests of Solar Collector Closed Loop:

The controller for the solar collector loop will be wired according to the schematic seen in Figure 1, and detailed in the controller manual. The heat quantity measurement will be enabled and recorded for this set-up.



Symbol	Specification
S1	Collector sensor
S2	Tank sensor below
S3	Tank sensor at the top (optionally)
S4 / TRF	Sensor for heat quantity measurement (optionally)
R1	Solar pump

Figure 2-1 Arrangement 1 sensor set up for solar collector loop

Once wiring set up is successful output data will be examined for validity. Expected output parameters will be S1, S2, S3 temperature readings as well as the result of S4 heat quantity measurement, expected to be in kWh.

Table 2-1 – Caleffii Controller Setting – Expected system inputs

Channel	Setting	Description
COL	Display	Temperature collector 1 (S1) Range -40 to +480F
TST	Display	Temperature tank 1 (S2) Range -40 to +480F
S3	Display	Temperature sensor 3
TRF (1)	Display	Temperature return sensor
S4 (2)	Display	Temperature sensor 4 Range -40 to +480F
hP	Display	Operating hours relay 1 (adds up solar operating hours of relay)
kWh (1)	Display	Heat quantity kWh (see 4.1.7)
MWh (1)	Display	Heat quantity MWh (see 4.1.7)
DTO		Switch on temperature diff (ΔT regulation)
DTF		Switch off temperature diff (ΔT regulation)
SMX		Maximum tank temperature 1
EM	285F	Emergency temperature collector 1
OCX	OFF	Option collector cooling collector 1
CMX	250F	Max temp collector 1
OKN	OFF?	Option minimum limitation collector 1
CMN	50-195F	Minimum temperature collector 1 (used if OKN = ON)

OCF	OFF?	Option antifreeze collector 1
CFR	15-50F	Antifreeze temperature collector 1 (used if OCF = ON)
OREC	OFF	Option recooling
OTC	ON?	Option tube collector
OHQM	ON	Option WMZ (heat quantity balancing)
FMAX (1)	0-20 L/min	Maximum flow (enter in value of pump)
MEDT (1)	0-3	Antifreeze type (0=water, 1=pro-glycol, 2=eth glycol, 3=Tyfocor)
MED%	20-70%	Antifreeze content (adjust to reflect actual content)
HND1	AUTO	Manual operation relay 1
HND2	AUTO	Manual operation relay 2
LANG	En	Language
UNIT	CEL	Change over FAH/CEL

2. Performance tests of Space Heating and Wood Boiler Loop:

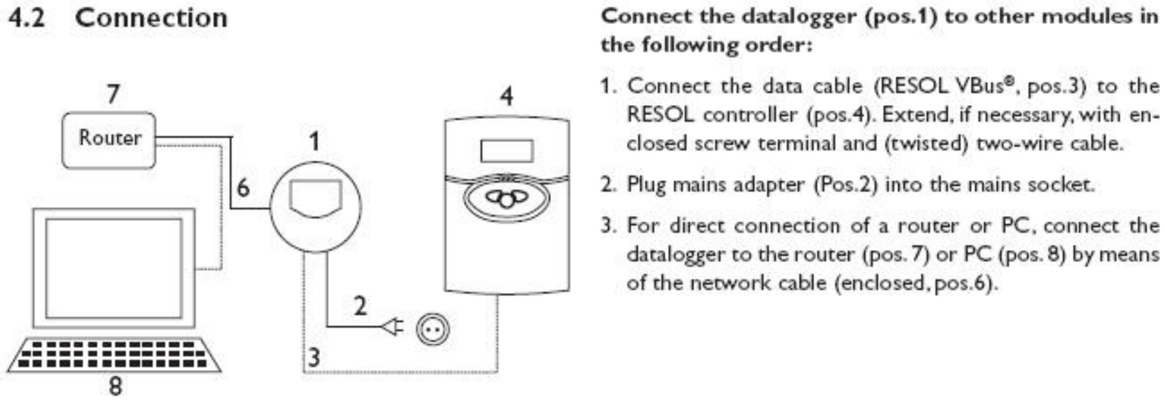
The controller for the solar collector loop will be wired according to the schematic seen in Figure 2, and detailed in the controller manual.

- Winter heating logic cycle (pump circulates fluid from boiler to tank):
- Boiler heated state usually > 140F (cooling phase deactivated).
- When S1-S2 > 120F then relay pump/valve switches to ON.
- When S1-S2 ≤ 1F then relay pump/valve switches to OFF.
- If S2 or S3 > 190F then relay shuts pump/valve OFF (tank hot).

Summer heat dump cycle/cooling phase:

- Boiler at a cooler state then tank.
- Heat dump keeps tank temperature between 185 -190F.
- When S4 < 140F and S3 ≥ 195F then relay pump/valve switches ON.
- When S3 ≤ 185F then pump/valve switches to OFF.

3. Data-logging using DL



4.2 Connection

Connect the datalogger (pos.1) to other modules in the following order:

1. Connect the data cable (RESOL VBus®, pos.3) to the RESOL controller (pos.4). Extend, if necessary, with enclosed screw terminal and (twisted) two-wire cable.
2. Plug mains adapter (Pos.2) into the mains socket.
3. For direct connection of a router or PC, connect the datalogger to the router (pos. 7) or PC (pos. 8) by means of the network cable (enclosed, pos.6).

Sample output files

Table 2-2 Winter Heating Phase – with wood inputs

Date/Time	Temperature sensor 1	Temperature sensor 2	Temperature sensor 3	Temperature sensor 4	Operating hours relay 1	Operating hours relay 2	Heat quantity
Mon Nov 1 11:20:00 2010	57	58.7	69.8	34.6	147	20	2313040
Mon Nov 1 11:25:00 2010	57	57.6	68.5	34.1	147	20	2313040
Mon Nov 1 11:30:00 2010	57.3	55.6	66.4	33.7	147	20	2313040
Mon Nov 1 11:35:00 2010	57.6	53	64	33.3	147	20	2313040
Mon Nov 1 11:40:00 2010	57.3	50.4	62.1	35.9	147	20	2314463
Mon Nov 1 11:45:00 2010	55.4	48.4	61.4	37.6	147	20	2316160
Mon Nov 1 11:50:00 2010	46.4	47.3	60.4	35.1	148	20	2317200
Mon Nov 1 11:55:00 2010	43.8	46.6	58.9	34	148	20	2317200
Mon Nov 1 12:00:00 2010	43.9	45.6	57.2	33.8	148	20	2317200
Mon Nov 1 12:05:00 2010	44.5	44.3	55.6	33.4	148	20	2317200
Mon Nov 1 12:10:00 2010	45.3	42.9	54	33.2	148	20	2317200
Mon Nov 1 12:15:00 2010	46	41.6	52.4	32.7	148	20	2317200
Mon Nov 1 12:20:00 2010	46.6	40.4	51.1	31.3	148	20	2317888
Mon Nov 1 12:25:00 2010	47.1	39.2	50.1	30.9	148	20	2319249
Mon Nov 1 12:30:00 2010	47.2	38.2	49.2	31.3	148	20	2320647
Mon Nov 1 12:35:00 2010	45.7	37.6	48.1	31.5	148	20	2321984
Mon Nov 1 12:40:00 2010	42.8	36.8	47	31.6	148	20	2322793
Mon Nov 1 12:45:00 2010	42.1	36.3	46	31.4	148	20	2322793
Mon Nov 1 12:50:00 2010	42.1	35.9	45.3	31.2	148	20	2322793
Mon Nov 1 12:55:00 2010	42.2	35.4	44.8	30.8	148	20	2322793
Mon Nov 1 13:00:00 2010	42.3	35.1	44.2	30.6	148	20	2322793

Table 2-3 Summer Thermal Collection Phase (no space heating; heat dump functional)

Date/Time	Temperature sensor 1	Temperature sensor 2	Temperature sensor 3	Temperature sensor 4	Operating hours relay 1	Operating hours relay 2	Heat quantity
Fri Jul 23 08:20:00 2010	26.8	67.1	72.6	25.7	0	6	0
Fri Jul 23 08:30:00 2010	26.6	67	72.5	25.7	0	6	0
Fri Jul 23 08:40:00 2010	26.6	66.9	72.4	25.7	0	6	0
Fri Jul 23 08:50:00 2010	26.4	66.8	72.3	25.7	0	6	0
Fri Jul 23 09:00:00 2010	26.4	66.8	72.2	25.7	0	6	0
Fri Jul 23 09:10:00 2010	26.4	66.8	72.2	25.7	0	6	0
Fri Jul 23 09:20:00 2010	26.4	66.7	72.1	25.6	0	6	0
Fri Jul 23 09:30:00 2010	26.3	66.6	72	25.6	0	6	0
Fri Jul 23 09:40:00 2010	26.3	66.6	72	25.6	0	6	0
Fri Jul 23 09:50:00 2010	26.1	66.5	71.8	25.6	0	6	0
Fri Jul 23 10:00:00 2010	26	66.4	71.8	25.6	0	6	0
Fri Jul 23 10:10:00 2010	26	66.4	71.8	25.6	0	6	0
Fri Jul 23 10:20:00 2010	25.8	66.3	71.6	25.6	0	6	0
Fri Jul 23 10:30:00 2010	25.8	66.2	71.6	25.6	0	6	0
Fri Jul 23 10:40:00 2010	25.8	66.2	71.4	25.6	0	6	0
Fri Jul 23 10:50:00 2010	25.7	66.2	71.4	25.6	0	6	0
Fri Jul 23 11:00:00 2010	25.7	66.1	71.3	25.6	0	6	0
Fri Jul 23 11:10:00 2010	25.6	66.1	71.2	25.5	0	6	0
Fri Jul 23 11:20:00 2010	25.6	66	71.2	25.5	0	6	0
Fri Jul 23 11:30:00 2010	25.6	65.9	71	25.4	0	6	0
Fri Jul 23 11:40:00 2010	25.4	65.9	71	25.4	0	6	0
Fri Jul 23 11:50:00 2010	25.4	65.7	70.9	25.4	0	6	0
Fri Jul 23 12:00:00 2010	25.4	65.7	70.9	25.4	0	6	0
Fri Jul 23 12:10:00 2010	25.4	65.7	70.8	25.4	0	6	0
Fri Jul 23 12:20:00 2010	25.3	65.7	71	25.4	0	6	0
Fri Jul 23 12:30:00 2010	25.4	65.9	71.6	25.3	0	6	0
Fri Jul 23 12:40:00 2010	25.3	66.3	72.2	25.4	0	6	0
Fri Jul 23 12:50:00 2010	25.3	66.8	73	25.4	0	6	0
Fri Jul 23 13:00:00 2010	25.3	67.4	73.7	25.4	0	6	0
Fri Jul 23 13:10:00 2010	25.3	68	74.4	25.4	0	6	0
Fri Jul 23 13:20:00 2010	25.3	68.6	75.3	25.3	0	6	0
Fri Jul 23 13:30:00 2010	25.3	69.3	76.1	25.4	0	6	0
Fri Jul 23 13:40:00 2010	25.3	70	76.9	25.4	0	6	0
Fri Jul 23 13:50:00 2010	25.3	70.7	77.6	25.4	0	6	0
Fri Jul 23 14:00:00 2010	25.3	71.4	78.6	25.4	0	6	0
Fri Jul 23 14:10:00 2010	25.3	72.2	79.4	25.4	0	6	0
Fri Jul 23 14:20:00 2010	29.3	72.8	79.6	63.2	0	6	0
Fri Jul 23 14:30:00 2010	33.9	72	76.6	59.6	0	6	0
Fri Jul 23 14:40:00 2010	33.7	71.5	77.3	51.1	0	6	0
Fri Jul 23 14:50:00 2010	33.6	71.7	78.2	46.3	0	6	0
Fri Jul 23 15:00:00 2010	33.4	72.2	79	43.1	0	6	0
Fri Jul 23 15:10:00 2010	33.3	72.8	80	40.9	0	6	0

Table 2-4 Sample Insolation Data; UVIC weather station network

	Cal Revelle	East Highland	Eagleview	Adjusted average	**Daily Total**
2011 04 24 02 00	0	0	0	0.00	
2011 04 24 03 00	0	0	0	0.00	
2011 04 24 04 00	0	0	0	0.00	
2011 04 24 05 00	0	0	0	0.00	
2011 04 24 06 00	5.53	4.29	6.51	5.44	
2011 04 24 07 00	43.13	32.06	48.16	41.12	
2011 04 24 08 00	84.33	70.55	110.89	88.59	
2011 04 24 09 00	132.53	109.16	156.2	132.63	
2011 04 24 10 00	200.24	169.95	253.68	207.96	
2011 04 24 11 00	221.55	144.09	205.8	190.48	
2011 04 24 12 00	131.61	97.09	163.8	130.83	
2011 04 24 13 00	307.18	154.97	275.53	245.89	
2011 04 24 14 00	253.36	188.21	315.1	252.22	
2011 04 24 15 00	215	109.43	424.39	249.61	
2011 04 24 16 00	143.85	131.22	188.04	154.37	

2011 04 24 17 00	140.4	122.22	177.17	146.60	
2011 04 24 18 00	75.85	54.19	68.92	66.32	
2011 04 24 19 00	16.5	8.62	14.11	13.08	
2011 04 24 20 00	0.79	0.17	1.27	0.74	
2011 04 24 21 00	0	0	0	0.00	
2011 04 24 22 00	0	0	0	0.00	
2011 04 24 23 00	0	0	0	0.00	**1925.88**
2011 04 25 00 00	0	0	0	0.00	
2011 04 25 01 00	0	0	0	0.00	
2011 04 25 02 00	0	0	0	0.00	
2011 04 25 03 00	0	0	0	0.00	
2011 04 25 04 00	0	0	0	0.00	
2011 04 25 05 00	0	0	0	0.00	
2011 04 25 06 00	1.8	1.58	4.78	2.72	
2011 04 25 07 00	11.92	11.01	19.26	14.06	
2011 04 25 08 00	41.42	18.34	32.37	30.71	
2011 04 25 09 00	87.13	58.02	85.88	77.01	
2011 04 25 10 00	76.38	77.36	107.95	87.23	
2011 04 25 11 00	132.6	76.77	131.03	113.47	
2011 04 25 12 00	245.22	152.14	108.9	168.75	
2011 04 25 13 00	178.18	146.58	233.3	186.02	
2011 04 25 14 00	293.99	218.21	325.16	279.12	
2011 04 25 15 00	345.24	240.49	431.62	339.12	
2011 04 25 16 00	202.73	178.18	290.33	223.75	
2011 04 25 17 00	112.89	113.06	175.39	133.78	
2011 04 25 18 00	74.37	63.24	113.37	83.66	
2011 04 25 19 00	26.32	21.59	57.96	35.29	
2011 04 25 20 00	0.91	0.52	2.27	1.23	
2011 04 25 21 00	0	0	0	0.00	
2011 04 25 22 00	0	0	0	0.00	
2011 04 25 23 00	0	0	0	0.00	**1775.92**
2011 04 26 00 00	0	0	0	0.00	

Based on data from Eagle View Elementary, Cal Revelle Nature Sanctuary and East Highlands Firehall
Weighted average where Eagle View elementary is weighted at 66.8%; East Highlands and Cal Revelle are weighted at 16.7% each. This is due to some shading issues that are prevalent at both sites on the east and west of the weather stations.

Results

The data collection for the Solar thermal tubes performed better than expected and data was collected except for a one week period when the laptop reading the data from the controller was unable to collect data. The lost data was negated due to the fact that the Calleffi controller logged and stored the lost data, and we were able to take the lump total collected over those days and determine the average daily gain. On November 3 an air lock was generated in the manifold causing the manifold to over heat (recording very high temperatures), and the pump to run without pumping fluid, creating an errant reading for that one day. This can be seen in the following two graphs.

Table 2-5 Comparison of Measured Solar thermal and Insolation to Theoretical availability via Webgraph

Monthly Solar kWhr SUM Month	Days	DAILY Collected Daily Ave.	DAILY Collected Hourly Ave.	MONTHLY Collected Ave kWhr	MEASURED Insolation Daily Ave	MEASURED Insolation Daily Hr. Ave	DAILY Estimated Coll. Webgraph	MONTHLY Estimated Coll. kWhr	Insolation Hours	collector efficiency
Jan	31	10.49	1.17	325.28	11.47	1.27	7.91	245.19	9	91.48
Feb	28	13.60	1.24	380.88	16.73	1.52	13.89	388.86	11	81.31
Mar	28	15.81	1.22	489.97	22.02	1.69	17.71	495.89	13	71.78
Apr	30	27.04	1.80	811.32	32.89	2.19	21.49	644.61	15	82.23
May	31	29.62	1.85	918.13	37.77	2.36	25.27	783.23	16	78.41
June	30	30.78	1.81	940.47	46.24	2.72	24.92	747.47	17	66.56
Jul	31	48.74	2.87	1510.98	52.71	3.10	28.67	888.90	17	92.47
Aug	31	47.44	3.16	1470.78	45.86	3.06	27.05	838.48	15	103.46
Sept	30	30.82	2.57	924.65	30.48	2.54	25.51	765.23	12	101.12
Oct	31	34.28	3.43	1062.57	27.52	2.75	16.73	518.62	10	124.55
Nov	30	7.91	0.88	237.43	11.01	1.22	10.18	305.33	9	71.88
Dec	31	7.92	0.99	245.61	10	1.25	7.08	219.54	8	79.23

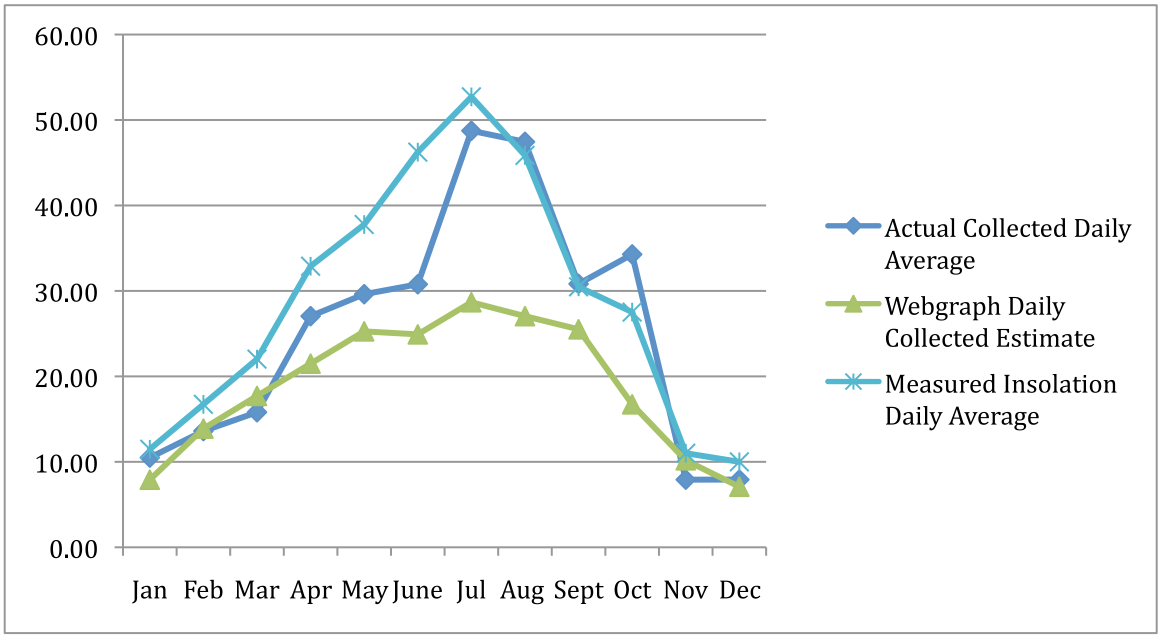


Figure 2-2 Comparison of the average Actual collected Solar thermal to Webgraph Estimate, and to Actual insolation

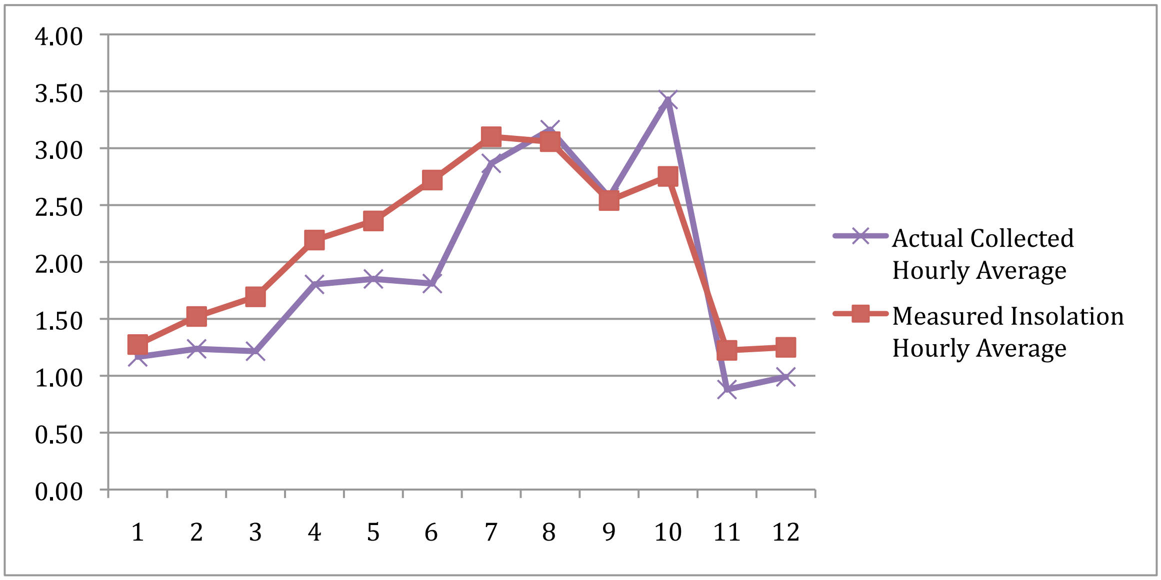


Figure 2-3 Comparison of Hourly Average Solar Thermal collected to the measured insolation

Note: The peak at the end of October is due to an errant reading wherein ther was an airlock.

Total kWhrs produced from the Solar Thermal Systems was 9318.5 kWhrs
Monthly collected totals are shown in the table below.

Table 2-6

Solar Thermal Monthly	Solar Thermal Monthly (kWhrs)	Insolation (W/m2)	Solar Thermal used for heat (kWhrs)	Un-Utilized Solar Thermal (kWhrs)	Solar Thermal Contribution to Space Heat (%)	Solar Thermal Used for DHW (kWhrs)	Solar PV Consumed (kWhrs)
January	325.28	21.54	260.61	0.00	7.2%	64.67	173.33
February	380.88	35.60	299.31	0.00	10.0%	81.57	153.38
March	489.97	62.12	366.59	0.00	12.4%	123.38	218.05
April	811.32	102.76	698.01	0.00	36.6%	113.30	180.80
May	918.13	137.39	797.41	0.00	47.8%	120.72	176.95
June	940.47	172.68	26.41	775.04	0.0%	139.01	204.75
July	1510.98	193.74	0.00	1357.50	0.0%	153.47	200.35
August	1470.78	147.61	0.00	1322.50	0.0%	148.27	195.05
September	924.65	83.13	571.93	188.70	67.7%	164.01	197.65
October	1062.57	56.59	956.36	0.00	33.5%	106.21	166.83
November	237.43	20.88	184.69	0.00	4.7%	52.74	185.08
December	245.61	16.79	201.57	0.00	4.9%	44.05	203.73
Totals	9318.05	1050.82	4362.89	3643.75		1311.41	

Table 2-7 Comparison between Solar Thermal & PV generation

Solar Thermal Monthly	Solar Thermal Monthly (kWhrs)	Solar PV Generated (kWhrs)	Difference b/n Solar Thermal over Solar PV kWhrs
January	325.28	107.33	67.0%
February	380.88	107.38	71.8%
March	489.97	206.05	57.9%
April	811.32	272.80	66.4%
May	918.13	313.95	65.8%
June	940.47	397.75	57.7%
July	1510.98	339.35	77.5%
August	1470.78	312.05	78.8%
September	924.65	248.65	73.1%
October	1062.57	197.83	81.4%
November	237.43	97.08	59.1%
December	245.61	69.73	71.6%
Totals	9318.05	2669.93	69.0%

Of the two sustainable energy input sources, of solar thermal and solar PV, the solar thermal consistently adds more energy to the house, on average 69% more energy (Table 2-6, Figure 2-4). With the price per kWhr of PV being $0.82 when amortized over the lifespan of the system, solar thermal (20 years at a cost of $17,000), has a price tag is $0.091/kWhr.

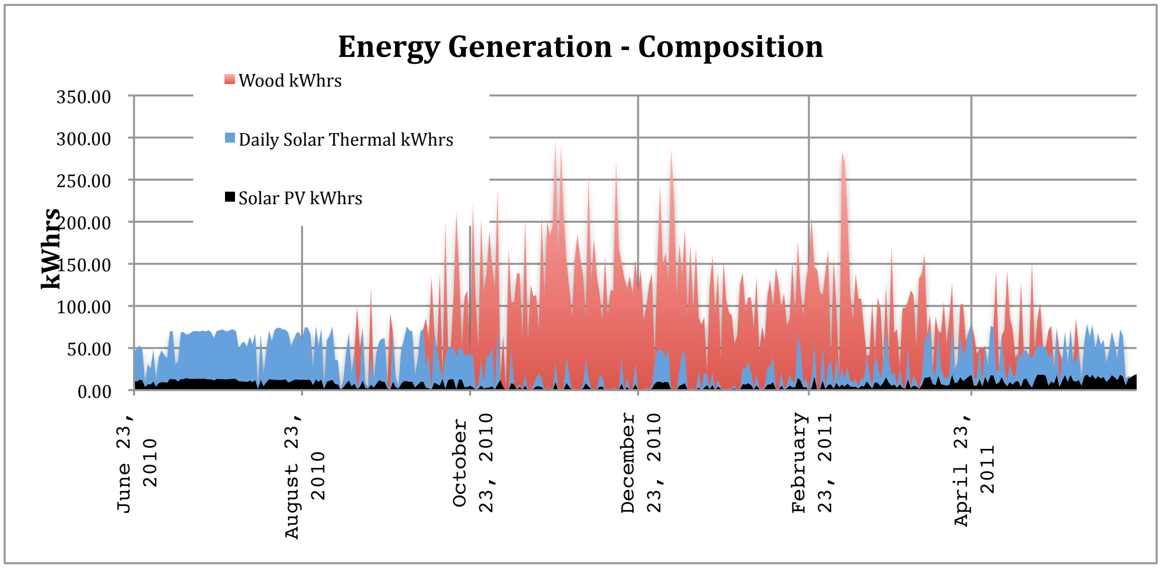


Figure 2-4 Energy contribution profile

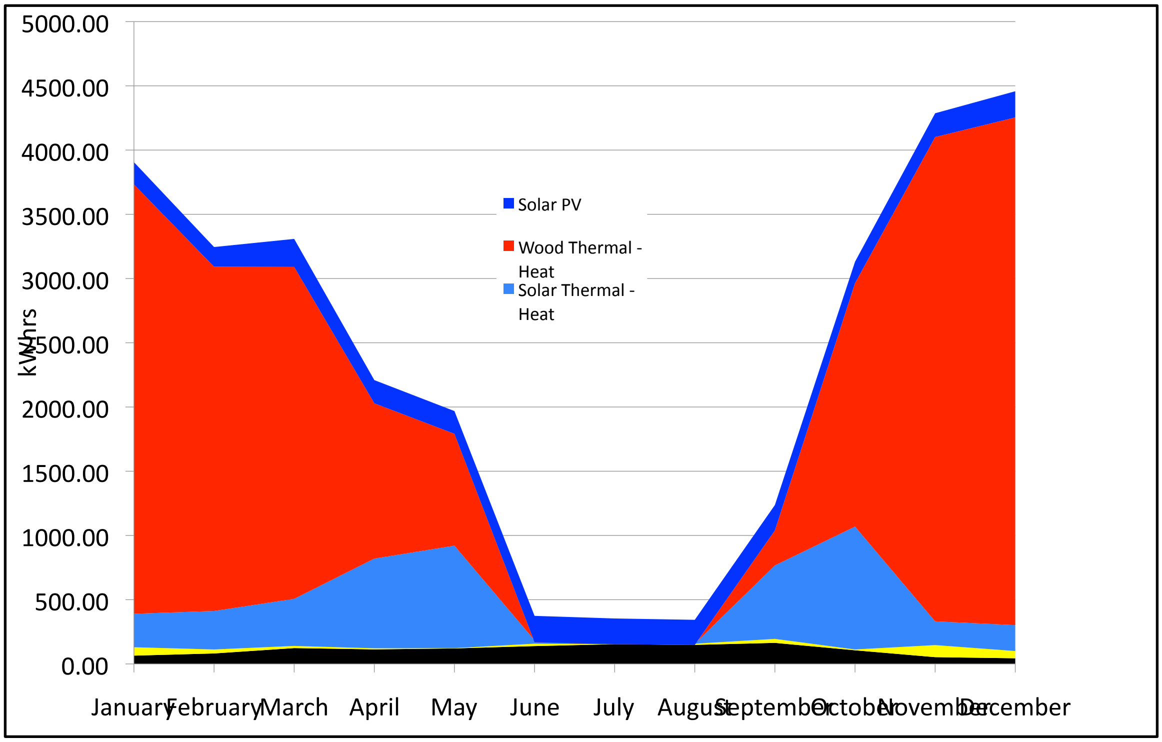


Figure 2-5 Energy contribution to End-use

It was observed that solar thermal contribution as a percentage of total energy inputs for space heating was greatest in the shoulder seasons (see Figure 2-5); methodology of the extrapolation is explained in Appendix Note 6-3. In the winter the insolation is greatly diminished, resulting in reduced contribution from solar thermal collection. In the summer season there is no demand for heating thus the excess solar thermal energy is dumped. In the shoulder seasons there are two factors at play; increasing insolation, and decreasing heat load demands, thus the solar thermal is able to play a greater role in meeting the overall demands.

The total solar thermal energy that could not be utilized, and subsequently dumped was 3643 kWhrs. This is approximately 14% of the total heat demand used within the home.

$$3643 \text{ kWhrs}/(20550.84 + 4362.7) = 14.6\%$$

This unused excess could be stored to take advantage of the otherwise dumped energy.

Energy stored - or available - can be calculated as

$E = c_p \, dt \, m$

where

E = *energy (kJ, Btu)*

c_p = *specific heat capacity (kJ/kg^{o}C, Btu/lb^{o}F) (4.2 kJ/kg^{o}C, 1 Btu/lb$_m$^{o}F for water)*

dt = *temperature difference between water stored and the surroundings (^{o}C, ^{o}F))*

m = *mass of water (kg, lb$_m$)*

If we assume that a storage system is insulated to R 40 thus negligible heat loss, then we can calculate the volume of storage required for this system to be of use.

3643.8 kWhr = 13 117 680 kilojoules

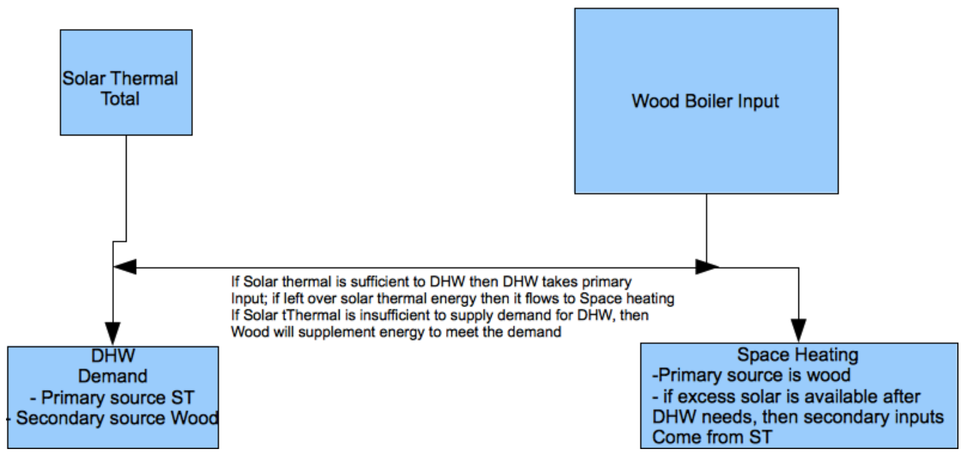
$13,117,680\text{kJ} = 4.2(\text{kJ/kg}^{o}\text{C})(85^{o}\text{C})m$
$m=36744.2$ kg

Water weighs approx 1 kg/litre therefore approximately 36,750 litres of storage would be required to store the excess solar thermal energy.

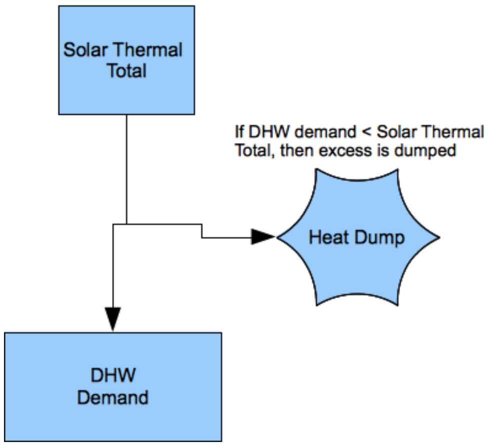
Domestic Hot Water
Domestic hot water energy demand can be extrapolated by knowing the volume of DHW consumed. The water has a fixed cold water supply temperature of 40 F, and a fixed hot water output temperature at 130 F. With the known volumes and known temperature differential we can identify energy used to heat the water, Appendix Note 6-4

The following flowchart shows the thermal energy flows within each of the two phases, winter heating season, and summer season. Each End-use (DHW, space heating) draw upon the total energy inputs, but vary slightly in has they are dispersed depending on the phase.

Heating Season



Summer Season



Conclusions:

The Baird’s solar thermal system was found to be functioning above the manufactures specifications, which may be due in part to having the manifolds plumbed in parallel, and being able to draw heat out of their tank quickly for space heating thus allowing a cooler tank to better able absorb new and continuous thermal inputs efficiently because of larger temperature differentials between inputs and tank temperature.

It was found that the solar thermal system really plays a role in the shoulder seasons, and thus design considerations could be implemented to increase storage capacity to better utilize otherwise lost (dumped) thermal inputs.

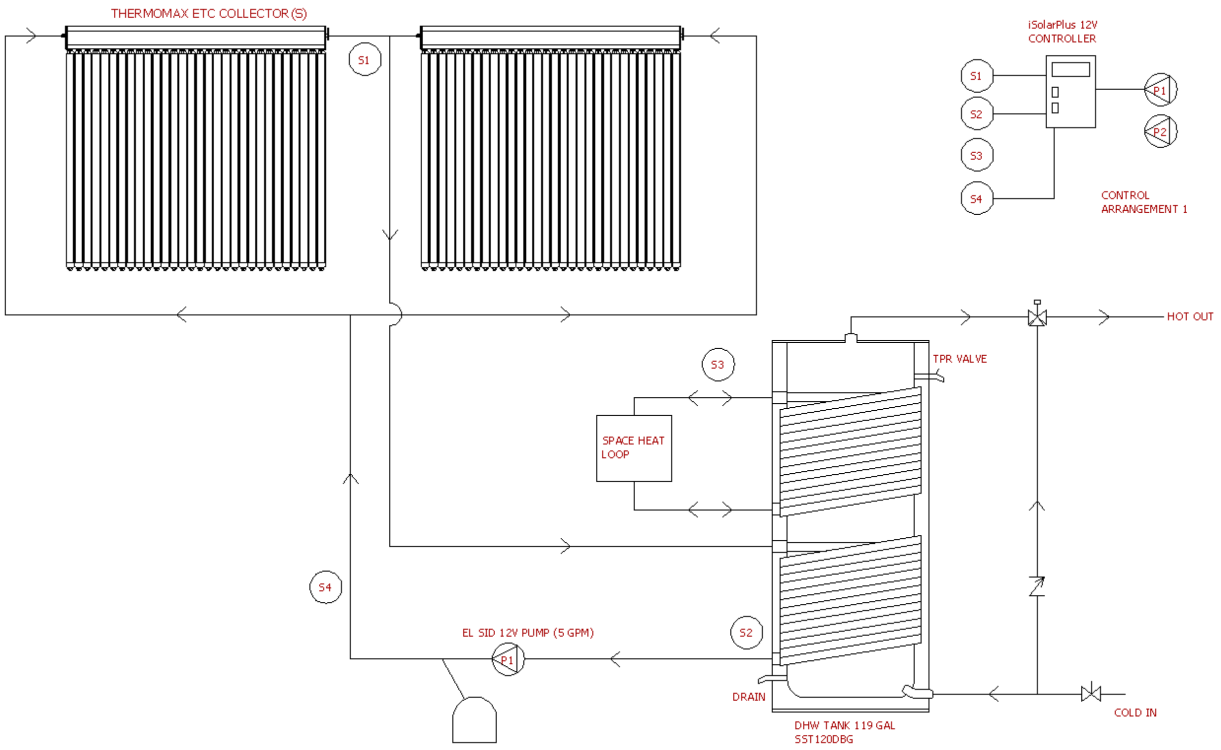
Based on its present level of functioning and the life expectancy, the low cost of $0.09 kWhr of solar thermal energy far surpasses what is garnered from solar PV, and virtually compares to what BC Hydro’s charge would be for the same energy.

The obvious conclusion is that the workhorse of the home jumps into action in the winter months to top up space heating, this is the wood boiler. At the time of writing this paper the Baird’s were in the process of researching a Daikin Altherma air-to-water heat pump with a Coefficient of Performance (COP) of 4.5. The addition of this would in effect cut down the energy requirements in kWhrs from wood source by 75%, a drastic decrease, and the energy would be derived from a lowered carbon footprint source.

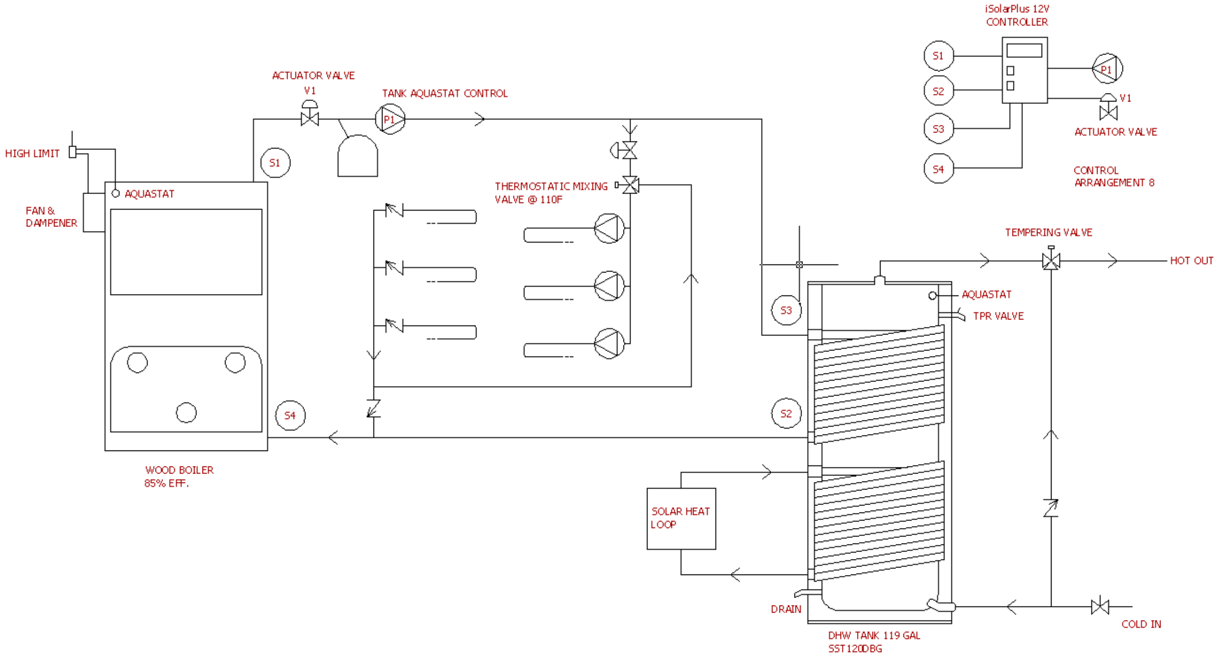
Due to the design of solar thermal and wood source systems, and their nature, it has been learned that owners should acquire the basic knowledge to service the components, if even on a yearly schedule.

References:

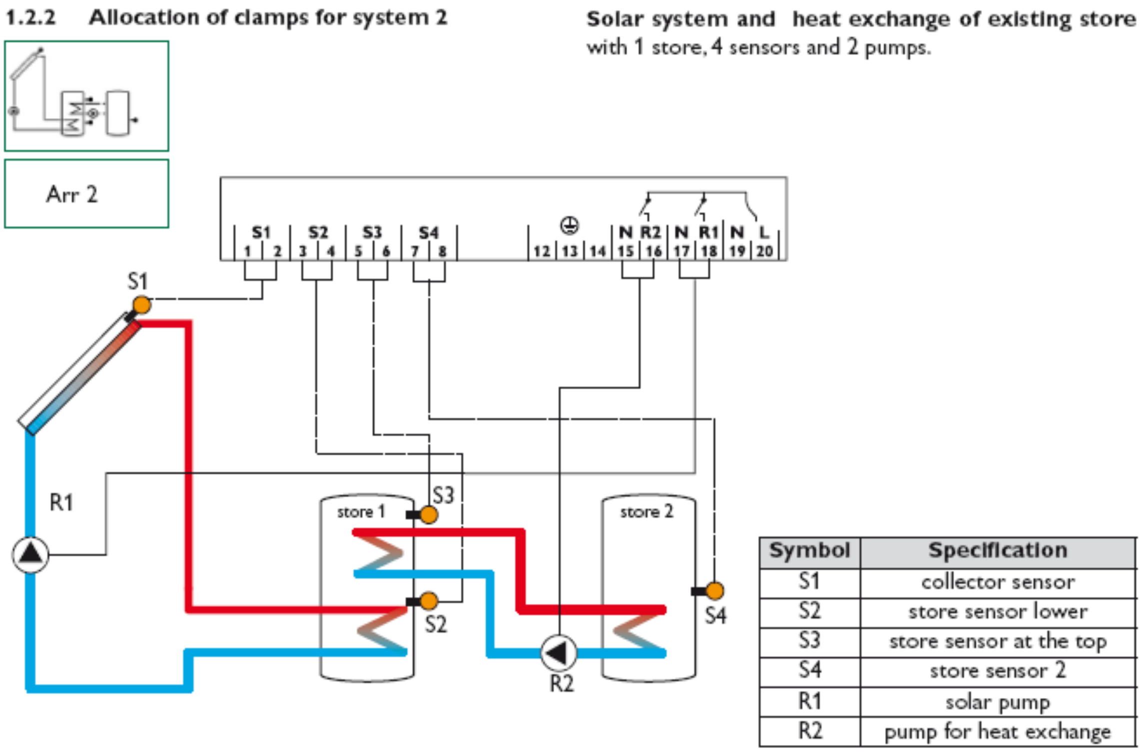
Solar Collector Closed Loop



Space Heating and Wood Boiler Loop



BS Pro Previous Control Logic for Boiler/Space Heat Loop



1.2.2 Allocation of clamps for system 2

Solar system and heat exchange of existing store with 1 store, 4 sensors and 2 pumps.

Symbol	Specification
S1	collector sensor
S2	store sensor lower
S3	store sensor at the top
S4	store sensor 2
R1	solar pump
R2	pump for heat exchange

Channel	Setting	Description
COL	Display	Temperature collector 1 (one collector system) (S1)
TST1	Display	Temperature store 1 below (S2)
TSTU	Display	Temperature store 1 upper/above (S3)
TST2	Display	Temperature store 2 below (S4)
n1%	Display	Pump speed relay 1 (R1)
n2%	Display	Pump speed relay 2 (R2)
hP1	Display	Operating hours relay 1
hP2	Display	Operating hours relay 2
DTO	10	Switch on temperature difference (ΔT)
DTS	n/a	Nominal temperature difference to step up pump speed
DTF	1	Switch off temperature difference
RIS	n/a	Increase
SMX	190	Maximum temperature store 1
EM	230	Emergency collector temperature 1
OCX	OFF	Option collector cooling collector 1
CMX		Maximum temperature collector 1
OCN	ON	Option minimum limitation collector 1
CMN	120	Minimum temperature collector 1
OCF	OFF	Option antifreeze collector 1
CFR		Antifreeze temperature collector 1
OREC	OFF	Option re-cooling

OTC	OFF	Option tube collector
DT30	2	Switch on temperature difference 3
DT3F	1	Switch off temperature difference 3
DT3S	n/a	Nominal temperature DT3 (as n1MN & n2MN set to 100% - deactivates pump speed control)
RIS3	n/a	Increase DT3 (as n1MN & n2MN set to 100% - deactivates pump speed control)
MX30	200	Switch on threshold for maximum temperature
MX3F	188	Switch off threshold for maximum temperature
MN3F	195	Switch on threshold for minimum temperature
MN30	185	Switch on threshold for minimum temperature
n1MN	100%	Minimum pump speed relay 1 (to 100% for valve control)
n2MN	100%	Minimum pump speed relay 2 (to 100% for valve control)
HND1	AUTO	Manual operation relay 1
HND2	AUTO	Manual operation relay 2
LANG	En	language

3. Heat Loss Load – Heating Degree Day

Appendix Table 3-1 – HDD Measured average compared to norm

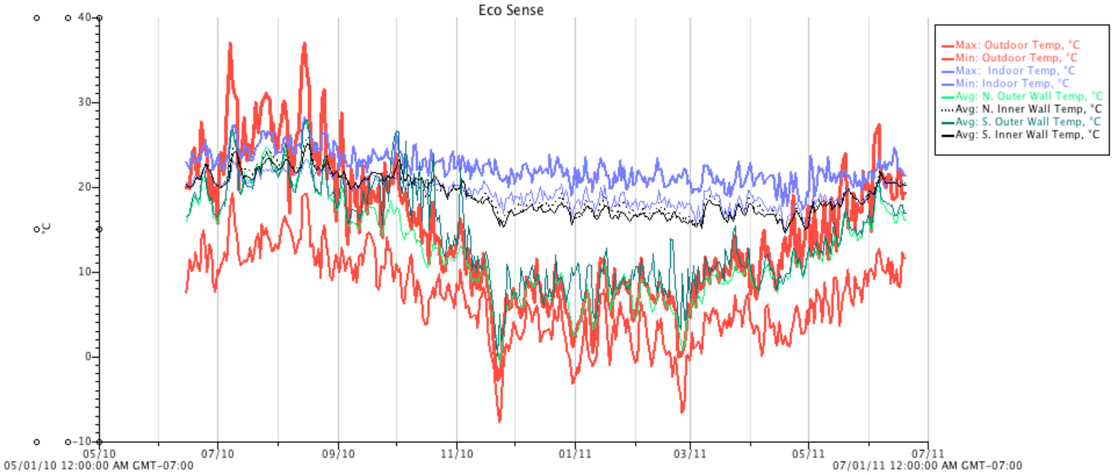
Avg HDD from June 2010-2011	HDD Eagle View WS	~~HDD East Highland FH WS~~	Cal Revelle Nature San. WS	BC Hydro Report - 2000-2008 avg
444.4	423.4	~~451.3~~	458.6	405
434.2	423.5	~~430.5~~	448.6	400
371.6	355	~~370.1~~	389.7	342
362.6	342.4	~~367~~	378.3	274
248.8	234.5	–	263	176
124.8	109	–	140.6	92
61.3	66.3	–	56.2	37
62.8	65	–	60.5	45
123.0	126.4	–	119.6	123
257.2	244.4	–	270	242
410.5	390.5	–	430.4	354
406.1	379.2	~~413~~	426.1	412
		–		
3307.1	3159.6	–	3441.6	2902

This table defines the measured HDD across two UVIC weather stations , then averages the findings and compares them to BC hydro's average for area. A 15% increase was found for the period of study, correlating to a 17% decrease in solar insolation for the same period.

Appendix Note 3-1 – Allocation of LPG to energy profile

[1] Eco-Sense uses LP gas for cooking, canning and preserving food. Unlike most homes, 80 % of the food for on average three people is provided onsite, without the reliance on embodied energy found in conventional foods bought at the grocery store. 300 lbs of LP gas is used per year, with an energy footprint of 1894.53 kWhr. To account for the sheer volume of processed and preserved foods, 1/3 of this number is estimated to be the embodied energy of preserving. This leaves a figure of 1263 kWhr allocated for conventional food prep.

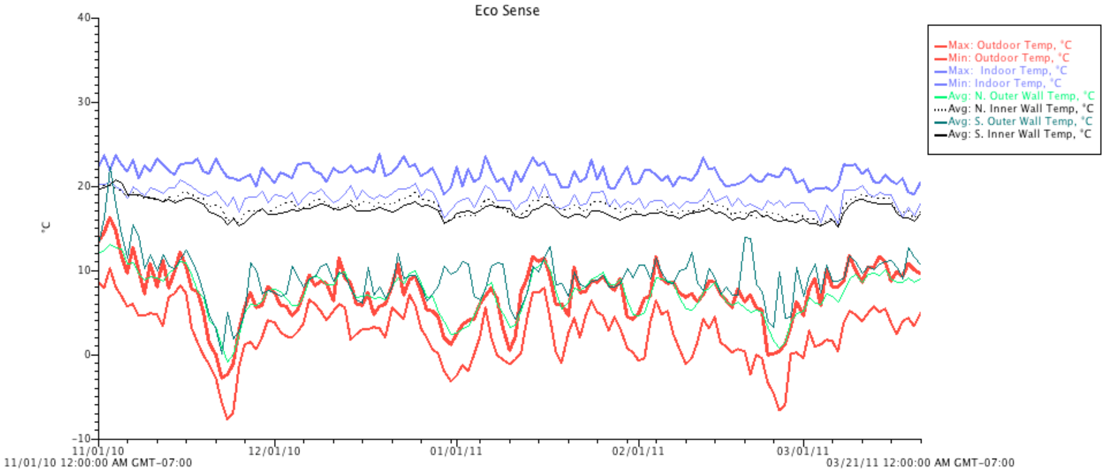
4. Cob Walls – RH, Moisture & Temperature Moderation



Appendix Figure 4-1– Annual temperature fluctuation

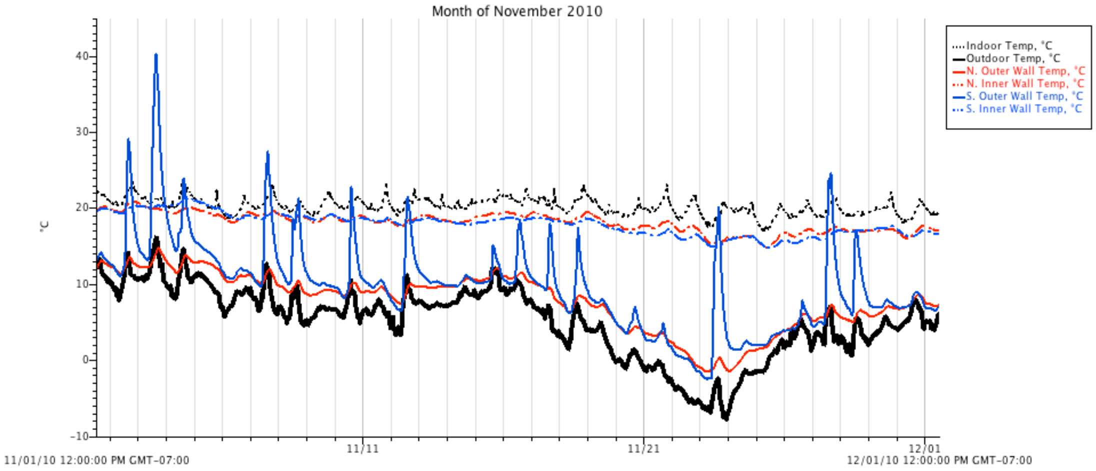
This is a plot of the Minimum and Maximum daily recorded temperature for each of the Indoor and Outdoor sensors; objective is to visually observe the range of variation for each variable.

Winter Season Temperature profiles



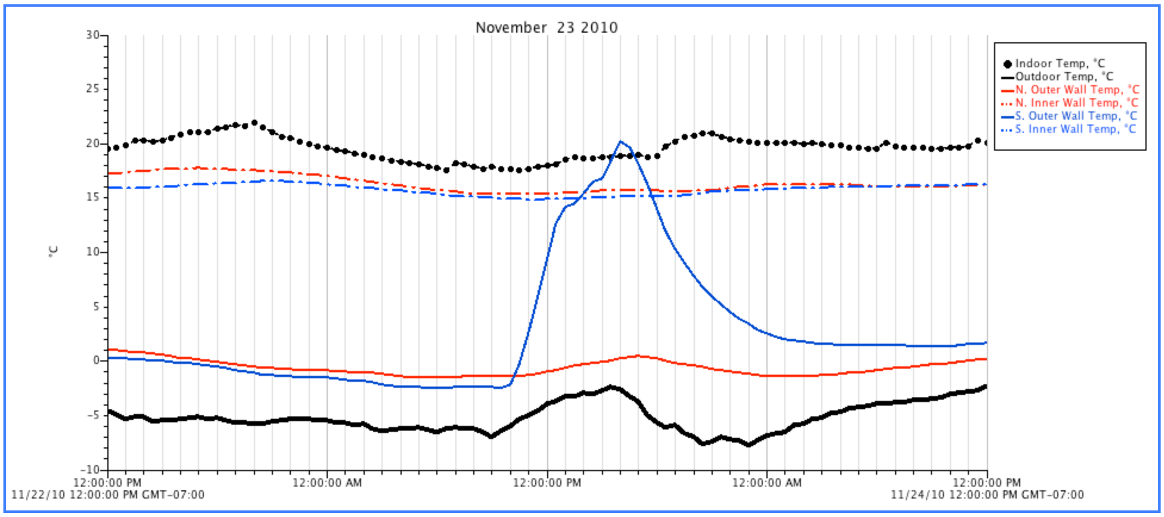
Appendix Figure 4-2 – Winter season temperature fluctuation

This is a plot of the Minimum and Maximum daily recorded temperature for each of the Indoor and Outdoor sensors during the winter season; objective is to visually observe the range of variation for each variable.



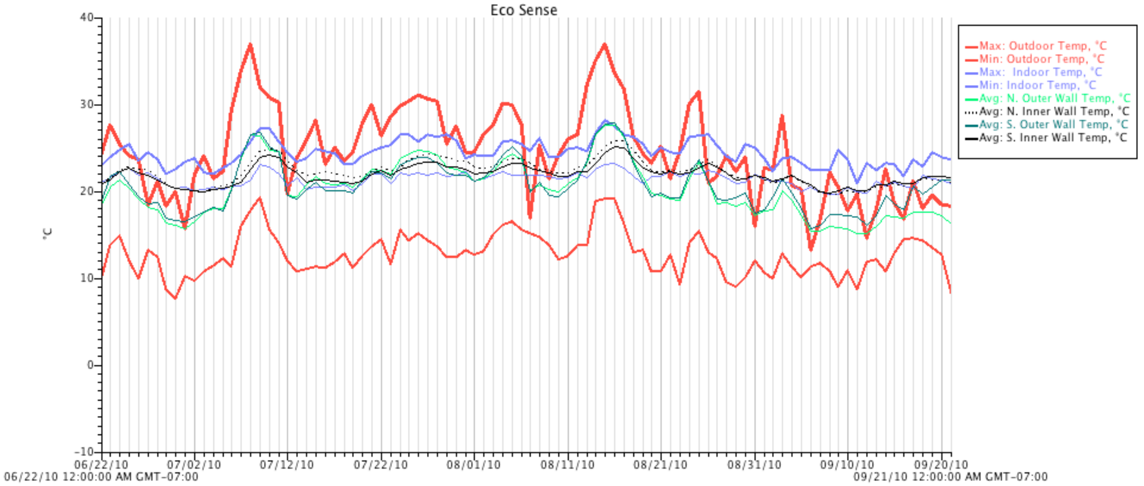
Appendix Figure 4-3 – November 2010 temperature plot

This is a plot for all the temperature sensors for the month of November 2010; the observation of note is the extreme heat fluxuation on the south outer wall, reaching temperatures exceeding 40 C. This is due to solar gain; the sun is lower on the horizon and shines on the wall.



Appendix Figure 4-4 – November 23 Temperature plot

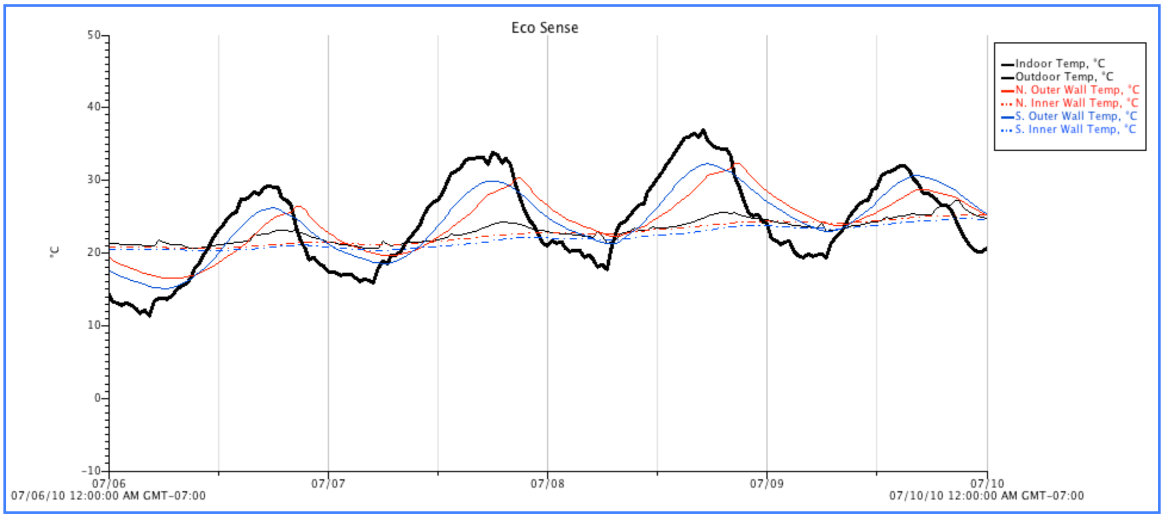
This is a plot of one of the coldest days of the year; of note is the steady state of the inner wall temperatures in relation the outer wall temperatures. Despite each outer wall having a different profile, the inner walls maintain the same profile.



Appendix Figure 4-5 – Summer season temperature fluctuation

This is a plot of the Minimum and Maximum daily recorded temperature for each of the Indoor and Outdoor sensors during the summer season wherein there is no space heating inputs; objective is to visually observe the range of variation for each variable.

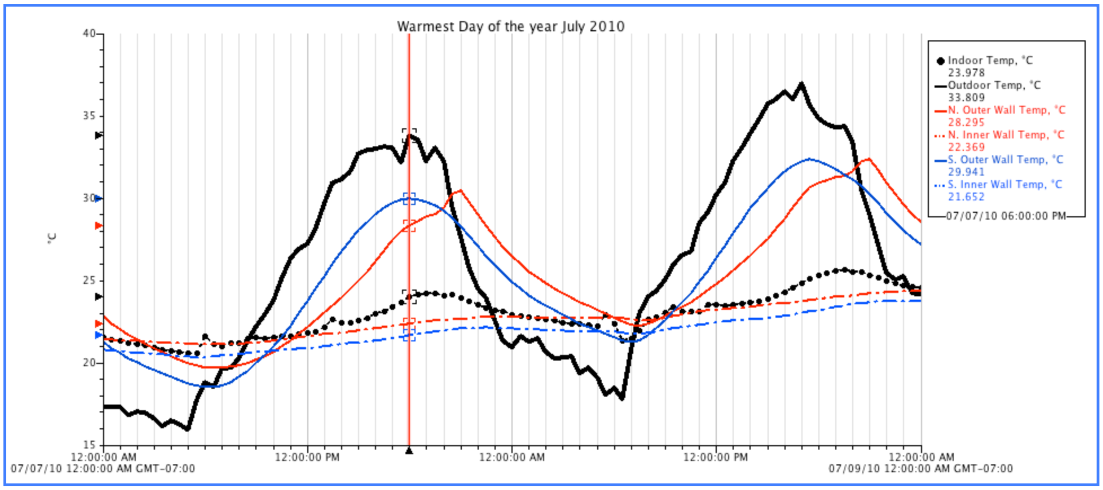
Summer Season Temp profile



Appendix Figure 4-6 – Summer season temperature profile – 5 day sample

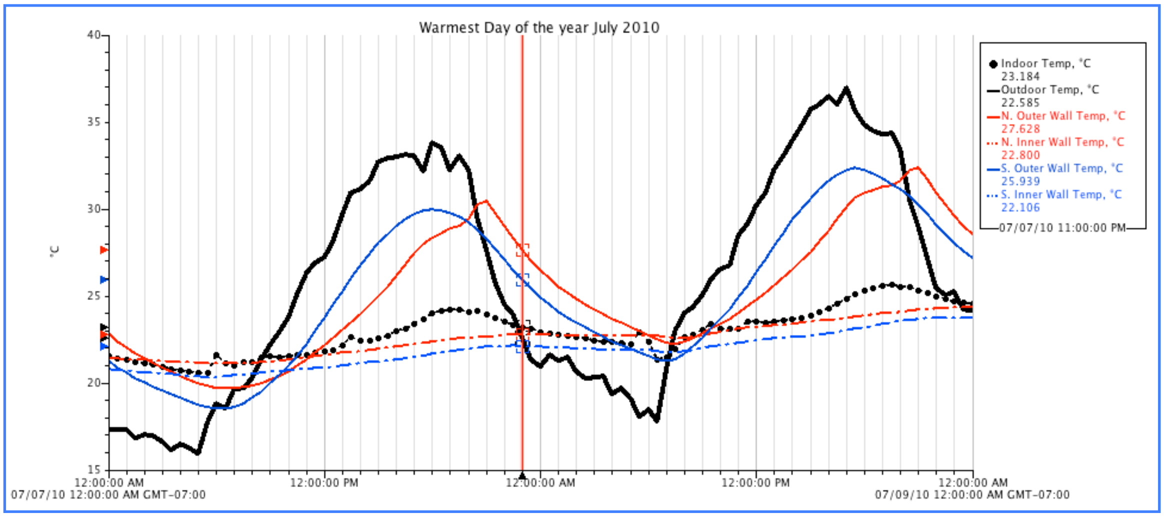
This plot compares the diurnal variation of outdoor temperature (and outdoor wall temps) to those inside; of note is the shallow amplitude of the indoor temperature variables in relation to the outdoor readings.

Temperature Lag time on warmest day of the year (Appendix Figures 7, 8, & 9)



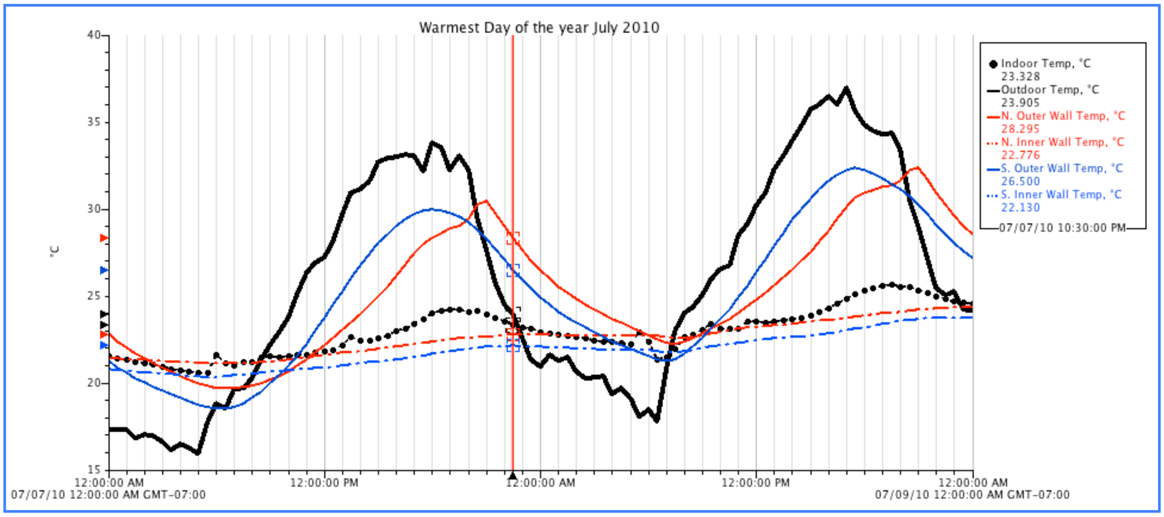
Appendix Figure 4-7 – Outdoor max temp July 7 2010 @ 6pm

Maximum outdoor temp (33.8 C) was reached at 6 pm; maximum inner temp (24.2 C) was reached 1.5 hours later at 7:30 pm.



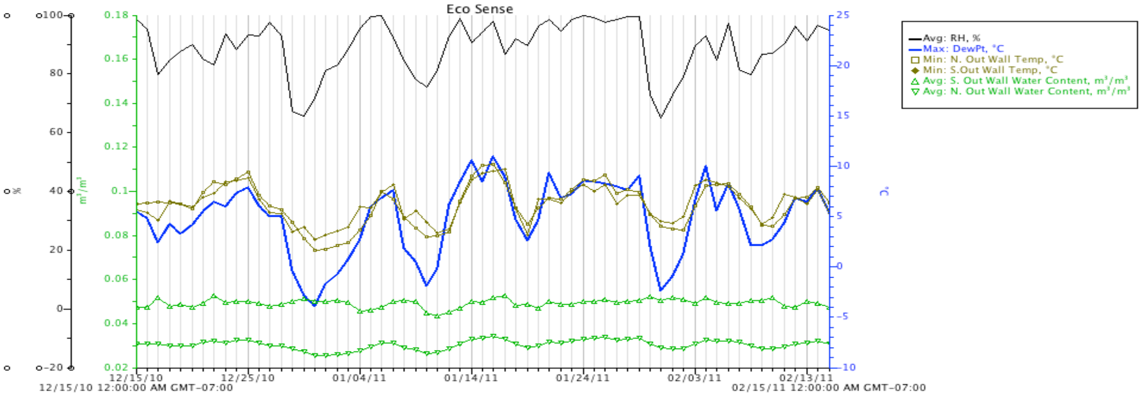
Appendix Figure 4-8 – North Inner Wall Maximum Temp July 7 2010 @ 11pm

The maximum indoor temp (24.2 C) was reached at 7:30 pm; the N. Inner Wall reached its maximum temp (22.8 C) at 11pm. This is a 3.5 hour time lag.



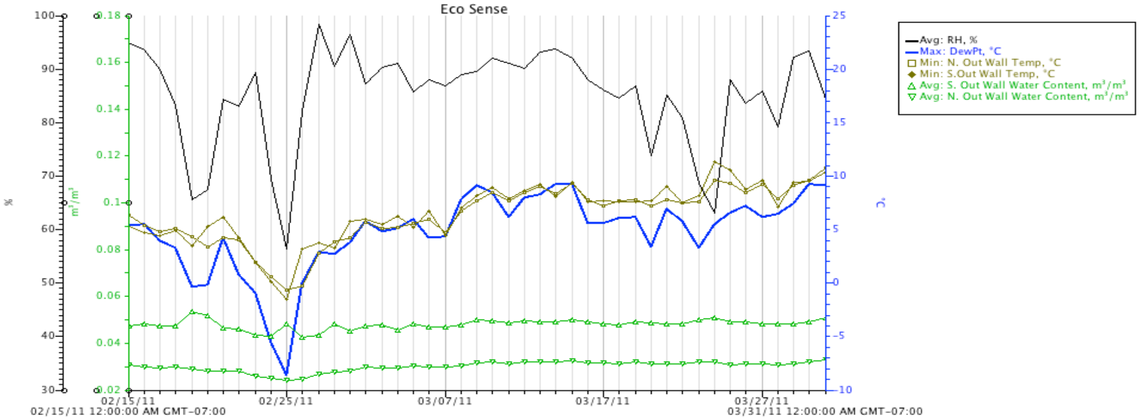
Appendix Figure 4-9 – South Inner Wall maximum temperature July 7 2010 @ 10:30pm

The maximum indoor temp (24.2 C) was reached at 7:30 pm; the S.. Inner Wall reached its maximum temp (22.13 C) at 10:30pm. This is a 3.0 hour time lag.



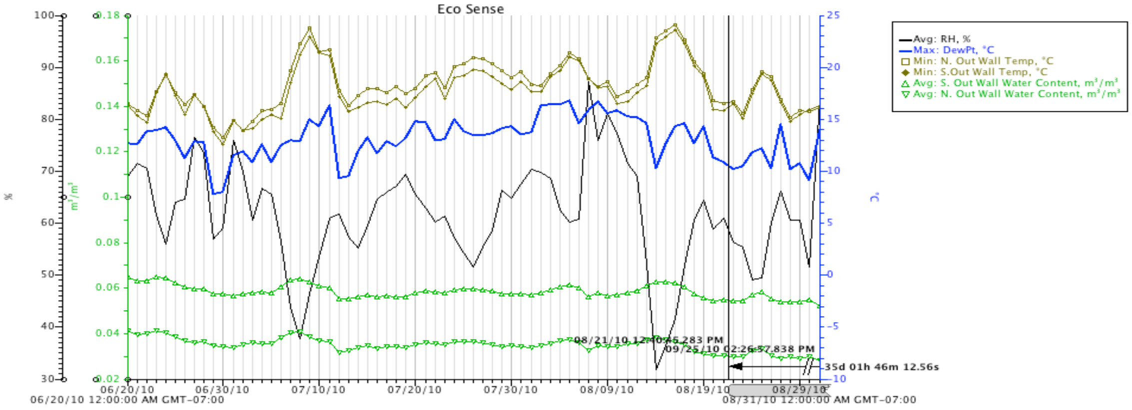
Appendix Figure 4-10 – Wall Moisture Content through Winter Months

Outer walls had a consistently higher level of water content than the inner walls; this graph plots the outer wall as it is more visible in variance than the inner wall, and note on the observation the very constant wall moisture content.



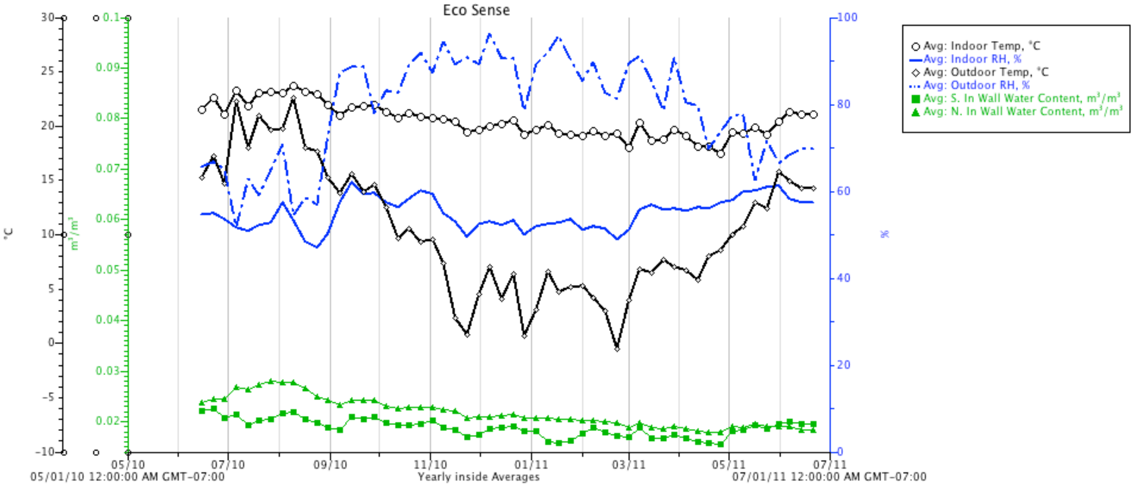
Appendix Figure 4-11 – Wall Moisture content through Spring Months

Outer walls had a consistently higher level of water content than the inner walls; this graph plots the outer wall as it is more visible in variance than the inner wall, and note on the observation the very constant wall moisture content.



Appendix Figure 4-12 Wall Moisture Content through Summer Months

Outer walls had a consistently higher level of water content than the inner walls; this graph plots the outer wall as it is more visible in variance than the inner wall, and note on the observation the very constant wall moisture content.



Appendix Figure 4-13 Annual Average RH and Indoor/Outdoor Temperature

5. Solar PV Data

Appendix Table 5-1 – Cumulative electricity tracking

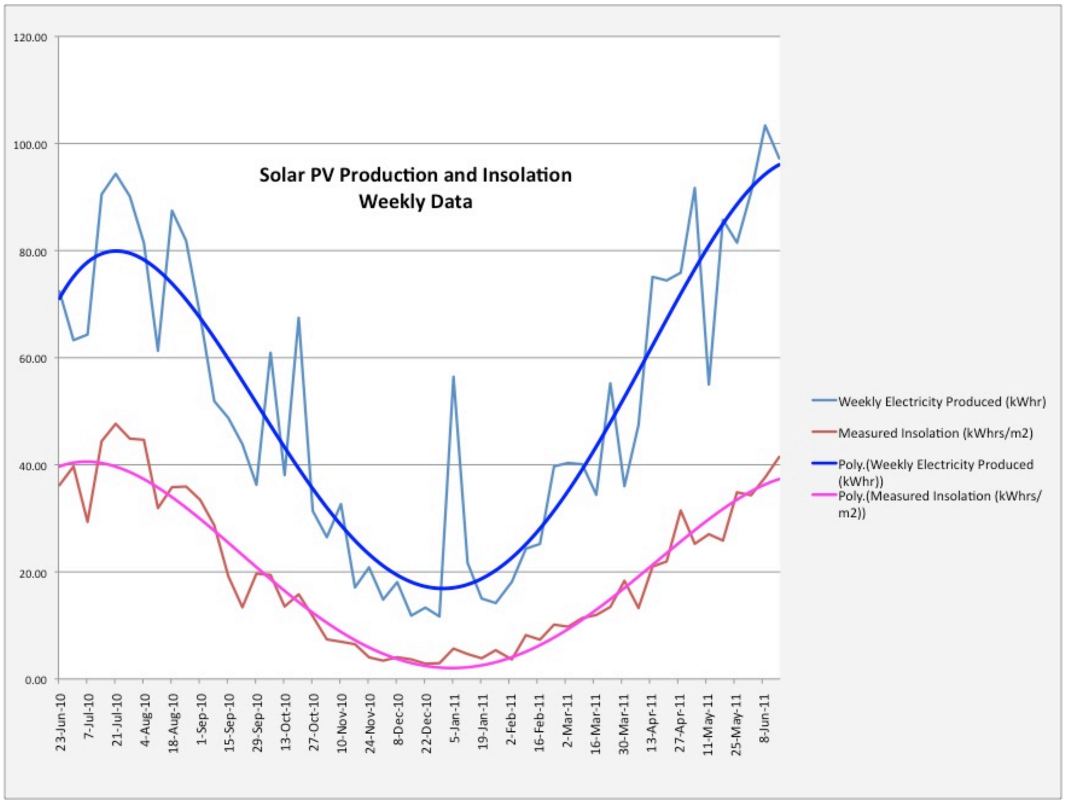
	CUMULATIVE (Year to date)				
Week of:	BC Hydro	Solar PV	Electricity	Electricity	Net Zero
	Running Tot.	Running Tot	Overall	Overall	Year To Date
	Buy	Sell	Production	Consumption	
23-Jun-10	21.00	40.00	72.40	53.40	19.00
30-Jun-10	40.00	82.00	135.68	93.68	42.00
7-Jul-10	58.00	115.00	200.00	143.00	57.00
14-Jul-10	76.00	175.00	290.53	191.53	99.00
21-Jul-10	97.00	242.00	384.88	239.88	145.00
28-Jul-10	122.00	303.00	475.03	294.03	181.00
4-Aug-10	140.00	358.00	556.48	338.48	218.00
11-Aug-10	159.00	395.00	617.78	381.78	236.00
18-Aug-10	186.00	458.00	705.23	433.23	272.00
25-Aug-10	205.00	503.00	787.08	489.08	298.00
1-Sep-10	226.00	552.00	854.95	528.95	326.00
8-Sep-10	250.00	582.00	906.85	574.85	332.00
15-Sep-10	273.00	606.00	955.60	622.60	333.00
22-Sep-10	293.00	635.00	999.45	657.45	342.00
29-Sep-10	312.00	661.00	1035.73	686.73	349.00
6-Oct-10	330.00	702.00	1096.65	724.65	372.00
13-Oct-10	355.00	727.00	1134.73	762.73	372.00
20-Oct-10	381.00	767.00	1202.18	816.18	386.00
27-Oct-10	413.00	793.00	1233.55	853.55	380.00
3-Nov-10	447.00	802.00	1260.03	905.03	355.00
10-Nov-10	473.00	830.00	1292.68	935.68	357.00
17-Nov-10	508.00	837.00	1309.78	980.78	329.00
24-Nov-10	552.00	844.00	1330.63	1038.63	292.00
1-Dec-10	590.00	860.00	1345.45	1075.45	270.00
8-Dec-10	623.00	870.00	1363.53	1116.53	247.00
15-Dec-10	657.00	875.00	1375.35	1157.35	218.00
22-Dec-10	700.00	885.00	1388.68	1203.68	185.00
29-Dec-10	732.00	890.00	1400.35	1242.35	158.00
5-Jan-11	762.00	930.00	1456.80	1288.80	168.00
12-Jan-11	804.00	944.00	1478.48	1338.48	140.00
19-Jan-11	836.00	952.00	1493.50	1377.50	116.00
26-Jan-11	868.00	960.00	1507.68	1415.68	92.00
3-Feb-11	904.00	975.00	1525.80	1454.80	71.00
10-Feb-11	933.00	986.00	1550.13	1497.13	53.00
17-Feb-11	962.00	1004.00	1575.35	1533.35	42.00
24-Feb-11	988.00	1034.00	1615.05	1569.05	46.00
3-Mar-11	1019.00	1057.00	1655.40	1617.40	38.00
10-Mar-11	1044.00	1079.00	1695.50	1660.50	35.00
17-Mar-11	1073.00	1097.00	1729.90	1705.90	24.00
24-Mar-11	1098.00	1124.00	1785.10	1759.10	26.00
31-Mar-11	1124.00	1158.00	1821.10	1787.10	34.00
7-Apr-11	1151.00	1174.00	1868.50	1845.50	23.00
14-Apr-11	1173.00	1237.00	1943.60	1879.60	64.00
21-Apr-11	1190.00	1279.00	2018.03	1929.03	89.00
28-Apr-11	1207.00	1333.00	2093.90	1967.90	126.00
5-May-11	1224.00	1390.00	2185.60	2019.60	166.00
12-May-11	1241.00	1429.00	2240.60	2052.60	188.00
19-May-11	1262.00	1484.00	2326.38	2104.38	222.00
26-May-11	1283.00	1546.00	2407.85	2144.85	263.00
2-Jun-11	1298.00	1593.00	2498.75	2203.75	295.00
9-Jun-11	1315.00	1663.00	2602.13	2254.13	348.00
16-Jun-11	1330.00	1727.00	2699.35	2302.35	397.00

Appendix Table 5-2 – Weekly electricity tracking

	WEEKLY				
Week of:	Weekly BC Hydro Bought	Weekly Solar PV Sold	Weekly Electricity Produced (kWhr)	Weekly Electricty Consumed	Net Zero Weekly
23-Jun-10	21.00	40.00	72.40	53.40	19.00
30-Jun-10	19.00	42.00	63.28	40.28	23.00
7-Jul-10	18.00	33.00	64.33	49.33	15.00
14-Jul-10	18.00	60.00	90.53	48.53	42.00
21-Jul-10	21.00	67.00	94.35	48.35	46.00
28-Jul-10	25.00	61.00	90.15	54.15	36.00
4-Aug-10	18.00	55.00	81.45	44.45	37.00
11-Aug-10	19.00	37.00	61.30	43.30	18.00
18-Aug-10	27.00	63.00	87.45	51.45	36.00
25-Aug-10	19.00	45.00	81.85	55.85	26.00
1-Sep-10	21.00	49.00	67.88	39.88	28.00
8-Sep-10	24.00	30.00	51.90	45.90	6.00
15-Sep-10	23.00	24.00	48.75	47.75	1.00
22-Sep-10	20.00	29.00	43.85	34.85	9.00
29-Sep-10	19.00	26.00	36.28	29.28	7.00
6-Oct-10	18.00	41.00	60.93	37.93	23.00
13-Oct-10	25.00	25.00	38.08	38.08	0.00
20-Oct-10	26.00	40.00	67.45	53.45	14.00
27-Oct-10	32.00	26.00	31.38	37.38	-6.00
3-Nov-10	34.00	9.00	26.48	51.48	-25.00
10-Nov-10	26.00	28.00	32.65	30.65	2.00
17-Nov-10	35.00	7.00	17.10	45.10	-28.00
24-Nov-10	44.00	7.00	20.85	57.85	-37.00
1-Dec-10	38.00	16.00	14.83	36.83	-22.00
8-Dec-10	33.00	10.00	18.08	41.08	-23.00
15-Dec-10	34.00	5.00	11.83	40.83	-29.00
22-Dec-10	43.00	10.00	13.33	46.33	-33.00
29-Dec-10	32.00	5.00	11.68	38.68	-27.00
5-Jan-11	30.00	40.00	56.45	46.45	10.00
12-Jan-11	42.00	14.00	21.68	49.68	-28.00
19-Jan-11	32.00	8.00	15.03	39.03	-24.00
26-Jan-11	32.00	8.00	14.18	38.18	-24.00
3-Feb-11	36.00	15.00	18.13	39.13	-21.00
10-Feb-11	29.00	11.00	24.33	42.33	-18.00
17-Feb-11	29.00	18.00	25.23	36.23	-11.00
24-Feb-11	26.00	30.00	39.70	35.70	4.00
3-Mar-11	31.00	23.00	40.35	48.35	-8.00
10-Mar-11	25.00	22.00	40.10	43.10	-3.00
17-Mar-11	29.00	18.00	34.40	45.40	-11.00
24-Mar-11	25.00	27.00	55.20	53.20	2.00
31-Mar-11	26.00	34.00	36.00	28.00	8.00
7-Apr-11	27.00	16.00	47.40	58.40	-11.00
14-Apr-11	22.00	63.00	75.10	34.10	41.00
21-Apr-11	17.00	42.00	74.43	49.43	25.00
28-Apr-11	17.00	54.00	75.88	38.88	37.00
5-May-11	17.00	57.00	91.70	51.70	40.00
12-May-11	17.00	39.00	55.00	33.00	22.00
19-May-11	21.00	55.00	85.78	51.78	34.00
26-May-11	21.00	62.00	81.48	40.48	41.00
2-Jun-11	15.00	47.00	90.90	58.90	32.00
9-Jun-11	17.00	70.00	103.38	50.38	53.00
16-Jun-11	15.00	64.00	97.23	48.23	49.00

Appendix Table 5-3 – Year to Date average electricity Produced and Consumed

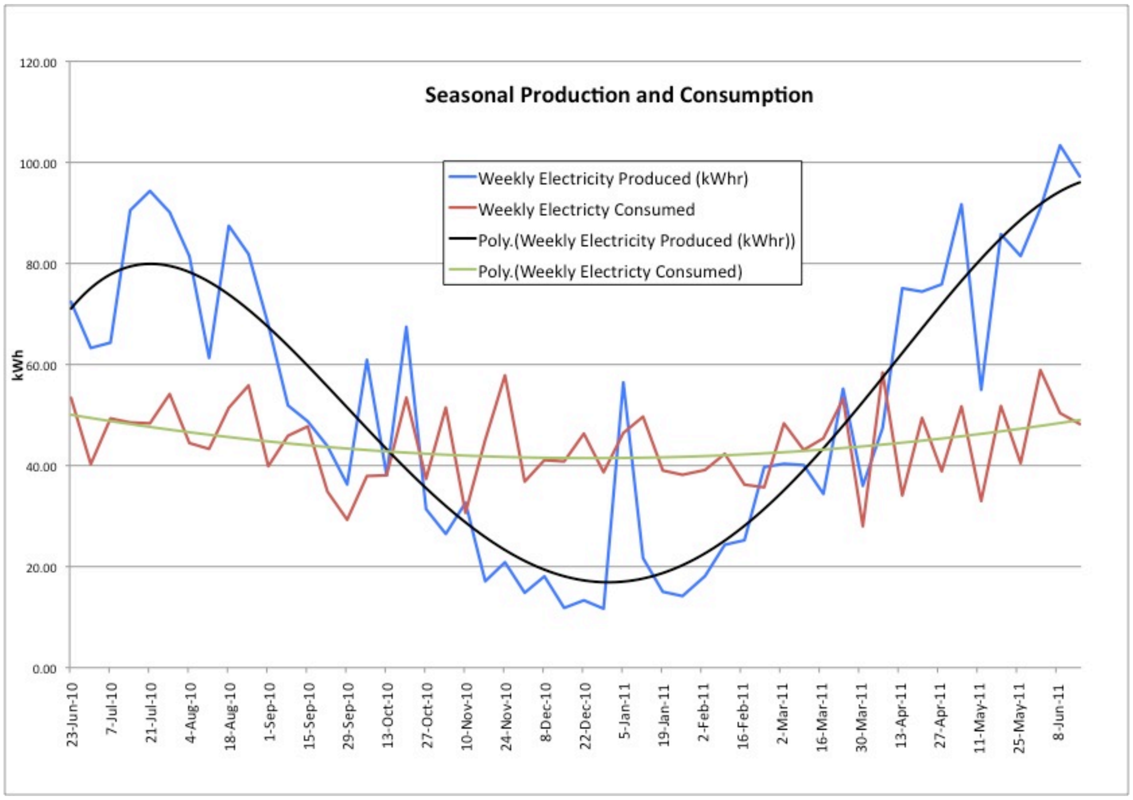
Week of:	YTD Average Daily Produced	YTD Average Daily Consumed	Measured Insolation (kWhrs/m2)
23-Jun-10	10.34	7.63	36.20
30-Jun-10	9.69	6.69	39.68
7-Jul-10	9.52	6.81	29.34
14-Jul-10	10.38	6.84	44.41
21-Jul-10	11.00	6.85	47.66
28-Jul-10	11.31	7.00	44.88
4-Aug-10	11.36	6.91	44.67
11-Aug-10	11.03	6.82	31.91
18-Aug-10	11.19	6.88	35.82
25-Aug-10	11.24	6.99	35.94
1-Sep-10	11.10	6.87	33.46
8-Sep-10	10.80	6.84	28.70
15-Sep-10	10.50	6.84	19.18
22-Sep-10	10.20	6.71	13.39
29-Sep-10	9.86	6.54	19.69
6-Oct-10	9.79	6.47	19.42
13-Oct-10	9.54	6.41	13.54
20-Oct-10	9.54	6.48	15.81
27-Oct-10	9.27	6.42	11.70
3-Nov-10	9.00	6.46	7.39
10-Nov-10	8.79	6.37	6.96
17-Nov-10	8.51	6.37	6.49
24-Nov-10	8.26	6.45	4.04
1-Dec-10	8.01	6.40	3.42
8-Dec-10	7.79	6.38	4.06
15-Dec-10	7.56	6.36	3.65
22-Dec-10	7.35	6.37	2.86
29-Dec-10	7.14	6.34	2.95
5-Jan-11	7.18	6.35	5.67
12-Jan-11	7.04	6.37	4.65
19-Jan-11	6.88	6.35	3.86
26-Jan-11	6.73	6.32	5.38
3-Feb-11	6.61	6.30	3.64
10-Feb-11	6.51	6.29	8.19
17-Feb-11	6.43	6.26	7.34
24-Feb-11	6.41	6.23	10.14
3-Mar-11	6.39	6.24	9.76
10-Mar-11	6.37	6.24	11.38
17-Mar-11	6.34	6.25	11.95
24-Mar-11	6.38	6.28	13.45
31-Mar-11	6.35	6.23	18.34
7-Apr-11	6.36	6.28	13.25
14-Apr-11	6.46	6.24	20.99
21-Apr-11	6.55	6.26	21.95
28-Apr-11	6.65	6.25	31.46
5-May-11	6.79	6.27	25.25
12-May-11	6.81	6.24	27.03
19-May-11	6.92	6.26	25.85
26-May-11	7.02	6.25	34.86
2-Jun-11	7.14	6.30	34.31
9-Jun-11	7.29	6.31	37.63
16-Jun-11	7.42	6.33	41.47



Appendix Figure 5-1 – Weekly Solar PV production to Insolation

Notes:

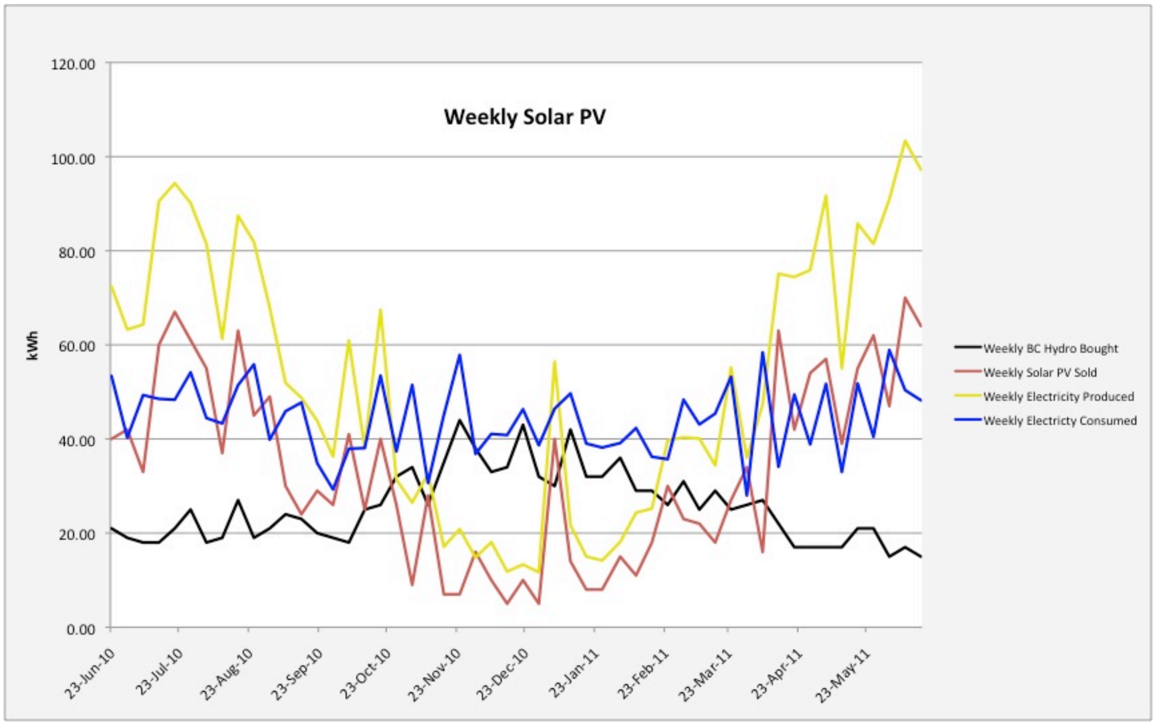
1. Using the polynomial trendline shows that the production of electricity for the solar PV system mirrors the measured insolation data.
2. Snow cover impacts measured insolation from the local school. This is the likely explanation for the Jan spike in production that is not mirrored in the insolation data.
3. The spread in trendlines is greater in the summer than in the winter. Solar PV efficiency is greater when the panels are cooler.
4. Snow on the eco-sense roof reflects more sunlight onto the solar panels thus explaining the observed high solar output in early Jan.



Appendix Figure 5-2 – Seasonal Production and Consumption of electricity

Notes:

1. Weekly electricity consumption is quite steady during the year with only a slight increase during summer months. May be due to water pumping for irrigation and aeration of grey water tank.



Appendix Figure 5-3 – Weekly Solar PV charting: Purchased from BC Hydro, Sold to BC Hydro, Electricity Produced, Electricity Consumed

Notes:

1. Weekly buy and sell relationship with BC Hydro is clearly demonstrated showing how these two are seasonally opposite.
2. Household consumption is calculated from measured values. Consumption = Production + (BC Hydro Sold – BC Hydro Bought).

6. Solar Thermal

Appendix Note 6-1 – Insolation Data Source

[1] Insolation data was collected across three weatherstations surrounding the Eco-Sense home, inclusive of Eagle View Elementary, Cal Revelle Nature Sanctuary and East Highlands Firehall. This data was supplied by UVIC.

Appendix Note 6-2 - Calculation of Thermal Storage Volume for Excess

The un-utilized solar thermal energy could be made available for later use if stored. The most widely used form of thermal energy storage is water. The following is the methodology for calculating thermal storage size

Energy stored can be calculated as:

$E = c_p dt\ m$

Where:

E = energy (kJ, Btu)

c_p = *specific heat capacity (kJ/kg°C, Btu/lb°F) (4.2 kJ/kg°C, 1 Btu/*lb_m*°F for water)*

dt = temperature difference between water stored and the surroundings (°C, °F))

m = mass of water (kg, lb_m*)*

If we assume that a storage system is insulated to R 40 or greater (negligible heat loss), then we can calculate the volume of storage required for this system to be of use. We are working on the assumption that storage temperature is 85 C.

3643.8 kWhr = 13 117 680 kilojoule

$13{,}117{,}680\text{kJ} = 4.2(\text{kJ/kg}^{\circ}\text{C})(85^{\circ}\text{C})\text{m}$

m=36744.2 kg

Note:

Water weighs aprox 1 kg/litre therefore approximately 36,750 litres of storage would be required to store the excess solar thermal energy.

Appendix Note 6-3 – Solar Thermal and Wood Contribution to Space Heating and Domestic Hot Water Methodology

Total Thermal Energy :

Total Thermal Energy = $ST_{total\ kWhrs} + WG_{total\ kWhrs}$

where :

ST = Solar Thermal and

WG = Wood Gassification

Thermal Energy required to heat DHW:

$DHW_{kWhrs} = (Temp\ Differential_{DHW\ Output\text{-}Supply}\ X\ Volume_{gal} X\ 8.34_{BTU})\ 0.00029307108333$

During Summer season:

Space heating loads for the home were required from September 10 2010 – June 2 2011; with this, any excess Solar Thermal Energy that was not allocated to DHW became allocated to space heating during the heating season. For the other periods, the excess solar thermal is dumped or un-utilized.

Therfore 2 options

If $DHW_{kWhr} < ST_{total}$ then ST – DHW = amount of ST diverted to space heating

If $DHW_{kWhr} > ST_{Total}$ then DHW – ST = amount of WG not used in space heating (allocated to DHW)

During Heating Season:

ST is still allocated to DHW production, with any additional excess ST gain going to space heating. At times when ST can not meet DHW demands, WG will provide inputs required, with the remaining wood energy going to space heating.

Appendix Note 6-4 – Domestic Hot Water methodology

Domestic hot water energy demand can be extrapolated by knowing the volume of DHW consumed. The water has a fixed cold water supply temperature of 40 F, and a fixed hot water output temperature at 130 F. With the known volumes and known temperature differential we can identify energy required to heat the DHW.

1 BTU is required to raise 1 lb of water 1 F;
1 gallon water = 8.34 lbs; it takes 8.34 BTUs to raise the temp of 1 gallon water by 1 ^{o}F
Therefore energy equation to heat a volume of water is:

The conversion factor to convert BTU to kWhr is 0.00029307108333.
Energy required to heat water from the water entering the home (supply) to delivery temp (DHW output) via 130 ^{o}F tempering valve where Supply = 40 F and DHW output = 130 F is:

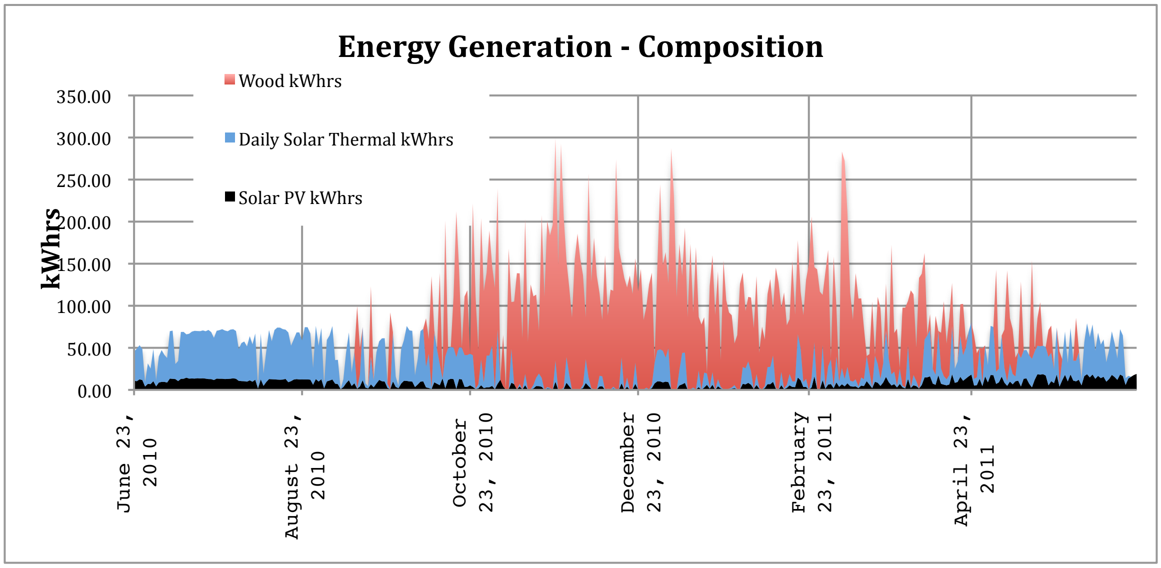
$(90^{o}F\ X\ DHW_{gallons}\ X\ 8.34_{BTU})\ X\ 0.00029307108333 = Required\ kWhr$

Appendix Note 6-5 – Thermal Energy Flowchart

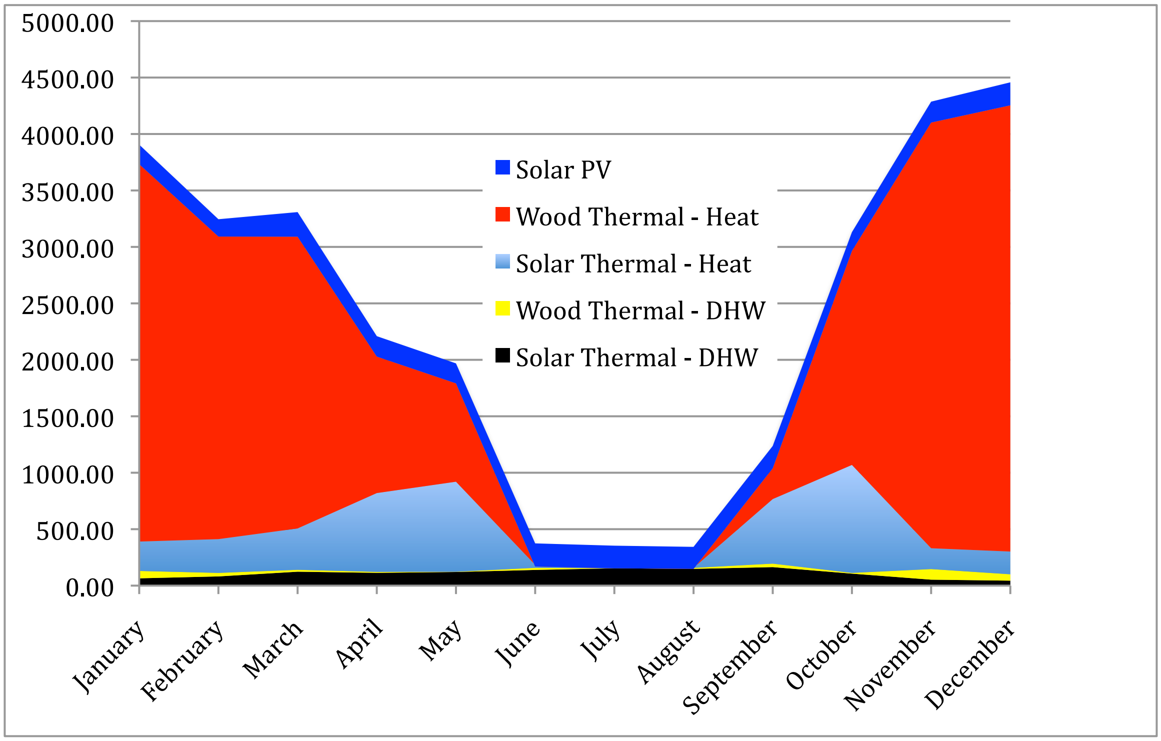
This flowchart charts primary and secondary energy flows from the thermal energy sources (solar and/or wood), for both of the seasons, denoted as Heating Season and Summer Season.

In the heating season, there are two draws upon thermal inputs, these are Space Heating and DHW. Throughout the year there is usually enough solar gain to cover DHW energy demand, therefore we say that DHW draws upon Solar Theraml as is 1st cjoice of inpu; when there is a lack of solar thermal to meet full demand, then DHW draws upon wood. We therefore assume that all wood thermal inputs go to space heating unless the condition is met where DHW is > Solar thermal production. Also during this season, when Solar thermal production surpasses the demand required for DHW, then the excess is passed onto space heating.

In the summer heating season there is no draw upon any thermal production system for space heating. Therefore wood is not used, and only the solar thermal system is activated. DHW draws upon the solar thermal inputs, and because there is not other demand, the excess solar thermal energy is dumped, and thus classified as un-utilized.



Appendix Figure 6-1 Energy Generation Composition



Appendix Figure 6-2 Energy Consumption Profile

Appendix Table 6-1

Solar Thermal Monthly	Solar Thermal Monthly (kWhrs)	Insolation (W/m2)	Solar Thermal used for heat (kWhrs)	Wood Used for Heat (kWhrs)	Solar Thermal Used for DHW (kWhrs)	Wood used for DHW (kWhrs)	Un-Utilized Solar Thermal (kWhrs)	Solar Thermal Contribution to Space Heat (%)
January	325.28	21.54	260.61	3342.00	64.67	65.18	0.00	7.2%
February	380.88	35.60	299.31	2679.76	81.57	31.08	0.00	10.0%
March	489.97	62.12	366.59	2583.67	123.38	16.70	0.00	12.4%
April	811.32	102.76	698.01	1208.76	113.30	8.55	0.00	36.6%
May	918.13	137.39	797.41	870.94	120.72	2.36	0.00	47.8%
June	940.47	172.68	26.41	-14.57	139.01	18.53	775.04	0.0%
July	1510.98	193.74	0.00	0.00	153.47	0.00	1357.50	0.0%
August	1470.78	147.61	0.00	-9.27	148.27	9.27	1322.50	0.0%
September	924.65	83.13	571.93	272.63	164.01	30.84	188.70	67.7%
October	1062.57	56.59	956.36	1894.83	106.21	6.46	0.00	33.5%
November	237.43	20.88	184.69	3770.11	52.74	93.86	0.00	4.7%
December	245.61	16.79	201.57	3951.99	44.05	56.40	0.00	4.9%
Totals	9318.05	1050.82	4362.89	20550.84	1311.4	339.22	3643.75	

7. BC Building Code

Overview

Earthen architecture has been used for centuries, and buildings of 500 and 700 years of age are still in use. Building codes and regulations did not exist at this time, but these ancient building co-exist beside and among new buildings that have been constructed under modern day regulations. The building codes and regulations evolved for primarily two purposes, to develop a set a minimum standard for construction and promote building practices that would allow buildings to meet minimum performance levels for energy efficiency. In Canada, we have seen the code change and respond to past failures, and increased demand for more energy efficient buildings. The 1970 Canadian Code for Residential Construction was 213 pages; there has been a lot of failures since then, as the 2006 BC Building Code has a whopping 870 pages.

A falsehood about the code, is that it sets the highest standard for buildings to be built to… quite the contrary, as it is the minimum standard that must be obtained. Many of the homes and buildings that have been built under the code have had early deaths as a result of sealing up buildings in an effort to make them more efficient, thus they rot and mold from trapped moisture in the process of achieving this efficiency [Lstiburek]. It is a common understanding that the lifespan of a new construction is vastly shorter than that of a building built 100 years earlier. A testament that "new" isn't always better. What we need to address is how de we utilize traditional construction styles, to meet the energy performance required, and do so within an ever increasingly narrow set of standards.

There has been a resurgence through many parts of the world to try and re-incorporate earthen building systems into the codes and standards, which include volumes of research on moisture durability and performance, seismic durability, and thermal performance. The new ASTM standard for Earthen Building ASTME2392M-10, released in 2010 refers to some of the standards of which it drew upon to develop its standard:

Australian Earth Building Handbook
California Historical Building Code
Chinese Building Standards
Ecuadorian Earthen Building Standards
German Earthen Building Standards
Indian Earthen Building Standards
International Building Code / provisions for adobe construction
New Mexico Earthen Building Materials Code
New Zealand Earthen Building Standards
Peruvian Earthen Building Standards

The challenge we face with comparing cob or other earthen building materials to conventional codes, is that the materials have vastly different qualities and behaviours when it comes to how it responds with moisture and thermal performance. It is for this very reason that new codes have been written focusing specifically on earthen construction.

The following discussion touches on these discrepancies, and in comparing how the Eco-Sense Cob home addresses the issues of heat transfer, air leakage and condensation control.

Section 9.25 BC Building Code

This section relates standards and regulations pertaining to Heat Transfer, Air Leakage, and Condensation Control.

The Building code sets out the required thermal insulation, air barrier and vapour control that is required in "Assemblies". The assembly that we will focus on is the cob mass wall system, as all other components of the home are considered conventional. The cob wall assembly is a core of cob 56 cm thick, with earthen clay plasters 3cm thick on either side in direct contact with the cob, then an exterior skin of lime plaster 1 cm thick; total wall thickness varies but is approximately 63 cm (24.5").

The wall system was monitored for a complete year, via soil moisture sensors and soil temperature sensors placed 5 cm inside the wall on a north wall and a south wall (8 sensors total). With this data, indoor and outdoor temperature and RH data was collected. Data was measured every 5 minutes for a period of one year.

In conjunction a KD2 Pro Thermal property Analyzer was used to test sample of the wall, to garner RSI and K values.

Thermal Insulation Section 9.25.2

Thermal Insulation minimum requirement

For framed wall assemblies in this region (below 3500 HDD), walls must be a minimum of 2.45 RSI (or R13.9) (BC Building Code: Notes to Table 9.25.2.1).

Cob walls have traditionally had an R value of R 0.6/inch, with the wall assembly being a nominal 61 cm (24") thick. Traditional cob would dictate that the wall thickness requirement should be increased to 71 cm (28") thick to meet minimum code. Data taken from the KD2 Pro thermal Properties Analyzer places the R value at an average of R 0.9/inch for an assembly value of R21.6.

In addition, note (3) table 9.25.2.1, the Code goes on to state that the above noted RSI requirements are not intended to apply to masonry or construction without a cavity, and that alternative to the stated requirements "may be determined through the use of energy consumption estimation, computer modeling, or using other acceptable good engineering principles" [9.25.2.1.2]. The Code does not specify the energy intensity (kWhr/m2) that they deem acceptable for energy consumption. The code could set out a minimum standard of energy intensity in kWhrs/m2 dedicated to heat inputs to make it easier to determine if the "modeling or energy consumption estimate" are acceptable.

This is well within the code.

Thermal Insulation with relation to Mass Wall/Dew Point

In BCBC Appendix A: A-9.25.1.2 discussion on thermal insulation notes that if a low permeance product like foam is used then the temperature of the inner surface of this product will be similar to the interior temperature of the building, and thus no additional vapour barrier is required, that the dew point will not be achieved.

Though Cob is vastly different than insulative foam, the theory has been demonstrated through the research on the mass wall that the interior of the wall, (5 cm or 2" in), maintains a temperature that is the same as the interior of the home. Therefore the applicability of a dew point on a mass wall is not of relevance. It should also be pointed out that based on the discussion in the BC Building Code, a vapour barrier is NOT required.

Of special note – BC Building Code states in discussion in Appendix A: A-9.25.1.2:

> "For locations in the BC Coastal Region, the warmer winter conditions are such that interior RH (Relative Humidity) levels higher than 35% can be tolerated. However, if the use of the space is such that indoor RH will be maintained above an average 60% over the entire heating season, the ratios in Table 9.25.1.2 should not be relied upon to provide protection from moisture accumulation due to vapour diffusion"

What this is in effect saying, is that in a conventional wall assembly system all bets are off; at Eco-Sense, where RH (relative humidity) levels consistently popped up to 63%, with no condensation, and no significant increase in wall water content (ranged from 1.8% to 2.025%) the wall system functioned beyond what the BC Building code could envision. This would be an example of far surpassing the minimum standard.

Insulation Materials 9.25.2.2 – Flame spread

Insulation materials must conform to a variety of standards (eg, CAN/ULC-S704, CAN/ULC-S706). Many of these ratings are to address the flammability of insulation products. Cob bluntly has no rating or standard. Earth has been used as a fireproof building material and as a fire suppressant, as seen in earthen ovens the world over, clay bakeware, and pottery, and the actions of firefighters using shovels and dirt to cover and smother out flames. Cob has no flame spread.

Air Barrier System Section 9.25.3

Air barriers are designed to stop air infiltration and exfiltration under differential air pressures, and must be continous throughout the assembly, and sealed to where it meets other assemblies (roof, foundation, windows). Of particular weakness in air barriers are protrusions (eg electrical services, venting, plumbing).

The BC Building code states "The current requirements specify only a maximum air leakage rate for the material in the air barrier system that provides the principal resistance to air leakage", A-5.4.1.2.(1) and (2). This explicitly points to the recognized problem of not looking at the whole system.

The Code then moves on to discuss recommended leakage rate for small sections of the exterior envelope. Table A-5.4.1.2.(1) and (2) denote air leakage recommendations for portions of a building envelope, and are not intended for whole building performance, and thus do not include the presence of windows, doors and other openings

Cob is by it's very nature as a monolithic mass wall, a continuous air barrier assembly. This said all places where cob meets other assemblies, must be detailed to continue this air barrier. This is easily managed for protrusions, as the holes are backfilled with cob/plaster. Foundations to cob junctions are of no consequence as typically there is several tons of form fitted material atop the foundation. Roof structures are of issue. At the Eco-Sense home the roof vapour barrier is glued to the cob wall via acoustic sealant, and then as the cob wall is plastered (1.5 cm thick) the materials are applied over the plastic barrier, thus achieving a double seal to prevent air infiltration.

The Eco-Sense home had an air leakage test performed. The leakage results are exceptional particularly as it is not for a "section" of the assembly, but for the whole house. City Green Solutions in Victoria, at the time of the blower door test noted this was one of the most air tight homes they had ever tested.

Results:

Blower Door Results: 2.12 ACH@50Pa
Equivalent Leakage Area of 684 sq cm,

Vapour Barrier Section 9.25.4

The BC Building Code stipulates that "Thermally insulated wall, ceiling and floor assemblies shall be constructed with a vapour barrier so as to provide a barrier to diffusion of water vapour from the interior into wall spaces, floor spaces, or attic or roof spaces."

The best research to date has been performed by John Straube in Canada and Gernot Minke in Germany.

Based on their findings lime plasters have a permeance rating of 500 ng/Pa s m2 (9 US perms); Straw clay loam (cob) has a permeance of 1088 ng/Pa s m2 (28.4 US perms), and earthen plasters a permeance of 1200 ng/Pa s m2 (20 US perms). As Struabe points out, 38mm (1.5") of earthen plaster has the equivalent perm rating as some building papers and house wraps (rated at 20 us perms).

The nature of the code would dictate that the earthen wall assembly does not conform as they allow a maximum permeance for a vapour barrier of only 60 ng/Pa s m2.

This section of the code is the biggest stumbling block, as historical evidence has shown the effectiveness of these mass walls with high permeance, in which the wall, exterior plaster and interior plaster are a combined unit. A-927.2.2 describes the requirement for capillary breaks between components; this would in essence stop the mass wall from functioning be removing the permeance interaction between the mass wall components. In Appendix A: A-9.27.3.1 there is a discussion point on "Appropriate Level Of Protection" wherein it does state that local practice with demonstrated performance should be considered. We would like to point out that there is now local performance demonstrating superior functioning, beyond the descriptions as laid out in the BC Building code.

Summary of Building Code

The building code is a document the looks at individual components as a parts of the larger systems. Its metrics specify individual requirements, yet fail to provide over all performance standards as seen with a lack of information to recommended energy intensities required for space heating, or whole house air leakage guidelines. The code also fails to recognize traditional materials and that these materials like cob, despite historic significance through the world, and thus uses metrics that do not apply to earthen building systems.

The issue of least or little concern within the code as it applies to Cob, is the structural issues. All cob buildings of load bearing capacity as Eco-Sense, required a structural engineers stamped plans and submission of Schedule B's to the overseeing building official, thus removing risk and liability from the city/district/municipality.

The issues of greatest concern are those listed in Section 9.25 of the code and pertain to thermal performance, vapour performance and air leakage. It can be shown that the Eco-Sense home excels in all aspects, despite the metrics being incongruent between vapour permeance standards of the code and actual performance.

It is apparent from trying to fit a "round house" into a square box, why so many jurisdictions throughout the world have moved to the development and creation of earthen building standards. It is our recommendation that the Government of BC follow this route via adoption of the International Construction Codes newly released Green construction code (IgCC) which includes earthen building standards.

References

Straube, J.F. *Moisture Properties of Plaster and Stucco for Strawbale Buildings*, Report for Canada Mortgage and Housing Corporation, June 2000

Minke, Gernot Building With Earth: Design and technology of a sustainable architecture, Birkhäuser, 2006.

Lstiburek, J; Understanding Vapour Barriers; Building Science Digest, BSD 106, 2006.

ASTM International, Standard Guide for Design of Earthen Wall Building Systems; ASTM-E2932M-10, 2010.