# AFFORDABLE, SUSTAINABLE HOMES

## Eco-Sense and the Future of Green Building

**We gratefully acknowledge the support of our sponsors:**

Vancity

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Front cover: Figure 1. Baird Residence

Photo credit Ann and Gord Baird

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## Executive Summary

The Eco-Sense home is a Living Building Challenge Petal Certified home built on Vancouver Island in British Columbia, and was completed in December 2008. The cob house is 200 $m^2$ and was built by the owners for six members of a multi generational family. It has five bedrooms, two baths and two kitchens, and is located in the Highlands municipality of the Capital Regional District on Vancouver Island.

This report focuses on the energy and water performance of the Eco-Sense home during one year of monitoring, June 15th, 2010 – June 15th, 2011, and also addresses the code barriers and opportunities that arose through this project.

Overall the energy use of the home was calculated to be 55.6 percent less than an average BC home. The energy performance is affected by three main components: the thermal mass performance of the cob walls, the amount of electricity generated by the photovoltaic system, and the space and water heating demands. For the year that was monitored, the photovoltaic system generated all the electrical needs for the home. For space heating the home had a higher energy intensity than that of an average BC home. This was caused by the 15 percent decrease in solar insolation for the year studied. Water heating for the home was 84.6 percent less per person than the BC average.

Eco-Sense was fitted with sensors monitoring indoor/outdoor temperature, dewpoint and relative humidity, along with embedded sensors in the earthen wall measuring temperature and water content. The results demonstrate the exceptional performance of the walls in moderating humidity through all situations and seasons, responding within minutes to the changing respective indoor and outdoor environments. The cob wall acted like an impassible barrier with sponges on each side that could absorb and release moisture without condensation. The study of the cob walls showed that they maintained a stable range of 5-6 percent moisture content unrelated to external temperature or humidity fluctuations. A more detailed report of the cob wall performance is provided in the Appendix.

Due to water efficient appliances, composting toilets and lifestyle choices, the water consumption in the home per person per day is 6 times less than the average consumption for a home in BC or Canada. The home owners selected to use a well for all water uses within the home and use the rainwater collection and grey water re-use systems to irrigate the edible gardens.

A summary of policy barriers and opportunities experienced during this project is included in the report. Several issues are identified within the BC Building Code as well as within regional policies.

## 1. Introduction

The Eco-Sense building is a Living Building Challenge Petal Certified home built on Vancouver Island in British Columbia, Canada. Completed in December 2008, it features passive solar design, solar photovoltaic panels (for electricity), solar thermal water heating, composting (no flush) toilets, rain water harvesting, grey water re-use, a living roof, earthen floors, and natural, non-toxic finishes in a net-zero electricity, earthen home.

The Eco-Sense home is the world's first residence to achieve partial petal certification under the Living Building Challenge standard and has garnered much media and public attention. The building required rigorous research and assessment to meet this standard, and provides an excellent model for BC's residential sector.

This report focuses on the energy and water performance of the Eco-Sense home during one year of monitoring, June 15th, 2010 – June 15th, 2011. The house is located in the Highlands municipality of the Capital Regional District on Vancouver Island. A summary of policy hurdles experienced during construction also is included.

This report is complemented by an ongoing education and media outreach program. Through education and dialogue, Eco-Sense seeks to familiarize critical stakeholders, policymakers, builders and the broader public with the clear practical and cost advantages of deep green buildings and thereby facilitate their wide acceptance.

Figure 2: Baird Family Residence Exterior

Photo Credit Ann and Gord Baird

Figure 3: Project Overview

| | |
|---|---|
| End of construction: | December 2008 |
| Construction duration: | 20 months |
| Total square footage: | 200 $m^2$ (2,500 $ft^2$ outside 2,150 $ft^2$ inside)<br>5 bedrooms, 2 baths, 2 kitchens |
| Use: | Home to six members of a multi-generational family |
| Integrated systems design: | House, land, water, energy, and lifestyle |
| Firsts: | First load bearing code approved cob dwelling in North America, first Living Building Challenge participant to achieve Petal Certification in Canada. |

Figure 4: Entry to One of Two Kitchens

The walls and floor for the home were constructed by hand of mass cob. Earthen floors, earthen counters, natural plasters, natural milk paints were used for the interior and have no VOC's, thus they produce no toxic off-gassing.

Figure 5: Eco-Sense Walls at Six Weeks

Figure 6: Envelope and Materials Overview

| | |
|---|---|
| Wall system | Mass cob (clay, sand, straw) wall system insulated with locally mined pumice. Interior walls light clay infill. R-24.5 |
| Roof insulation | Formaldehyde-free fiberglass insulation. Estimated R-40 |
| Floor insulation | Rigid Styrofoam. Estimated R-12.5 |
| Earthen floors, counters, interior plaster and milk paints | No volatile organic compounds. |
| Recycled materials | 80 percent of wood in the building. Most plumbing and light fixtures. |
| High fly ash concrete | Minimal carbon footprint |

## 2. Energy System Analysis

Figure 7: Cob Cold Storage

This picture shows earthen plaster students at work on the cob cold storage, which is used to store produce at low temperatures through the winter.

The Eco-Sense house uses both active and passive systems to achieve net zero electricity and maximize energy efficiency. It employs historic building technologies, including the use of cob, which has low embodied energy and high thermal mass. The builder owners, Ann and Gord Baird, also address ongoing energy use patterns via the use of a cold storage shed and the avoidance of conventional modern conveniences like toasters and dishwashers.

There are three active energy systems in the home. The electrical system is a two-kilowatt (2 kW) solar photovoltaic array with a tie into BC Hydro's electrical grid. The hot water heating system, comprised of sixty solar evacuated tubes, provides for domestic use (faucets and showers) as well as in-floor heating. Hot water is distributed for domestic hot water throughout the year and then re-used directly for in-floor heating in the winter. Winter heating is augmented by a wood fired gasification system that provides winter heating, is smokeless and 85 percent efficient. In addition a range of passive solar design features and energy efficiency measures are included in the design and operation.

Figure 8: Eco-Sense Home (under construction) showing photovoltaic array
Photo Credit Ann and Gord Baird

Figure 9: Energy Systems Overview

| | |
|---|---|
| Passive features | Thermal Mass cob walls<br>Passive solar<br>Natural Daylighting<br>No windows on north wall.<br>Deciduous plants on west exposure. |
| Electricity | 2 kW solar array grid tied to BC Hydro<br><br>Total yearly production 2699 kWh<br>Total yearly consumption 2302 kWh<br>Electricity surplus 397 kWh per year |
| Hot water system | 60 solar evacuated tubes for heating hot water for combined system:<br>Hydronic in-floor space heating<br>Showers & sinks |
| Supplemental (winter) heating | Wood gasification stove - 85 percent efficient. |
| Energy efficiency measures | Wired for 24vDC and 110vAC. Workshop also has 240vAC<br>LED lighting<br>DC appliances (2 fridges and 1 shared freezer)<br>High Efficiency front loading shared washer, drying room in mechanical room, clothes line, no kitchen appliances<br>DC brushless fans for bathroom ventilation and range hoods<br>Bedrooms have master switch to turn off all AC power<br>No phantom loads<br>No cordless phones<br>Root cellar for cold storage. |
| Cooking | Propane |

## Energy Data Overview

The Eco-Sense home generates all of its needs for electricity from the photovoltaic array and supplies an excess of electricity to BC Hydro. The energy intensity of the home is 150.43 kWhr/$m^2$. The breakdown of energy utilized for the test year in the home is shown below.

Figure 10: Actual Energy Use by System

June 15 2010-June 15 2011

| Energy system | Energy use / generated energy |
|---|---|
| Wood gasification | 20890.7 kWh |
| Solar thermal collection | 5709.29 kWh |
| Electricity | 2324.85 kWh |
| Cooking | 1263 kWh |

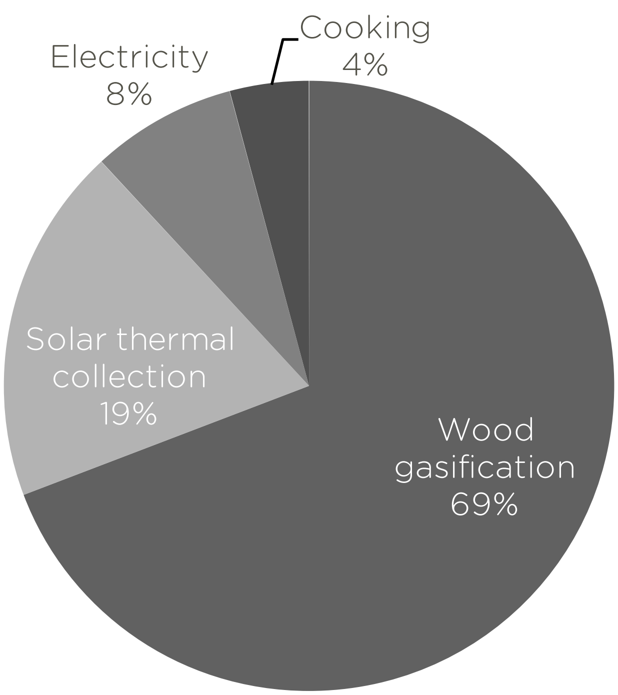


Figure 11: Eco-Sense Solar Hot Water Class

Photo Credit Ann Baird

## Solar Thermal Hot Water System Performance

The solar thermal hot water system is used for space heating and domestic hot water. The floor, which contains a hydronic heating system, is comprised of three layers:

1. Bottom: 3” of clay/sand mix that contains hydronic tubing.
2. Middle: 2”-4” of cob (clay/ sand/ straw).
3. Top: 1/2”-1” of horse manure, sand, and clay (same mixture used to plaster the walls).

The hydronic heating system is very efficient, and only draws 300 watts per 24-hour cycle.

Figure 12: Earthen Floor

Photo credit: Ann and Gord Baird.

Water heating is generally controlled by the usage patterns of the residents. The Eco-Sense average energy per person is 330.13 kWhrs. This is a dramatically different usage pattern than that of the average BC resident. Eco-Sense uses 84.6 percent less energy to heat its domestic hot water on a per person basis. Of all the heated water, the majority is from solar thermal collection.

Figure 13: Solar thermal hot water system performance

| Total household usage (kWhr) | Usage / person (kWhr) | Intensity / $m^2$ ($kWhr/m^2$) |
|---|---|---|
| 1650.63 | 330.13 | 8.22 |

## Photovoltaic panel performance

The photovoltaic panel system is grid connected, enabling the system to send surplus energy back to BC Hydro.

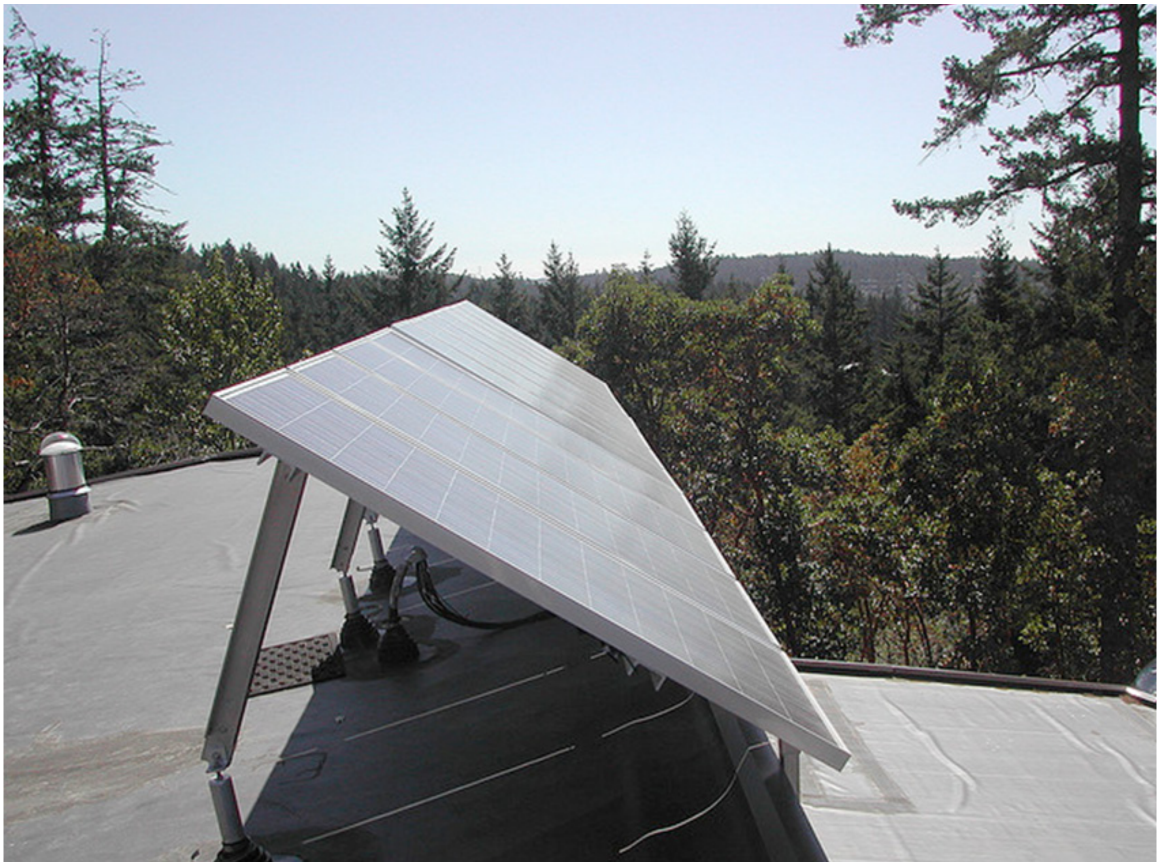
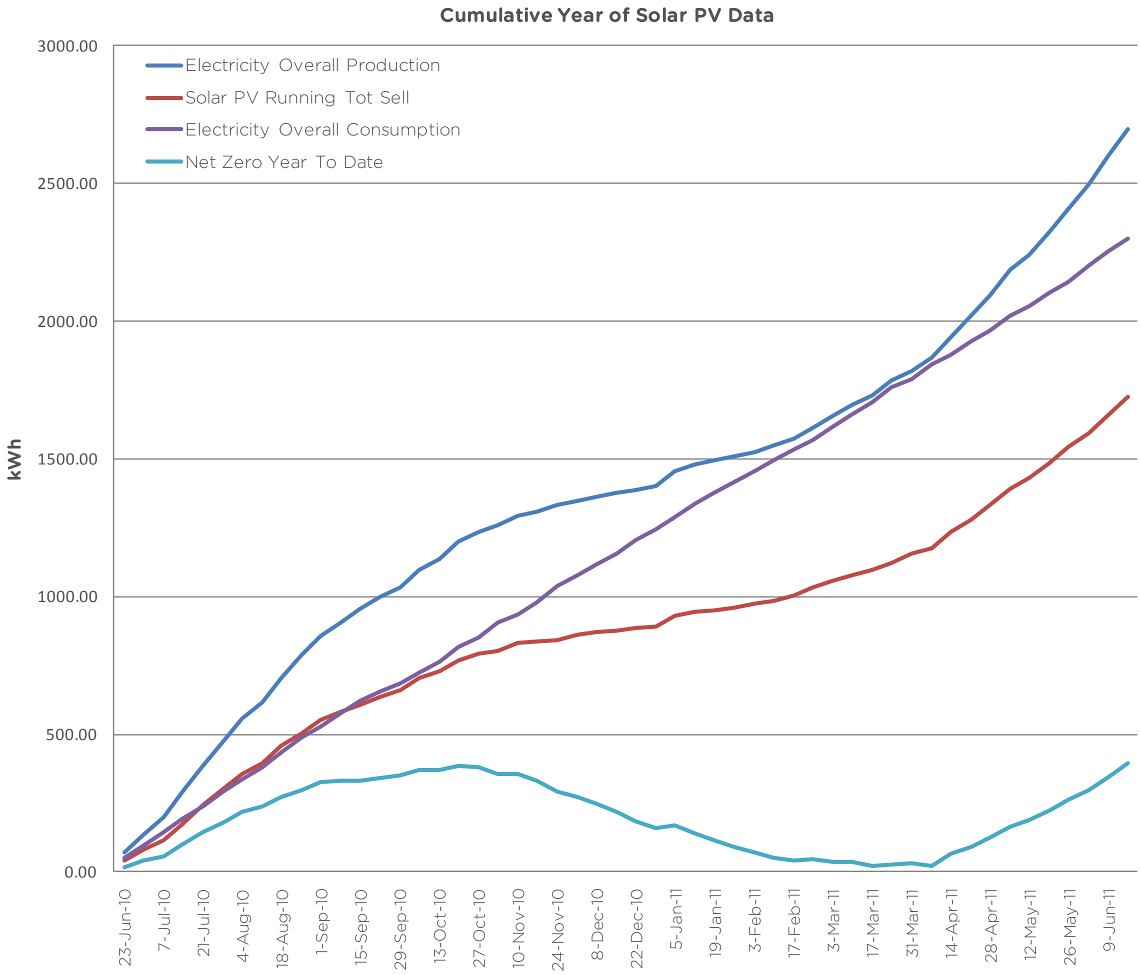


Figure 14: Photovoltaic system before Living Roof was planted
Photo credit: Ann and Gord Baird.

Eco-Sense started the test year with twelve Sharp 175w PV panels, providing a 2kW array. On October 12, 2010 the panels were tilted to their winter position and four new 175w panels were added. On March 20, 2011 the panels were tilted back to the summer angle. The summer angle is 60 degrees and the winter angle is 35 degrees.

All sixteen panels are wired to feed two parallel Outback MX 60 Charger controllers, an 800 amp hour sealed AGM battery bank, 3500W Outback Grid-Tie inverter, and linked to the BC Hydro grid. There is no generator backup power supply. When batteries are fully charged and the panels are producing extra electricity, it is fed into the BC Hydro grid. When the house is using electricity and drawing the batteries down, the inverter will keep the batteries topped up either from the PV system or the BC hydro grid. Every day, the BC Hydro net meter sells and buys electricity with Eco-Sense.

Figure 15: Photovoltaic panel yearly performance




It is important to look at external factors that might impact the generation of electricity from the panels. Using the polynomial trend-line shows that the production of electricity for the system mirrors the measured insolation data. Snow cover is the likely explanation for the January spike in production that is not mirrored in the insolation data. Snow on the Eco-Sense roof reflects more sunlight onto the solar panels thus explaining the observed high solar output in early January. The spread in trend-lines is greater in the summer than in the winter as efficiency is greater when the panels are cooler.

Figure 16: Weekly electricity produced compared with the measured insolation

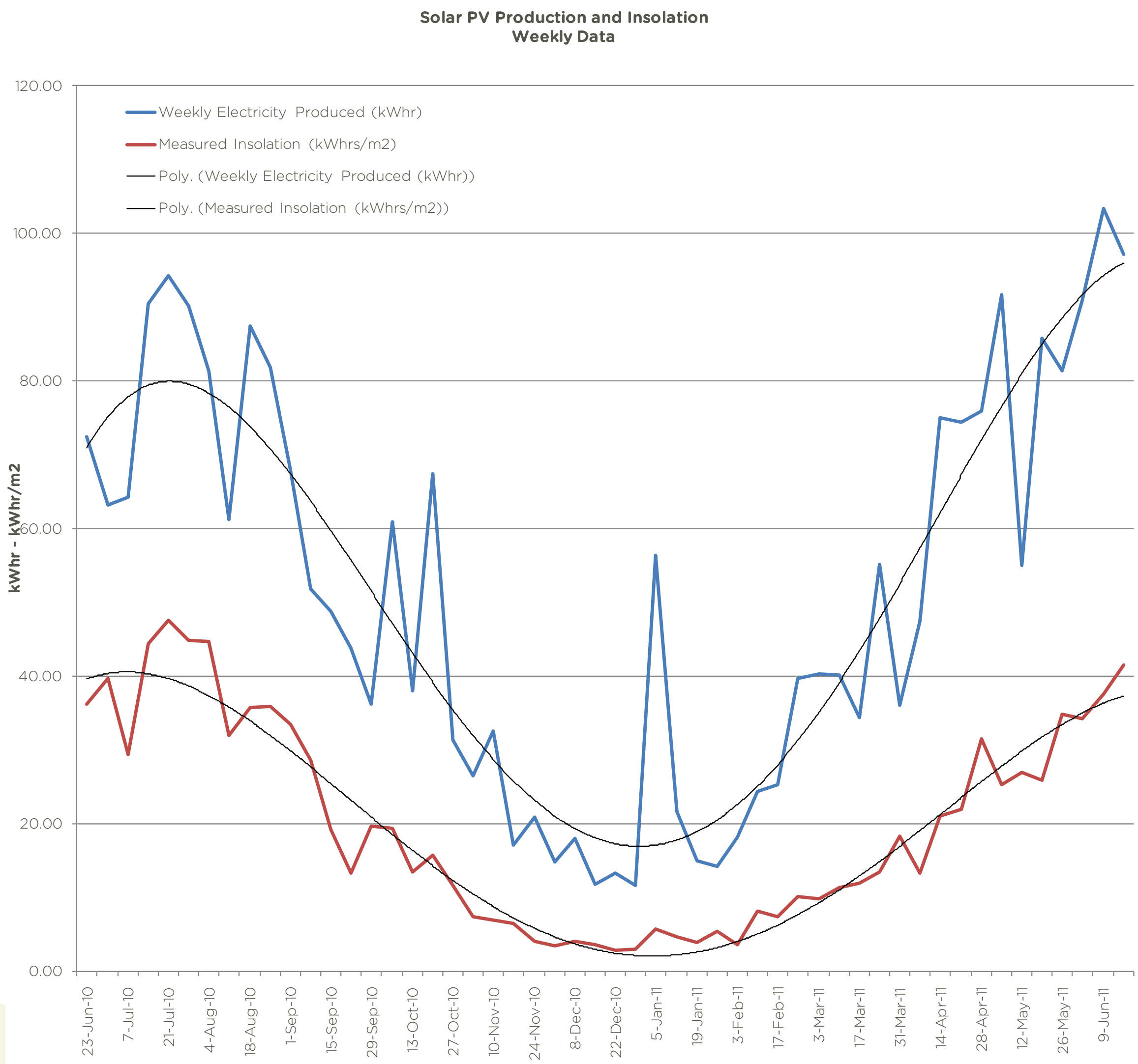
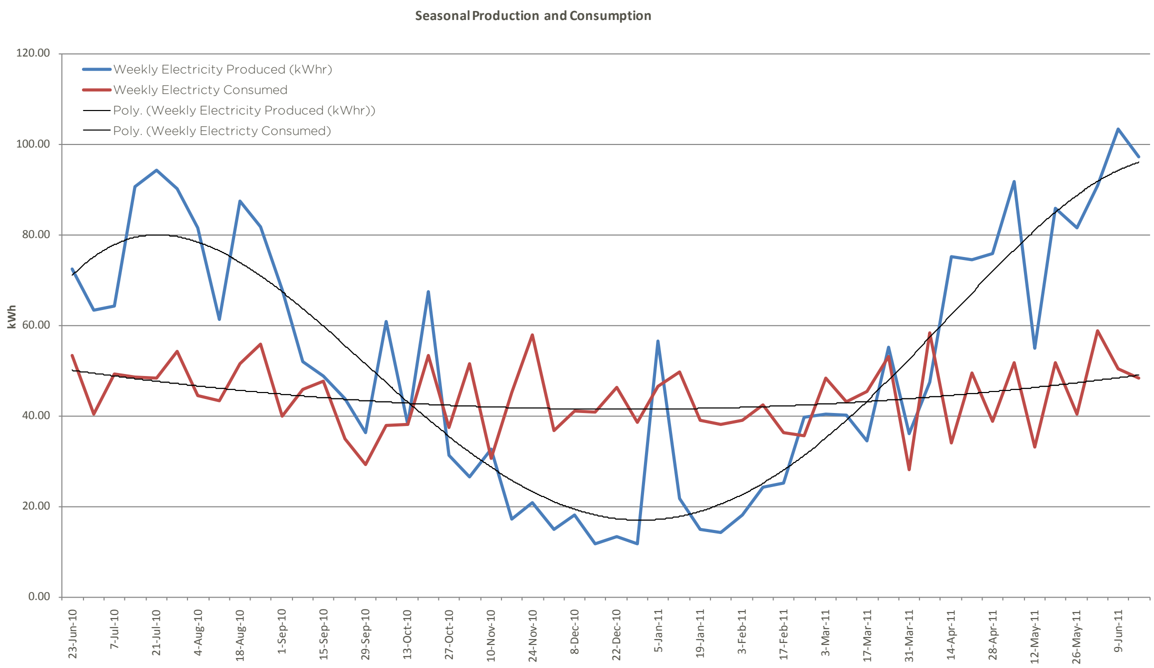


Figure 17: Seasonal production and consumption of photovoltaic electricity




## Mass wall thermal performance

The Eco-Sense House is North America's first code-approved, seismically engineered, load bearing insulated cob (clay, sand and straw) residence. The cob used in Eco-Sense also incorporates pumice to boost insulation. Roof insulation is R-40 formaldehyde free fibreglass, while the floor is insulated with R-12.5 rigid Styrofoam. Many interior walls are constructed with light clay infill. High fly-ash concrete was used where needed in order to reduce carbon footprint. Exterior lime plaster is almost carbon neutral, and its pigmentation is achieved with iron oxides.

One of the largest challenges with earthen architecture is how to apply modern day standards, codes, rules and regulations to earthen wall assemblies, in particular the metrics for moisture and vapor performance. Available historical data[1] demonstrates earthen buildings last for centuries longer than their modern day counterparts built using modern day standards, codes, and building science.

### The vapor barrier problem

The gap between traditional and modern day building information seems especially wide when it comes to vapor and moisture control. A questionable 1940's study

1 Keefe, Laurence: Earth building: methods and materials, repair and conservation, 2005

established the arbitrary definition of vapor barrier permeance at 1 US perm or less, did not take into account situations when walls perform better without them, such as in the case of walls constructed with strawbale.[2] It can be further argued that vapor barriers are a cold climate artifact, embedded into current building practices more from habit then from understanding of moisture physics..

Vapor barriers are intended to prevent building assemblies from getting wet. However, through incorrect use of vapor barriers, assemblies that have been getting wet have been prevented from drying by the same barrier, increasing moisture related problems.[3]

It is now standard across all North American codes to regard vapor transmission in assemblies as the main topic of concern. One of the biggest outstanding issues is how a mass cob wall with high permeance and capillarity can function without becoming saturated and without creating a dew point within the wall assembly.

In a conventional wall assembly there will be a point, usually at the vapor barrier wherein one side is exposed to cooler air and the other side to the warmer moisture-laden air, where condensation occurs on the warm side. This is where the dewpoint is met, and water vapor transforms into liquid. The BC Building code tries to alleviate this issue by controlling the Relative Humidity (RH) inside the structure to stay around 35 percent. Humidity beyond this poses increased risk of condensation inside the wall cavity, which leads to moisture levels that support mold, rot and general decay.

**Cob Walls**

One of the concepts building officials now struggle with is how cob walls absorb and release water vapor, particularly given generally higher humidity levels within the cob structure and thus greater vapor pressure on the earth wall assemblies. Conventional vapor transmission beliefs support the assumption that higher vapor pressure and humidity will continue to accumulate inside the cob wall. This misapprehension commonly leads officials to assume that cob will achieve moisture content of 14 percent and beyond. This is untrue and can be illustrated with basic moisture physics and data monitoring.

The low equilibrium moisture content of earthen walls (0.4 percent to 6 percent by weight) combined with the ability of the walls to transmit moisture, actually keeps the timber elements within the earthen walls dry.[4] If designed properly, cob walls will wick and evaporate moisture, allowing moisture to evaporate before it weakens the structure.

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

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

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

Natural earthen coatings do not inhibit this wicking effect, and in fact are porous enough to allow water to evaporate as readily as it is absorbed.

### Moisture Content Data

The data from the year of monitoring show that the yearly levels of moisture content within the cob walls at Eco-Sense is very low, and the outer wall water content reaches a maximum of 8 percent.

Research has shown that clay straw mixes have a moisture equilibrium of between 0.4 – 6.0 percent.[5] The research data on the Eco-Sense walls shows that on the inside of the home, (the wall surface receiving the highest vapor pressures), the moisture level does not exceed 3 percent.

Figure 18: Moisture levels and percentages within the cob wall.

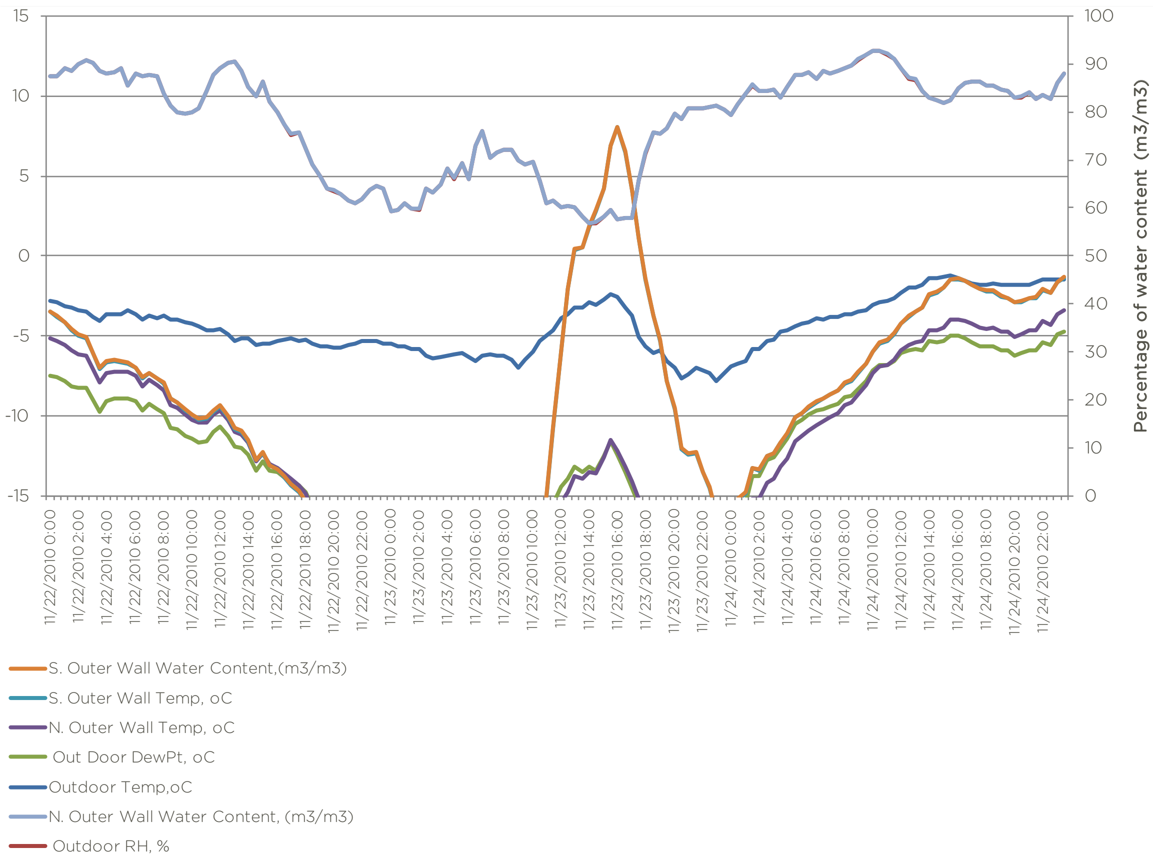
| | $m^3/m^3$ | Percentage |
|---|---|---|
| Max S. Inner Wall Water Content | 0.0235 | 2.35% |
| Max N. Inner Wall Water Content | 0.0293 | 2.93% |
| Max S. Outer Wall Water Content | 0.0773 | 7.73% |
| Max N. Outer Wall Water Content | 0.0555 | 5.55% |

During the year of data collection, the exterior wall assembly temperature dropped below the outdoor dew point, a condition avoided in conventional building. This occurred several times, evidenced not by a spike in moisture readings from the sensors as one might expect (due to presence of condensation), but by the readings of the temperature sensors and the outdoor RH/Temp sensor. The walls did not experience condensation (which would be indicated by a dramatic increase in moisture content) but instead maintained a stable range of 5-7 percent moisture content. The earthen materials controlled the moisture levels, ensuring water content stayed well below the dangerous levels (above 14 percent) required for insect and fungal life.

It was also found that the granular porous characteristic of cob withstood the freeze and thaw cycles despite 5 percent moisture content, within the 5 cm of the exterior wall surface, without damage. This is very similar to the theory behind the performance of air-entrained concrete.

5 Ibid.

Figure 19: Sub zero characteristics of the cob wall




The above graph shows characteristics when the exterior is at sub zero temperatures (-8°C) when the sun comes out. The North and South outer wall assemblies maintained similar temperatures, and their moisture content stayed firm, despite the low outside air temperature of below 0°C, and wall temperature spike up of greater than 20°C.

Three important conclusions:

1. The subzero temperatures do not perceivably alter the walls moisture content level.
2. As the temperature rose, due to solar insolation on the surface of the wall, a dramatic shift occurred with the moisture in the wall. Moisture physics suggest that the moisture had the opportunity to flow out of the wall with the shift in temperature gradient. The warming and increase in vapor movement would allow moisture to easily escape from the warm porous lime plaster surface, thus creating a capillary flow to the hot surface.
3. It was noticed that the surface of the wall was subjected to sub-zero temperatures earlier in the day, and then ranged over 20°C. In following days it stayed above freezing. In fact, each day the sun was out the thermal mass of the wall absorbed and held onto some of its solar gain into the following day.

The third conclusion is significant because in conventional building science this would not translate into much of a difference in the temperature differential between inside and outside of the home, so heat flows and heat loss would continue. With the earthen mass wall heating up to such a degree, and the fact the wall assembly is one solid continuous mass, the inner wall would see the outer wall as warmer, and thus reverse the heat flows through the wall in response to the temperature gradient. Heat travels from warm to cold, so usually in the winter from inside to out, but in this case there would be a period where the flow in that direction would stop and reverse, thus making the wall perform as if it were actually of higher insulation value.

### Dew Point Observations in exterior wall

Observing seasonal snapshots of the outer wall assembly performance in relation to outside dewpoint and relative humidity showed that moisture levels stay well within their narrow acceptable range. Of particular note is where the wall temperatures drop below the dewpoint. It is at these times that one might expect drastic changes in the moisture content in the walls, but this does not happen.

Moisture levels in the inner wall maintain a static level under 3 percent, no matter the relationship between temperature and inner wall water content.

### Relative Humidity ranges for the year

The wall experienced a wide daily difference between the outside relative humidity minimum and maximum, but it corresponded with a very narrow range seen with the indoor relative humidity.

### Indoor Dewpoint - Relation to Inner Wall Temperature

In conventional construction, insulation is used to attempt to reduce the temperature gradient (Delta T) on the cooler side of the vapor barrier. Water condenses to liquid at a dewpoint, and these barriers are the places where the dewpoint occurs in conventional building.

The data shows that the cob wall is a large thermal mass and that the mass is a degree or so cooler than the inside temperature. The dewpoint for the inside is considerably lower and at no time do the inner walls come close to the dewpoint.

### Cob Wall Thermal Performance

In addition to the measurements taken to monitor water content, relative humidity, dewpoint, and temperature, the thermal conductivity of the cob walls was also monitored. Thermal resistance values had an R value per inch range of 0.19 – 0.39 which is consistent with measurements used in engineering calculations conventionally (R1 per inch of cob).

Through the calculated weighted average we can conclude that the Baird cob walls are a very effective insulator and the rule of thumb method is not unreasonable.

Figure 20: Calculation of R value

| Method | R value |
|---|---|
| Rule of Thumb | R1 per inch |
| Degree Days | Envelope R8.5 (peak coldest) |
| Weighted Average | Overall Wall R24.5 |

Figure 21: Mass Wall with Tension Cables

Note: This picture shows the cob mass wall, and the 'V' form that ties the upper bond beam to the foundation. This is what gives the engineer the tensile numbers that are required, though cob is historically good in tension. In a potential earthquake, the cables would be stressed and would cause the bond beam to compress the cob, and take some of the sheer load. Photo credit Ann and Gord Baird.

Figure 22: Cobb Mass Wall Builder

Photo credit TJ Watt

**Conclusions**

Findings from this research begin to demonstrate why earthen buildings have lasted 5 to 7 centuries even in wet climates. Eco-Sense's cob walls function very differently from the conventional systems addressed in BC codes and regulations, and that the metrics used within the building code are too narrow to incorporate an unmeasured "different animal." This explains the hesitation from banks, insurance companies and building inspectors to allow such building projects. A previous lack of technical information and a steep new learning curve has caused hesitation at many levels.

The basis for this report includes more than 212,000 data points collected over a one year period. The information on the energy performance analysis, combined with the performance of the wall system, lend credibility to the viability of these building methods as a safe alternative in a wet climate and seismically active area. A more detailed analysis of the wall performance is provided in the Appendix.

## Energy Analysis

**Comparison to other Buildings in BC and Canada**

Eco-Sense exemplifies an emerging trend in housing that integrates sustainable energy and water systems with low carbon construction materials and methods. This project began as a challenge to build a home as sustainable as the BC Building Code would allow. What emerged was the first legal, seismically engineered load bearing high occupancy cob building in North America. Based on the earthen architectural concepts that have been utilized for millennia throughout the world, this home incorporates the science of modern structural engineering while surpassing codified standards.

The performance of the Eco-Sense cob home compares very favorably with other modern technology and housing standards. Specific research addresses heating, cooling, moisture control, and temperature moderation while providing a living space equal or superior to that found in many contemporary homes.

Comparison to conventional: A critical area of the research is the comparison of the Eco-Sense home with that of the average typical detached residence in British Columbia. The 2008 year represents the most recent data available from the Natural Resources Canada's (NRCan) National Energy Use Database (NEUD): Comprehensive Energy Use Data.

Review of the Climatic variables - Insolation: Solar insolation was abnormally low for the region for the year of study. The average yearly insolation is 1,242 kWhr/$m^2$; the measured value was 1,050 kWhr/$m^2$, or approximately 15 percent below average available sunshine. This equates to missing approximately two months of solar insolation. The months that showed the largest actual decrease were the shoulder seasons (spring and fall), when reliance on the solar insolation for both passive and active solar heating is greatest.

Figure 23: Comparison of Actual and Average Monthly Insolation

| | Actual Monthly Insolation (kWh/m²) | Average Insolation for Lat/Log from NASA (kWhr/m²/day) | Average Monthly Insolation for Lat/Log from NASA (kWhr/m²) | Average difference from expected |
|---|---|---|---|---|
| Jan | 21.54 | 1.04 | 32.24 | -33.20% |
| Feb | 35.6 | 1.91 | 53.48 | -33.40% |
| Mar | 62.12 | 2.93 | 90.83 | -31.60% |
| Apr | 102.76 | 4.2 | 126 | -18.40% |
| May | 137.39 | 5.17 | 160.27 | -14.30% |
| Jun | 172.68 | 5.67 | 170.1 | 1.50% |
| Jul | 193.74 | 6.08 | 188.48 | 2.80% |
| Aug | 147.61 | 5.4 | 167.4 | -11.80% |
| Sep | 83.13 | 4.07 | 122.1 | -31.90% |
| Oct | 56.59 | 2.25 | 69.75 | -18.90% |
| Nov | 20.88 | 1.18 | 35.4 | -41.00% |
| Dec | 16.79 | 0.86 | 26.66 | -37.00% |
| | | | | |
| | 1050.82 | | 1242.71 | -15.40% |

A year with a 15 percent overall decrease of insolation results in higher energy inputs for heating across this region, and is demonstrated in the difference between the average Heating Degree Days (HDD) for the area (2902 HDD)[6], and the measured HDD (3307 HDD). This notable difference translates into a 14 percent increase in HDD for the time period of study.

**Energy Intensity:** In BC the average single detached residence has a footprint size of 187.7 m², inhabited by 2.5 occupants.[7] The Eco-Sense house has an area of 200 m², with an average of five occupants. The average space per BC resident is 59.1 m²; whereas at Eco-Sense it is 40 m², a decrease in footprint per occupant of 32 percent from the BC normal.

When the measured energy data for heating is adjusted to account for the actual low insolation period (based on the difference in HDD), the adjusted energy intensity numbers show how the house would perform in an average year. This method would give a more accurate comparison.

6 The average heating degree day for the area is 2902 HDD. Report: Roland V. Wahlgren "Heating/Cooling Degree-Day Seasonally in British Columbia." BC Hydro Customer Information Management – Load Analysis Jan 2010.

7 Statistics Canada 2006 census http://www40.statcan.gc.ca/l01/cst01/famil53c-eng.htm

Overall energy usage shows Eco-Sense consumed 94.7 percent of that of a typical average residence in BC. The make-up of energy consumption shows a drastically decreased use of electricity, using only 18.3 percent of the average, but is accounted for with the use of wood fuel where the numbers are reversed. Due to this drastically different energy make-up between the "Average" and Eco-Sense, we must drill down and look at the energy intensity of the home, the area of the home and relate it to the residents.

Eco-Sense is approximately 13 $m^2$ larger in living area than the BC average, with a total area of 200.67 $m^2$. The energy intensity per square meter for Eco-Sense is 150.43 kWhr/$m^2$ (or 0.54 GJ/$m^2$) vs. 169.44 kWhr/$m^2$ (0.61 GJ/$m^2$); this is a difference of -11.2 percent, or Eco-Sense has an energy footprint that is 88.8 percent of the average.

Energy intensity measurements take into account both the operations of the structure and the lifestyles of the occupants and therefore the energy footprints of individuals are included. (Examples of lifestyle energy footprints include length of hot showers, size and number of TV's, number of household appliances, type of cooking, etc)
The residents of Eco-Sense have an energy footprint of 6037 kWhrs/year as compared to the average BC resident at 12744 kWhrs/year; a difference of 52.6 percent less energy per person, then that of the average resident in a similar home.

When the energy footprint from above is applied to the space they inhabit, the results show that energy intensity/person/$m^2$ is more substantial; that Eco-Sense has an intensity of 30.09 kWhrs/person/$m^2$ versus the BC average of 67.78 kWhrs/person/$m^2$. Therefore on a per person /$m^2$ basis, the individual energy intensity is 55.6 percent less than that of the BC average.

The Eco-Sense results would have been quite different if the data were collected in an average insolation year as seen in the following figure.

Figure 24: Eco-Sense energy intensity compared with BC average single- family residence.

| | BC Avg Single Detached Residence (NRCAN NEUD 2008) | Actual Eco-Sense (kWhr) | Adjusted Eco-Sense (kWhr) | % Difference from average |
|---|---|---|---|---|
| Energy Use by Energy Source (kWhr) | | | | |
| Electricity | 12731.12 | 2324.85 | 2324.85 | |
| Natural Gas – LP Gas | 16235.09 | 1263.00 | 1263.00 | |
| Heating Oil | 204.40 | 0 | 0 | |
| Other2 (inclusive of Solar Thermal) | 262.80 | 5709.29 | 5709.29 | |
| Wood | 2452.78 | 20890.7 | 17965.46 | |
| Total Energy (kWhr) | 31886.19 | 30187.84 | 27262.60 | |
| | | | | |
| Energy Source Breakdown (%) | | | | |
| Electricity | 39.9% | 7.6% | 8.5% | |
| Natural Gas | 50.9% | 4.2% | 4.6% | |
| Heating Oil | 0.6% | 0.0% | 0.0% | |
| Other2 (including solar thermal) | 0.8% | 18.9% | 20.9% | |
| Wood | 7.7% | 69.2% | 65.9% | |
| | | | | |
| Average Floor Space ($m^2$) | 187.74 | 200.67 | 200.67 | |
| Energy Intensity ($GJ/m^2$) | 0.61 | 0.54 | .49 | -20% |
| Energy Intensity (GJ/household) | 114.70 | 108.7 | 98.15 | -14.4% |
| Energy intensity/person/$m^2$ (per detached residence) | 0.24 | 0.11 | .10 | -58.3% |
| Energy intensity/person/ detached residence | 45.88 | 21.70 | 19.63 | -57.2% |
| | | | | |
| Energy Intensity ($kWhr/m^2$) | 169.44 | 150.43 | 135.86 | -19.8% |
| Energy Intensity (kWhr/ household) | 31861.11 | 30187.84 | 27262.60 | -14.4% |
| Energy intensity per person $m^2$ (per detached residence) ($kWhr/m^2$) | 67.78 | 30.09 | 27.17 | -60% |
| Energy intensity per person per detached residence (kWhr) | 12744.44 | 6037.57 | 5452.55 | -57.2% |

Summary of Energy Intensity: A more efficient use of space produces a home that uses less energy across a wide range of indices, where the energy intensity of the building itself is 11.2 percent less than typical buildings, where the residents use 52.6 percent less than the average BC resident, and where the energy intensity per person/$m^2$ is 55.6 percent less than that of the average BC resident's footprint intensity. These comparisons are between an average house in an average insolation year and it has been clearly demonstrated that the period of research was not a normal year, implying that the Eco-Sense house performance would compare even more favorably in an average year.

This demonstrates an exceptional divergence from normal values in the energy profile of the home and the occupants.

Space Heating: In an average year, the average residence in BC uses 19,739 kWhrs of energy to heat its space resulting in energy intensity of 105 kWhrs/$m^2$; for comparison, Eco-Sense, in a sunlight deficient year, used 24,948 kWhrs for an intensity of 124 kWhrs/$m^2$. As noted earlier the test year observed a 15 percent decrease in solar insolation and a subsequent increase in HDD by 14 percent. If the research study had been conducted in an average year the adjusted space heating would have been 21,719 kWhr for an intensity of 108 kWhrs/$m^2$. This demonstrates that the envelope is performing very similar, with an increased energy intensity usage of 2.9 percent. As noted earlier, the recorded insolation deficiency came in the Spring and Fall when the Eco-Sense home was very dependent on solar gain for both passive and active solar heating.

Figure 25: Eco-Sense space heating compared to an average BC single family residence with Eco-Sense data adjusted for a normal insolation year.

| Average Single Detached 2008 (kWhr) | Average Space Heating intensity (kWhr/$m^2$) | Eco-Sense Space Heating (wWhr) | Eco-Sense Space Heating Intensity (kWhr/$m^2$) | Adjusted Eco-Sense Space Heating (kWhr) | Adjusted Eco-Sense Space Heating Intensity (kWhr/$m^2$) |
|---|---|---|---|---|---|
| 19739.07 | 105.14 | 24948.72 | 121.99 | 21719.16 | 108.21 |

Since the completion of the Eco-Sense house, its owner builders have learned of additional measures that would greatly increase the thermal performance of future earthen homes. Such improvements would include:

1. The detailing of the insulation of the concrete foundation with the addition of better thermal breaks;
2. The use of light clay (wood chip and clay) infill for the upstairs exterior walls instead of pumice cob.
3. Addition of a Larson truss on the exterior north load bearing cob wall filled with a light clay infill and then plastered.
4. Utilizing a summer heat dump under the earthen slab for storing surplus solar energy to draw upon in winter heating months.

Water Heating: Water heating is generally controlled by the usage patterns of the residents. The BC average energy per person per BC household is 2148.64 kWhr; the Eco-Sense average is 330.13 kWhrs. This is a dramatically different usage pattern than that of the average BC resident wherein Eco-Sense uses 84.6 percent less energy per person to heat its domestic hot water on a per person basis. Of all the heated water, the majority is from solar thermal collection.

Figure 26: Eco-Sense water heating compared with BC average.

| 2008 BC Average Total usage/household (kWhrs) | 2008 BC Average Intensity/m² (kWhr/m²) | Eco-Sense Total Household | Eco-Sense Intensity/m² (kWhr/m²) |
|---|---|---|---|
| 5371.61 | 35.96 | 1650.63 | 8.22 |
| Avg usage/Person (kWhr) | 2148.64 | 330.13 | |

Carbon Analysis: Average BC annual green house gas equivalent (GHGe) for operations of a detached BC household in 2008 was 3.15 metric tons.[8] Note that electricity generation is excluded from the 2008 BC average GHGe, however electricity is included in the Eco-Sense calculations.

Average construction GHGe based on a house the same size using the Build Carbon Neutral carbon calculator is 65 metric tons. The average lifespan of a conventional home is 40 years. The overall carbon footprint/year for the average home is 40 years x 3.15 = 126 metric tons, plus 65 metric tons for a total of 191 metric tons of GHGe/carbon emitted over the life span, or 4.78 metric tons of GHGe per year.

Eco-Sense GHGe carbon from construction derived from the Environmental Agency and Green Footprint calculators estimates the carbon footprint of construction at a zero carbon footprint.

For operations, the Eco-Sense average GHGe from wood is based on 17965 kWhrs of energy. There is 5.49 kWhr/kg of energy; therefore there is 3272 kg of wood used to produce 17965 kWhrs – with a conversion factor of 1.779 this equates to 5821 kg of $CO_2e$ with a allowance for a half charge to be accounted for re-uptake, this leaves 2910 kg (2.91 tons)[9] of yearly emissions.

In addition there is 266 litres of propane consumed, which is equivalent to 400 kg $CO_2$ (0.4 ton). Thus the annual carbon footprint emitted from operations is 3.79 tons. Average Lifespan 500 - Overall carbon footprint per year over lifespan of 500 years

8 (NRCAN NEUD: Table 34: Single Detached Secondary Energy Use and GHG Emissions by Energy Source).

9 Eco-Sense uses LP gas for cooking, canning and preserving food. Unlike most homes, 80 percent 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.

is 500 x 3.79 = 1895 tons of carbon, which is 3.79 tons per year. Therefore the overall carbon footprint of the Eco-Sense home is 1 ton lower than that of a conventional house of the same size over its lifespan. On a per person basis (4.78/2.5) 1.91 tons is emitted per BC resident on average, whereas at Eco-Sense 0.66 tons are emitted per person.

Figure 27: Summary of GHGe for Eco-Sense compared to a BC average single family residence.

| | Average House/year (2.5 people) | Eco-Sense House/year (5 people) |
|---|---|---|
| GHGe operations | 3.15 | 3.31 |
| GHGe construction | 1.625 | 0 |
| tGHGe | 4.78 | 3.31 |
| tGHGe per person | 1.91 | 0.66 |

Affordability: Stats Canada data from 2009 Mortgage loan approvals shows new residential construction and existing residential properties, by province and territory: Alberta, British Columbia, Yukon, Northwest Territories[10] show that the average new construction cost for a single detached home in BC was $441,197; as the average size is 147.7 m$^2$, this comes to a cost /m$^2$ of $2987/m$^2$ (or $277/ft$^2$). For comparison, the Eco-Sense cost of construction was $1593/m$^2$ (or $148/ft$^2$). The monthly costs for energy are drastically different as the costs of wood per year do not exceed $550 (average of $45/month). Other costs are negligible, such as minor charges like an Eco Fee on the BC Hydro statement.

Compared to the average new construction, Eco-Sense was 46.5 percent less expensive to build with the added benefit of minimal $45 in additional costs to service supplemental energy that is not generated onsite.

If the Eco-Sense homeowners were to invest the $40,000 to remove all requirements for fossil and wood fuels (i.e. install a heat pump and more solar panels), the costs would increase an additional amount of $200/m$^2$ for a total of $1793/m$^2$ (or $167/ft$^2$). Still a reasonable cost in relation to today's construction costs.

10 Statistics Canada : http://www40.statcan.ca/l01/cst01/manuf03c-eng.htm

Net Zero Buildings in the U.S. and Internationally

Figure 28: Energy Intensity of Canadian Advanced Houses[11]

| Project | City | Predicted Energy Consumption (kWh/yr) | Actual Energy Consumption (kWh/yr) | Energy Intensity (kWh/ m²·yr) | PV Capacity | Solar Thermal |
|---|---|---|---|---|---|---|
| BC Advanced House | Surrey | 13 696 | 12 266 | 45.4 | | |
| SK Advanced House | Saskatoon | 20 514 | 31 322 | 91.9 | 1.92 KW | Yes |
| MB Advanced House | Winnipeg | 17 156 | 20 463 | 110 | | |
| Waterloo Green Home | Waterloo | 11 990 | 14 987 | 65 | Water pump | Yes |
| Hamilton Neat Home | Hamilton | 12 500 | 19 834 | 49 | | |
| Innova House | Ottawa | 13 877 | 18 053 | n.d. | 2,6 kW | |
| Maison Novtec House | Montreal | 11 422 | n.d. | - | | |
| Maison Performante | Laval | 11 067 | 11 607 | 63.8 | | Yes |
| PEI Advanced House | Charlottetown | 13 997 | n.d. | - | Water pump, 10 kW wind | Yes |
| The Envirohome | Bedford | 17 390 | n.d. | - | Water pump | Yes |

11 "A Review of Low and Net-Zero Energy Solar Home Initiatives" Natural Resources Canada. http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/buildings_communities/buildings/pv_buildings/publications/2005133.html

Another reference point is the energy intensity of net zero buildings around the world.

Figure 29: Low Energy International Developments[12]

| Name of Project, Location | Building Type | Year Complete | kWh/ $m^2$/ year including electricity | Notes |
|---|---|---|---|---|
| Västra Hamnen, Malmö, Sweden | Residential | 2001 | 105 | • 100 percent renewable energy supply<br>• waste management system designed to use waste and sewage as an energy source |
| Teri Retreat, Gurgaon, India | Training center | 2000 | 96 | • "Passive" concepts minimize energy demands, such as solar orientation, latticework for shading, insulation and landscaping<br>• space conditioning and lighting demands that are met through energy efficient systems using renewable energy sources. |
| Council House 2, Melbourne, Australia | Office building | 2006 | 35 | • high thermal mass concrete<br>• solar electricity and water<br>• water towers for cooling<br>• green roof space<br>• roof-mounted wind turbines<br>• CH2 will pay for its sustainability features,<br>• worth US$ 9.330 million, in a decade. |

In Canada, CMHC's Equilibrium project showed that it was possible to build net zero energy homes across Canada.[13]

12 Energy Efficiency in Buildings: Business Realities and Opportunities. World Business Council for Sustainable Development. www.wbcsd.org

13 Canada Mortgage and Housing Corporation http://www.cmhc-schl.gc.ca/

Figure 30: Net Zero Energy Demonstration Homes across Canada

| Project Name | Team Name | Location |
|---|---|---|
| Abondance le Soleil | Équipe EcoCité-Sodero | Montréal (Verdun), QC |
| Alstonvale Net Zero House | Sevag Pogharian Design | Hudson, QC |
| Avalon Discovery 3 | Avalon Master Builder | Red Deer, AB |
| Echo Haven | Echo-Logic Land Corporation | Calgary, AB |
| ÉcoTerra™ | Les Maisons Alouette Homes | Eastman, QC |
| The Green Dream Home | Canadian Home Builders' Association Central Interior and Thompson Rivers University | Kamloops, BC |
| Harmony House | Habitat Design + Consulting Ltd. and Insightful Healthy Homes Inc. | Burnaby, BC |
| Inspiration – the Minto ecohome | Minto Developments Inc. | Ottawa (Manotick), ON |
| The Laebon CHESS Project | Laebon Developments Ltd. | Red Deer, AB |
| The Moncton VISION Home | AlternaHome Solutions Inc. and VISION Land Development Ltd. | Moncton, NB |
| Now House™ | The Now House™ Project Inc. | Toronto, ON |
| Riverdale NetZero Project | Habitat Studio and Workshop Ltd. | Edmonton, AB |
| Top of the Annex TownHomes | Sustainable Urbanism Initiative (SUI) | Toronto, ON |
| Urban Ecology | Winnipeg Housing Rehabilitation Corporation (WHRC) | Winnipeg, MB |
| YIPI! Net Zero Footprint Housing | Nexus Solar; and Spruce Home RTM Builders Ltd. | Regina Beach, SK |

Other net zero projects in BC include the Austria Passivhaus, a demonstration home in Whistler, BC, built for the Olympics.

Figure 31: Austria Passivhaus.

This four bedroom home is net zero energy with geo-exchange heat pump, heat-recovery ventilator, triple glazing, "massive wood" construction. Photo credit James Glave.

While it is difficult to get a sense of how many net zero energy homes exist in the United States, there are several signs that the market is at a turning point.

The below list is taken from a report entitled The Potential Impact of Zero Energy Homes, prepared for the National Renewable Energy Laboratory and published 2006. It includes "Building America research homes completed in 2002 and 2003."

- Shea Homes, San Diego (100 of 300 homes)
- Centex Homes, Livermore, CA (1 home)
- John Wesley Miller Companies, Tucson, AZ (99 homes)
- Pardee Homes, Los Angeles, CA (Optional in 4 subdivisions)
- Pardee Homes, Las Vegas, NV (NAHB Show home + optional)
- Clarum Homes, East Palo Alto (20 Homes); Watsonville, CA (250 Homes)
- Morrison Homes, Sacramento, CA (12 Homes)
- Bradley Builders, Long Island, NY (1 Home); Leesburg, VA (1 home)
- Claretian Associates, Chicago, IL (3 Homes)
- Habitat for Humanity, Oak Ridge, TN (5 homes)

Projects in progress include:

- Premier Homes, Sacramento, CA (144 homes)
- Centex Homes, San Ramon, CA (2 models & optional)
- Northern Capital, Inc., San Diego, CA (50 homes)
- Lennar/BVHP, San Francisco, CA (1,600 homes)
- Ponderosa Homes, Pleasanton, CA (1 home)
- Clarum Homes, Menlo Park, CA (20 homes)
- Pardee Homes, San Diego, CA (126 homes)
- Pinnacle Homes, Las Vegas, NV (1 home)
- Western Massachusetts Electric Company (1 home)
- Clarum Homes, Borrego Springs, CA (4 homes)
- Habitat for Humanity, Sacramento, CA (1 home)
- Genesis Group, Atlantic City, NJ (6 homes)
- Austin Department of Housing + utility, Austin, TX (100 homes)
- Veridian Homes, Madison, WI (1 home)
- Grupe, Sacramento, CA (1 home)
- Monley-Cronin, Sacramento, CA (1 home)
- Bentwood Custom Homes, Dallas, TX (1 home)

The U.S. government is encouraging net zero energy homes. For the fiscal years 2008 to 2012, the U.S. Department of Energy plans to award $40 million to four Building America teams and a consortium of academic and building industry leaders. The funds will be used to develop net-zero-energy homes that consume at 50 to 70 percent less energy than conventional homes.[14]

Additionally there are currently 22 homes registered with the Living Building Challenge, which requires net zero energy for those projects attempting full Living Building certification.

14 US Department of Energy, Energy Efficiency and Renewable Energy. http://apps1.eere.energy.gov/news/news_detail.cfm/news_id=11372

## 3. Water System Analysis

The water systems in the Eco-Sense House feature composting (no flush) toilets, rainwater harvesting, grey water re-use, and a living roof.

The composting system that is used for all toilets is a simple bucket system with no plumbing. To avoid smell, a fan ventilates the bucket cabinet. The home owners empty the buckets manually and find that, for a family of four, it takes about 10 minutes a week to clean out the system. Buckets are emptied into a designated humanure compost pile in the yard. The aerobic thermophillic composting process does not produce methane or attract pests.

Figure 32: Water System Overview

| | | |
|---|---|---|
| Water systems | Living roof | Custom design with less manufactured materials (EPDM, armtec 400, perlite, filter cloth, pumice, leaf mulch, native plants and creeping thyme) |
| | Rain water harvesting | 10,000 Gal (37,854 litres) for irrigation of food gardens |
| | Domestic indoor water | Provided by an existing well on site.<br>Water conservation: no flush toilets; low flow fixtures; no bathtubs<br>Water usage is 19.7 litres/person/day<br>Average BC usage is 129.4 litres/person/day |
| | Water and resource recovery | Grey water: filtration of organic solids into worm castings<br>Water re-used for fruit/nut tree irrigation<br>Composting odorless toilet (no water). Based on the Humanure system. |

### Water Systems Performance

All Water systems within the Eco-Sense home have been performing as expected, and the water usage of the home is significantly lower than that of an average home in BC or Canada.

Figure 33: Water Usage table comparing Eco-Sense water consumption with BC and Canada

| June 15, 2010- June 15, 2011 | Total Indoor Water Used | Total Hot Water Used | | |
|---|---|---|---|---|
| Weekly | Gallons | Gallons | | |
| 18-May-10 | | 286 | | |
| 25-May-10 | 387.1 | 211 | | |
| 1-Jun-10 | 349.6 | 178.7 | | |
| 8-Jun-10 | 404.1 | 192.4 | | |
| 15-Jun-10 | 434.3 | 207.8 | | |
| 22-Jun-10 | 137.9 | 64 | | |
| 29-Jun-10 | 335.4 | 158.2 | | |
| 6-Jul-10 | 834.4 | 214.9 | | |
| 13-Jul-10 | 447.4 | 167.2 | | |
| 20-Jul-10 | 450.4 | 145.2 | | |
| 27-Jul-10 | 296.6 | 88.7 | | |
| 3-Aug-10 | 440 | 179.8 | | |
| 10-Aug-10 | 299.8 | 115.9 | | |
| 17-Aug-10 | 463.3 | 195.4 | | |
| 24-Aug-10 | 446.2 | 203.2 | | |
| 31-Aug-10 | 653.8 | 239.7 | | |
| 7-Sep-10 | 428.5 | 172.7 | | |
| 14-Sep-10 | 561.1 | 265.1 | | |
| 21-Sep-10 | 395.3 | 187.2 | | |
| 28-Sep-10 | 286.2 | 145 | | |
| 5-Oct-10 | 193.8 | 60.1 | | |
| 12-Oct-10 | 211.5 | 99.8 | | |
| 19-Oct-10 | 199.9 | 87.8 | | |
| 26-Oct-10 | 423 | 241.7 | | |
| 2-Nov-10 | 465.5 | 242.5 | | |
| 9-Nov-10 | 321.4 | 156.3 | | |
| 16-Nov-10 | 175.9 | 75.5 | | |
| 23-Nov-10 | 268 | 138.5 | | |
| 30-Nov-10 | 173.7 | 91.9 | | |
| 7-Dec-10 | 308.7 | 126.6 | | |
| 14-Dec-10 | 180.9 | 86.7 | | |
| 21-Dec-10 | 280.2 | 122.3 | | |
| 28-Dec-10 | 217.4 | 91.7 | | |

| June 15, 2010- June 15, 2011 | Total Indoor Water Used | Total Hot Water Used | | |
|---|---|---|---|---|
| Weekly | Gallons | Gallons | | |
| 4-Jan-11 | 296.6 | 130.2 | | |
| 11-Jan-11 | 345 | 166.3 | | |
| 18-Jan-11 | 294.9 | 156.2 | | |
| 25-Jan-11 | 253.9 | 114.9 | | |
| 1-Feb-11 | 273.7 | 146.7 | | |
| 8-Feb-11 | 221.6 | 111.4 | | |
| 15-Feb-11 | 316.6 | 164.1 | | |
| 22-Feb-11 | 212.9 | 99.2 | | |
| 1-Mar-11 | 308.2 | 153.9 | | |
| 8-Mar-11 | 153.2 | 97.6 | | |
| 15-Mar-11 | 389.2 | 201.8 | | |
| 22-Mar-11 | 279.4 | 145 | | |
| 29-Mar-11 | 298.1 | 137 | | |
| 5-Apr-11 | 197.8 | 99.3 | | |
| 12-Apr-11 | 412.7 | 176.6 | | |
| 19-Apr-11 | 197.1 | 103.3 | | |
| 26-Apr-11 | 288.5 | 155.8 | | |
| 3-May-11 | 160.4 | 70.2 | | |
| 10-May-11 | 322.9 | 119.8 | | |
| 17-May-11 | 223.7 | 99.8 | | |
| 24-May-11 | 428.3 | 215.4 | | |
| 31-May-11 | 406.8 | 208.9 | | |
| 7-Jun-11 | 372.8 | 202.8 | | |
| 14-Jun-11 | 561.2 | 234.5 | | |
| | | | | |
| Total Indoor for year | 17111.7 | 7674.3 | | |
| per week | 329.1 | 147.6 | | |
| Household per day | 46.9 | 21 | | |
| perperson/day | 9.4 | 4.2 | | |
| | | | | |
| Total Garden Irrigation for year | | | | |
| From Well | 8,906.30 | | | |
| From Rain Water System | 10,000 | | | |
| Total Garden Irrigation | 18,906.30 | | | |

| June 15, 2010- June 15, 2011 | Total Indoor Water Used | Total Hot Water Used | | |
|---|---|---|---|---|
| Weekly | Gallons | Gallons | | |
| Household per day | 10.4 | | | |
| | | | BC | Canada |
| Total water/person/day (gallons) | 19.7 | | 129.4 | 87.2 |
| Litres | 74.57 | | 490 | 330 |

**Living Roof Performance**

The living roof custom design was built with less manufactured materials (EPDM, armtec 400, perlite, filter cloth, pumice, leaf mulch, native plants and creeping thyme). Aside from its aesthetics, it benefits sound insulation, fire resistance, increases roof R-value, reduces roof temperature thereby increasing solar PV production, provides storm water management, and is a mini-watershed for water filtration. The living roof on the home acts as a sponge creating a delayed release during sudden downpours. The drainage layer within the living roof layers directs the water down to four downspouts and thus eliminates the need for gutters or the challenges with keeping gutters clean of debris. Before the rainwater enters the initial collection tanks (4000 gallon) it goes through a leaf and debris filter, which has proved itself very capable of handling large downpours without a problem.

Figure 34: Model of Living Roof Layers

**Rainwater Harvesting system performance**
Rainwater is harvested from the living roof of the house. Due to the vegetation, much of the common requirements of first flush diverters are not required. Water is collected and conveyed through 3 inch ABS pipe, to a debris filter, then into the series of storage tanks.

The two HDPE tanks on the west side of the house tie into the domestic water feed from the well, with a back-flow preventer stopping either from allowing water to flow into the other. In case of well failure this feed can be added on to with appropriate pump, filters and UV sterilizer for potable water usage.

As the two parallel HDPE tanks fill (2000 gallons each), they overflow into a third 2400 gallon concrete cistern located near the septic/greywater aeration tank. As this third cistern fills, it spills into a fourth and final 3300 gallon HDPE storage tank.

Figure 35: Rainwater storage tank

Water distribution: From the two upper HDPE tanks, water is pumped into a pressured distribution system, used to irrigate food gardens. This system is serviced by a 1/2 hp submersible pump and a pressure tank with a pressure switch set for 30-60 psi. The pressure tank bladder is set at 28 psi.

From the Lower 3300 HDPE tank, a gravity fed system services the lower garden.

Water balance: The water balance table shows the monthly breakdown of rainfall, collection and irrigation uses. Another 8,906 gallons of well water was used to supplement the rain water system for garden irrigation, an additional 10,000 gallon cistern is required in order to use only rain water to grow food as the family grows most of their own fruits, vegetables, eggs, and chickens.

Figure 36: Water balance table

| June 2011 to May 2010 | Actual Eagle View weather station (30% less than average) | Average rainfall (Ave. Precip. inches) | Total possible rainfall on roof (gallons) | % run off possible less evaporation from Living Roof (2000 ft$^2$) | Percent saturation of Living Roof (max 1000 g) |
|---|---|---|---|---|---|
| June | 0.72 | 1.2 | 747 | 75% | 25% |
| July | 0.02 | 0.7 | 21 | 0% | 0% |
| Aug | 1.02 | 0.9 | 1059 | 0% | 0% |
| Sept | 3.5 | 1.6 | 3634 | 75% | 25% |
| Oct | 2.62 | 6.2 | 2720 | 85% | 100% |
| Nov | 3.67 | 8.6 | 3810 | 85% | 100% |
| Dec | 6.47 | 8.2 | 6717 | 85% | 100% |
| Jan | 5.62 | 7.6 | 5834 | 85% | 100% |
| Feb | 1.5 | 5.3 | 1557 | 85% | 100% |
| Mar | 2.05 | 4.5 | 2128 | 85% | 100% |
| April | 4.3 | 2.2 | 4464 | 85% | 50% |
| May | 2.56 | 1.5 | 2658 | 85% | 50% |
| | | | | | |
| Total | 34.05 | 48.5 | 35,350 | | |

**Grey water system performance**

The home is serviced with four different grey water systems, with the added flexibility of having all fixtures feed into one main grey water treatment system or diverted into the septic system that was required as part of the permitting process.

The house is plumbed for both black water and grey water. Exiting the home under the west side front door entrance are two pipes, a 4” black water pipe, and a 2” grey water pipe. A diverter valve can divert the grey water into the black water system.

1. Worm Filter System: When the grey water is diverted to the worm bin, (the black water valve closed, grey water valve open), then the grey water flows through the worm bio-filter, is filtered, and then continues on to the bottom of the property to the gardening area where it waters the fruit trees.

2. Storage Tank (black/grey): The installed septic system, though functioning, has been converted to a grey water system, as no black water is created in the home (due to 100 percent reliance on composting toilets). At the diverter valve noted above, the grey water can be diverted into the "black water" infrastructure, thus bypassing the worm bio-filter, (Black water valve open, grey water valve closed). When this is done, grey water travels to the concrete septic storage tanks. In these tanks and aerator provides a continual flow of oxygen to allow the aerobic bacteria to continue digesting food particles in the stored water, thus ensuring it does not go anaerobic. As water volume increases, pumping of the tank is controlled via 2 float switches in the pump chamber. These fluids that are pumped have two pathways they can take: to the predesigned septic field or diverted to grey water distribution of the nut orchard surrounding the chicken coop.

3. Washing Machine: The option exists to isolate the grey water from the clothes washer from the main grey water system via a ball valve under the laundry. When the ball valve is open, water is diverted to the west side of the house via a branch drain system, watering raspberries, plumbs and hazelnuts.

4. Kitchen Sink: Under the kitchen sink of the west kitchen is a gate valve and a bucket. If desired, the gate valve can be opened and all grey water in the sink immediately above will be captured. When the bucket is full, it is taken outside to water potted plants, apples, grapes etc.

Figure 37: Worm filter system

## 4. Policy Overview: Barriers and Opportunities

The Eco-Sense project encountered a variety of policy obstacles and disincentives prior to, during, and after construction. Following is a summary of these challenges firstly within the BC Building Code, then in three major categories—water, energy and materials.

### BC Building Code

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 when they were constructed, but these ancient buildings co-exist beside and among new buildings that have been constructed under modern day regulations.

Internationally, there has been a resurgence of effort to incorporate earthen building systems into the codes and standards. Evidence that earthen homes can perform comparably or better than non-earthen homes includes 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 with comparing cob or other earthen building materials to conventional codes, is that the materials have vastly different qualities and respond differently to moisture and temperature differentials. It is for this reason that codes need to be amended to address earthen construction.

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 of the Eco-Sense house 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 56cm thick, with earthen clay plasters 3cm thick on either side in direct contact with the cob, then an exterior skin of lime plaster 1cm thick; total wall thickness varies but is approximately 63cm (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 wall 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 R-21.6.

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/$m^2$) that they deem acceptable for energy consumption. The code could set out a minimum standard of energy intensity in kWhrs/$m^2$ dedicated to heat inputs to make it easier to determine if the "modeling or energy consumption estimate" are acceptable.

Thermal Insulation with relation to Mass Wall/Dew Point: In BC Building Code 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 reached.

Though cob is vastly different than insulative foam, this study demonstrates that the interior of the Eco-Sense walls, (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 percent can be tolerated. However, if the use of the space is such that indoor RH will be maintained above an average 60 percent 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"

At Eco-Sense, where RH (relative humidity) levels consistently rose to 63 percent, with no condensation, and no significant increase in wall water content (ranged from 1.8 to 2.025 percent), the wall system functioned beyond what the BC Building code could envision.

Insulation Materials 9.25.2.2 – Flame spread: Insulation materials must conform to a variety of standards (e.g. CAN/ULC-S704, CAN/ULC-S706). Many of these ratings address the flammability of insulation products. Cob 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 ex-filtration under differential air pressures, must be continuous throughout the assembly, and must be sealed to where it meets other assemblies (roof, foundation, windows). Of particular weakness in air barriers are protrusions (e.g. 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 discusses 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 its 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. Foundation to cob junctions is of little consequence either 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 (blower door) 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 noted that Eco-Sense 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."

Research by John Straube in Canada and Gernot Minke in Germany found that lime plasters have a permeance rating of 500 ng/Pa s $m^2$ (9 US perms); Straw clay loam (cob) has a permeance of 1088 ng/Pa s $m^2$ (28.4 US perms), and earthen plasters a permeance of 1200 ng/Pa s $m^2$ (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 $m^2$.

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 capilliary breaks between components; this would in essence stop the mass wall from functioning by 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 BC performance, (the Eco-Sense house), demonstrating superior functioning, beyond the descriptions as laid out in the BC Building code.

Summary of Building Code: The building code looks at individual components as a parts of the larger systems. Its metrics specify individual requirements, yet fail to provide overall performance standards. This is evidenced by the absence of recommended energy intensities required for space heating, or whole house air leakage guidelines. The code fails to recognize traditional materials use metrics that do not apply to earthen building systems.

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.

## Water Systems

Composting Toilets: Eco-Sense's simple no-flow composting toilet is a bucket with no water entering and no drain. It is not considered a plumbing fixture, so the BC Plumbing Code does not apply. There are currently no policy laws against this type of toilet. It is incumbent upon the homeowner to demonstrate that the safety and objectives of the code are met for waste disposable.

Though there are no policies preventing composting toilets such as this, there are financial disincentives for using this water saving technology. To comply with code, Eco-Sense was required to purchase and install a low flush toilet, flush it once, then remove it. Also, at the time of the toilet installation, the Capital Regional District provided rebates for replacing older high flow toilets with low flow fixtures (this rebate plan sunset in December 2009). There was no similar incentive for a no-flow toilet.

Grey water: As of January 2011, British Columbia is the only Canadian province to have enacted a reclaimed water standard (Municipal Sewage Regulation) for limited applications, including toilet flushing and irrigation. The standard addresses reclaimed water from municipal sewage treatment, but not the use of domestic reclaimed water where a home or cluster of homes could reuse non-potable water on-site.

The Eco-Sense project was allowed to install a grey water system with the proviso that the home must be able to connect to an approved "waste treatment" system in case of system failure and/or to protect future owners. Since the completion of their system, the home-owners have offered classes and guidance on the installation of small-scale grey water systems. The popularity of these education services demonstrates strong public interest, at least locally, in more grey water use.

## Energy Systems

Eco-Sense collaborated with the BC Sustainable Energy Association (BCSEA) to identify specific barriers to the development of small-scale renewable energy systems in BC. "Most of these result from attitudes, regulations and criteria from the past era of abundant cheap hydropower being applied to the new renewable energy technologies, creating a 'bad fit'."

1. The disproportionately high cost of Electrical Code permitting for renewable energy systems.
2. Lack of renewable energy training for BC Safety Authority Inspectors
3. The limitations of Canadian Certification Standards

4. Excessive service size requirements for renewable energy sites
5. The lack of renewable energy training for electrical engineers and electricians. The loss of PST exemptions
6. Excessive BC Hydro manual disconnect requirements
7. Excessive municipal tax assessments on renewable energy
8. Lack of integrated design requirements for Remote Communities Electrification
9. Expensive red tape in renewable energy planning & approvals

In their document, "Ten Barriers to Small Scale Renewable Energy," BCSEA recommends that the provincial government establish a Small-Scale Renewable Energy Barriers Working Team to "examine the barriers, evaluate possible solutions, and give consistent leadership until they have been resolved."

Six of the ten (numbers 1, 2, 3, 4, 6 and 8) barriers listed above apply specifically to the Eco-Sense project.

*The Disproportionately High Cost of Electrical Code Permitting for Renewables*
The cost of electrical code permitting is set as a percentage of the net installation cost. Renewables have a big upfront cost, followed by decades of free energy, so this approach makes permitting for renewable energy proportionally far more expensive than for non-renewable systems.

*Lack of Renewable Energy Training for BC Safety Authority Inspectors*
BC's Safety Authority Inspectors do not receive specialized training in renewable energy, and this results in different inspectors giving contradictory rulings, or turning down an installation that has been previously approved by another inspector. An example of misinformation that could be avoided by specialized training occurred when a building official told the home owners that the law required them to connect with the electrical grid. This was inaccurate.

*The limitations of Canadian Standards*
A variety of international safety standards address electrical equipment, including renewable energy systems, but BC only recognizes one standard. The Canadian Standards Association (CSA) is a not-for-profit membership-based association. Product approval can be very slow and expensive, causing manufacturers to forgo the certification to enter the Canadian market. This lack of certification limited the choices for the refrigerator and lights. The certification system also impacted their solar thermal water heating system. The high efficiency evacuation tubes and the combined system were not addressed under the CSA system and were technically illegal to use. The home owners wrote a six page "alternate solution" that was presented to the body of South Island Plumbing Inspectors for review. The alternate solution, which included the non-CSA tubes and combined system, was ultimately accepted.

BCSEA suggests that BC recognize other widely accepted certification standards and accept equivalencies between standards, making it easy for renewable system manufacturers to sell in BC.

*Excessive service size requirements for renewable energy sites*
The size of an electrical service (e.g. 200 or 400 amps) is based on the square footage of a building. Green homes like Eco-Sense require much less energy use. BCSEA suggest that the Electrical Code allow smaller electrical services to such homes, to reflect the reduced demand.

*The loss of PST exemptions*
For the past few years and until July 2010, solar panels, wind generators and micro-hydro turbines and associated components benefited from a 7 percent PST exemption in BC. The loss of this exemption with the transition to HST causes an instant price increase for renewable energy installations like the one at Eco-Sense.

*Excessive municipal tax assessments on renewable energy*
The BC Assessment Authority taxes a property on its market value. When an owner adds photovoltaics (PV) or solar hot water, the valuation and assessment is increased accordingly, using a formula designed to mirror the supposed increased value of the property.

Eco-Sense installed a 2kW solar PV system and a solar hot water system. The PV generates 2400 kWh a year, and the solar hot water saves 2500 kWh a year. Due to the added value, their property taxes have been increased by $400 annually, which will cost them $10,000 over the life of the systems. This financial disincentive for energy conserving systems should be addressed by the Ministry of Finance.

## Sustainable Materials

Under the Homeowner Protection Act (HPA), registered contractors must possess Home Warranty insurance. This insurance is a prerequisite for the issuance of a license by the Home Protection Office.

Due to the high cost of insurance and the as yet uncommon practice of using cob construction, few contractors carry Home Warranty insurance for this technology, greatly limiting the use of cob by commercial builders. The HPA requirement does not apply to owner builders, but is a clear barrier to expanded use of this sustainable material.

Critical stakeholders: There is a growing interest in green building, with special interest in the construction of sustainable and affordable homes. The following stakeholder groups have demonstrated interest in the Eco-Sense project and provide opportunities and guidance for dissemination of this report and other information on the construction and operation of deep green homes.

1. Municipal Building Officials – charged with permitting buildings and systems and seeking examples of local successful implementation.
2. Planners and CAO's (other municipal staff tasked with reducing GHG's and water conservation strategies) – seeking to meet Provincial requirement to reduce GHG's and increase local water and energy resiliency.
3. Regional Districts – also seeking to reduce GHG's and increase local water and energy resiliency.
4. Educational Institutions (post secondary) – system integration, observing implementation of studied theories.
5. Provincial policy analysts – interested in addressing barriers to net zero homes.
6. Lending institutions – interested in how to finance homes, including those with alternative materials and high building performance.
7. Insuring institutions – ties in with lending institutions. Creation of actuarials with science based data.
8. Building trades – desire to learn systems (energy and water) and construction methods.
9. Designers – interested in form, structural and mechanical systems and scalability.
10. Owner Builders –interested in replicating or adapting techniques and technologies.
11. Citizens – general interest in climate adaptation and sustainability.
12. Students – looking for role models and future opportunities in green building.
13. Sustainable Energy Groups – interested in data on technology and performance.
14. Permaculture groups – interested in integration of systems to create a "living building."
15. Local economic groups (re-localizing) – Inspiration. Interested in production of local materials and the development of affordable housing.
16. Politicians – interested in cutting edge projects within their jurisdictions and advancing policies that promote sustainability.

## 5. Lessons learned

A year's worth of study produced an enormous amount of data and there is more that can be examined such as thermal conductance qualities of the cob walls.

What has become clear is that a conservation lifestyle and occupancy rates together play the biggest role in reducing the energy intensity within the household. Other research that can be pulled from the data set in the future include:

- Applicability of earthen architecture for affordable housing both on initial costs, system maintenance, and full lifecycle costs.
- Relationship between R value and moisture
- Specific recommendations for the Building Code for creation of guidelines for earthen architecture resulting from the drastically different and opposing metrics that apply to earthen wall systems
- Future modeling to incorporate solar hot water for space heating of both earthen and conventional wall systems.
- Applicability of using earthen components in conventional homes to address moisture control
- Documentation for the Home Warranty providers, enabling builders to contract new builds
- Direct application potential of integrating sustainable energy systems into earthen architecture for adaptation to Climate change
- Long-term health benefits of indoor air quality within an earthen home as it relates to the human respiratory system, household air borne pathogens, dust control, and dramatically reduced toxic off gassing from manufactured products.
- Full lifecycle cost analysis for human health, embodied carbon footprint, operational carbon footprint, and eventual deconstruction costs.

Some of the major lessons learned are:

1. Higher density living arrangements within a single family home promote decreased energy intensity overall.
2. Equal emphasis should be placed on occupant lifestyle **and** building envelope performance in regards to energy performance. The lifestyle of the inhabitants is connected to the performance of the building.
3. Equal emphasis should be placed on embodied energy for construction **and** operations over the expected lifespan of the building.
4. The earthen architectural method utilized for Eco-Sense requires a very similar amount of energy to heat compared to the average house in an average year.
    a. However, it has been demonstrated the importance of building such an earthen home in the full sun
    b. It is essential to incorporate passive solar features into the design.
    c. It is beneficial to increase the thermal performance of the north walls.
5. Green House Gas reduction possibilities for the Eco-Sense home include:
    a. atGHGe's for space heating could be reduced by installing an air to water heat pump instead of the wood gasification boiler. A heat pump (with a COP of 4.5) could reduce the energy intensity of the space heating from the 20890 kWhrs down to 4700 kWhrs, but would require 200 percent more solar panels (thirty-two 170 Watt) with a current value of $16,000.
    b. tGHGe's from cooking could be reduced by removing the propane ranges and replacing with electric. This would require an addition of 50 percent more solar panels (eight 170 Watt) at a cost of $4,000.
6. Eco-Sense could be an affordable net zero energy home:
    a. Addition of forty 170 Watt solar panels would decrease the annual carbon emissions of the home to zero, and thus make it truly a net zero energy home that uses no carbon emitting sources of energy.
    b. Total costs of these additions would equate to approximately $40,000 (heat pump, solar panels, mounting hardware, additional inverter, and professional install). Total cost per square foot would increase to $164/ $ft^2$.
7. Local Resiliency: The reliance on technology may decrease resiliency in the face of technological failure, and lower tech solutions are easier to repair and less costly to maintain.
8. Climate change: If the weather anomaly experienced for the duration of this research (June 15, 2010 to June 15, 2011) is any indication of insolation patterns to be expected in the future, it will become increasingly important to optimize passive solar design and size active solar installations appropriately and not to base these on past normals.

## 6. Appendix

See attached document