THE FACTOR 9 HOME: A NEW PRAIRIE APPROACH MONITORING FINAL REPORT

Revision 1

Prepared for:

John Gusdorf
Natural Resources Canada

By

Rob Dumont
Building Performance
Alternative Energy and Manufacturing Division

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Saskatchewan Research Council
15 Innovation Boulevard, Saskatoon, Saskatchewan S7N 2X8
306-933-5400

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EXECUTIVE SUMMARY

The Factor 9 Home: A New Prairie Approach is a demonstration project of a single family residence located in Regina, Saskatchewan, Canada, that features very high levels of energy efficiency and environmental performance. The home was completed in April 2007.

Energy and water savings targets were established for the Factor 9 Home. The Factor 9 Home was targeted to use a factor of nine times less energy per square metre of floor area than the average existing home in Saskatchewan (circa 1970). The resulting energy target is 30 kWh/m^2 per year (108 megajoules/m^2-year) of total purchased energy consumption.

Over the one year monitoring period from June 1, 2007 to May 31, 2008 the measured consumption was 33.1 kWh/m^2, which is about 10% higher than the energy target of 30 kWh/m^2. For comparison purposes, a monitored group of 1970 to 1973 homes in Regina had a measured annual consumption of 331 kWh/m^2 or 10 times as much energy use per unit floor area. Two additional energy conservation measures are recommended for the house: RSI 1.8 insulation should be added to the wood truss basement floor, and additional insulation should be added to the thermal storage tank for the active solar heating system. With these measures, the annual energy consumption for the house is projected to meet the 30 kWh/m^2 target.

Another numerical performance target for the home is a Factor 2 reduction in purchased water consumption from the utility compared with conventional homes. The house was also able to meet the water target.

For a family of four persons, the average water consumption in Canada is 501 cubic metres per year. For the one year monitoring period, the measured water consumption of the home was 171 cubic metres, a reduction in purchased water use of 66%. In the monitored year, the total precipitation was less than half of the long-term average of 388 mm for Regina, reducing the amount of water able to be gathered by the roof collection system. The exterior landscaping for the home was not completed during the one year of monitoring.

The major technical approaches used to develop the Factor 9 Home were Integrated Design and Value Engineering.

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1.0 INTRODUCTION AND BACKGROUND

The name “Factor 9” for the demonstration project was developed for the following reasons. World population is expected to increase from current levels by about a factor of 1.5 before stabilizing. Material consumption per average person in the world is expected to increase by a factor of about 3 from current levels before stabilizing. Climate scientists have called for a reduction of current greenhouse gas emissions by about a factor of at least 2 from current levels. If these three factors are multiplied together, the number 9 results. Hence the Factor 9 energy target for this demonstration house was developed.

The lot was chosen so as to have the rear of the house face south for passive and active solar gain. The lot address is 7335 Wascana Cove Place in Regina, Saskatchewan. The subdivision chosen is a new area in the city that has access to public transport. The topography is very level. To reduce water runoff from the roof, rainwater and melted snow water from the roof are stored in two 9500 litre storage tanks in the crawl space beneath the basement floor. This non-potable water is used for toilets and exterior water usage. Landscaping was designed to reduce the need for water.

The house features a very energy conserving envelope, with attic insulation levels of RSI 14.1 (R80), above grade walls of RSI 7.2 (R41), and basement wall insulation levels of RSI 7.7 (R44). At the rim joist area, the insulation level is RSI 4.7 (R26.9). The building was well sealed, with a measured air tightness level of 1.2 air changes per hour at 50 pascals, which is tighter than the R-2000 standard of 1.5 ac/h at 50 Pa.

Passive solar heating was used to provide part of the space heating (passive is projected to provide 41% of the total annual space heating requirement). Active solar heating is used with 20.4 square meters of double glazed vertical solar panels mounted on the south wall of the house. The south wall faces 26 degrees east of due south. A 2350 litre water storage tank in the basement is used to store the heat from the solar panels. To distribute the space heating for the house, a fan coil with brushless direct current motors is used.

The active solar panels are used to provide part of the domestic water heating. A passive drain water heat exchanger is used to preheat the domestic hot water prior to the solar storage tank. An instantaneous electric heater is used to provide the auxiliary energy needed for domestic water heating.

To provide mechanical cooling in the summer, a network of plastic pipes was installed in the 22 of the 33 concrete pilings in order to extract cooling from the ground. The approximate annual ground temperature at the base of the pilings is about +5 C. The water in the plastic pipes can provide space cooling for the house. The same fan coil used for space heating is also used for space cooling.

Energy efficient lights and appliances are also used. Energy StarTM appliances and compact fluorescent lamps are mostly used in the house.

2.0 DESCRIPTION OF HOUSE FEATURES

2.1 Foundation

Regina has active clay soils that shrink and swell greatly under varying moisture conditions. To limit movement of the house and garage and greatly improve durability, 33 concrete pilings 4.6 metres deep have been used for the foundation. A concrete grade beam sits on the pilings.

A photo of the basement excavation, taken in May 2006, is shown in Figure 1.

Figure 1: Basement excavation and drilling of the piles for the home

Placement of the cooling pipes in the piling holes. Figure 2 shows the steel rebar along with the plastic cooling pipes.

Figure 2: Rebar and plastic cooling pipes for the pilings

A photo of the tops of the concrete pilings is shown in Figure 3. The orange plastic pipe is visible at the top of each pile. A total of two loops of plastic pipe were placed in each of the piles to extract cooling.

Figure 3: Leveling of the piling caps

A concrete grade beam was placed on top of the pilings, and a wood truss floor used for the basement floor. A picture of the wood floor is shown in Figure 4. Some of the basement walls have been put in place. A generous crawl space is placed beneath the basement floor. Two membrane tanks have been placed in the crawl space for storage of water collected from the roof.

Figure 4: Basement floor with wood trusses

2.2 Envelope

The basement walls are structural insulated panels with polyurethane foam between the inner skin of oriented strand board and the outer skin of pressure treated plywood.

A picture of the basement walls being assembled is shown in Figure 5. The canvas straps are used to pull together the panels.

Figure 5: Concrete grade beam and the SIPs for the basement walls

Another view of the basement walls and floor is shown in Figure 6. The window opening in the foreground is on the south side of the house.

Figure 6: Basement walls and floor for the house

Structural insulated panels were also used for the main floor of the house. A view of the main floor walls is shown in Figure 7. The blue material on the basement walls is a peel and stick waterproofing membrane. Granular material was used as backfill for the basement walls to help avoid soil pressure loads from the expanding clay soil. High heel roof trusses were used to help accommodate the high attic insulation levels.

Figure 7: View of the house from the south

A cross section of the construction of the walls of the house is shown in Figure 8. The basement walls use structural insulated panels. The middle rim joist area uses an insulated rim board. The upper walls are also structural insulated panels. The exterior of the house is clad with an insulating brick product.

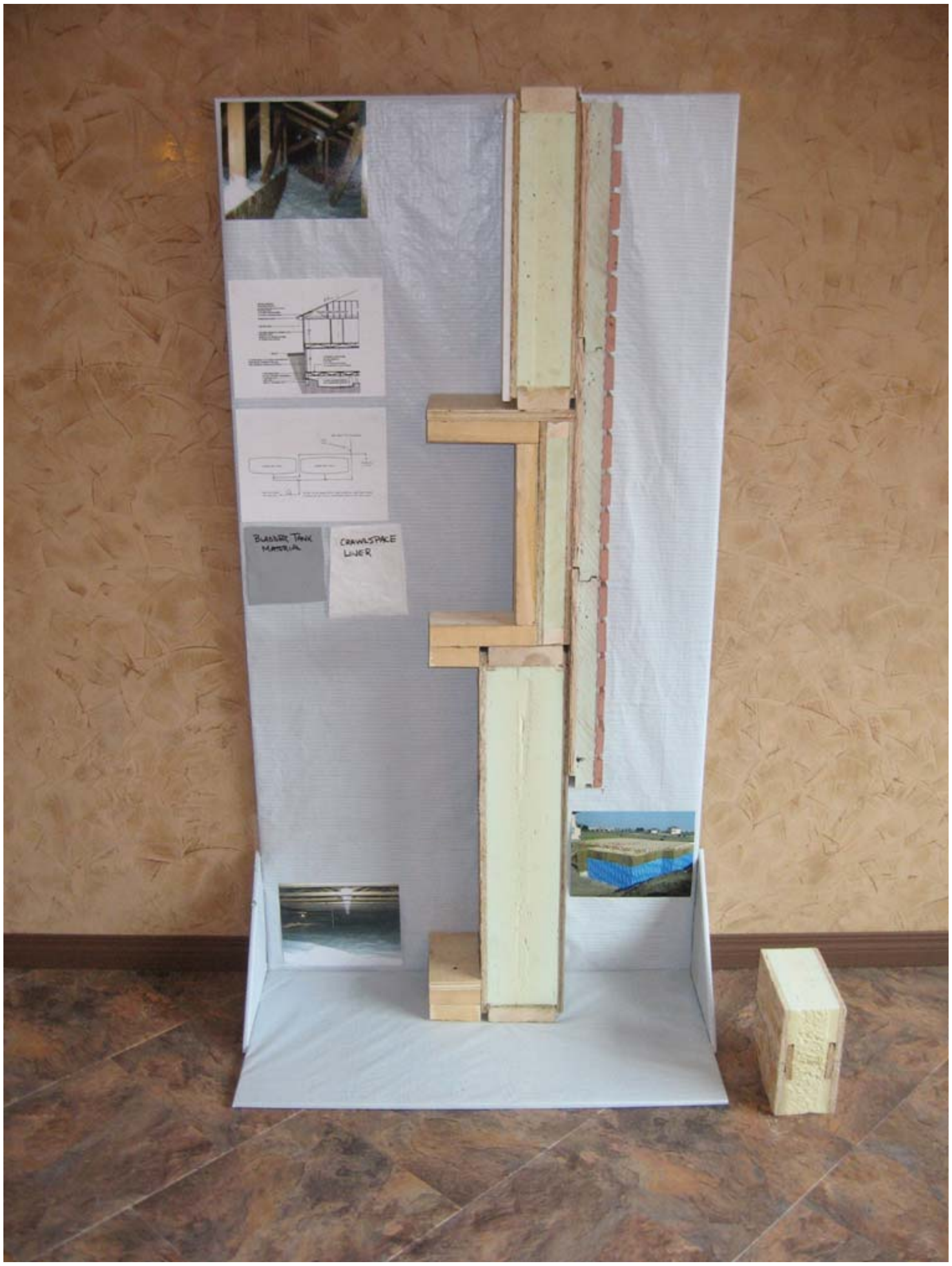

Figure 8: Cross section of the wall construction for the house

A view of the house near the completion of the framing stage is shown in Figure 9. This photo was taken August 6, 2006.

Figure 9: View from the southwest as framing is nearing completion

The exterior cladding of the entire house and garage is an insulated brick product. A photo of the brick is shown in Figure 10. The garage door is on the left.

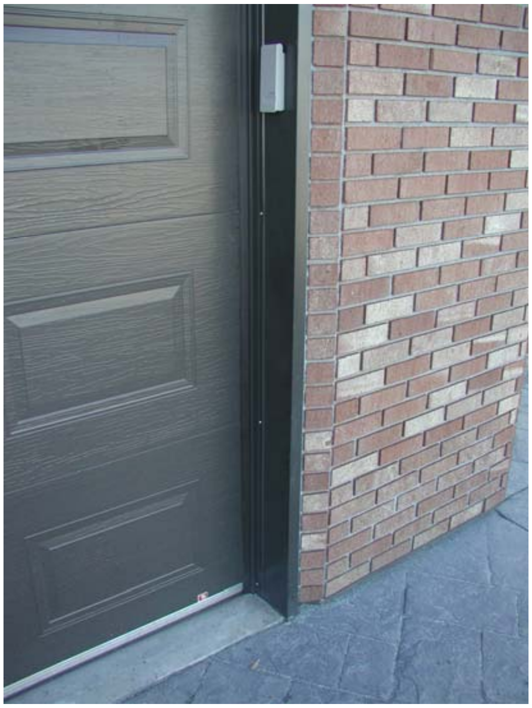

Figure 10: View of the insulating brick product on the front of the garage

Upgraded asphalt shingles were used on the roof. A picture is shown in Figure 11. The asphalt shingles have been installed, along with the windows and exterior insulating brick.

Figure 11: View from the north of the house

A photo of a window installed in the East bedroom is shown in Figure 12. The East, West and North facing windows are triple glazed with two low emissivity coatings and argon gas fill. The windows have wood frames with aluminum cladding on the exterior for low maintenance.

Figure 12: Window installed in an east-facing wall

A view of the inside of the windows is shown in Figure 13. These windows are in the basement in the approximate middle of the south wall. Note the wood frames for the windows.

Figure 13: South facing windows in the basement of the house

2.3 Heating System

The active solar heating panels were installed on the south wall of the house. A view of the south is presented in Figure 14. The active solar heating panels are being installed in a horizontal band between the lower windows in the basement and the windows on the main floor. Two of the glass cover plates for the solar panels are visible on the right of the wall.

Figure 14: View of the south side of the house

A closer photo of the active solar heating panels being installed is shown in Figure 15. The absorber plates are mounted on the vertical. Double glazing was used.

Figure 15: Active solar heating panels being installed

The space heating for the house is provided by a combination of passive solar heating, internal heat gains from electricity use and occupant heat, and an active solar space heating system. When additional heat is required, plug-in electric heaters are used. The house also has a high efficiency wood burning fireplace that also can be used to heat the house, but was used only occasionally during the monitoring period.

A photo of the storage tank for the active solar heating system is shown in Figure 16. This 2350 litre tank is a recycled stainless steel tank originally used in a brewery. The lower part of the tank has a dimpled appearance. This lower part is the external heat exchanger on the tank through which the propylene glycol and water mixture passes.

Figure 16: Stainless steel heat storage tank

The water in the tank is not used directly for hot water in the house. An immersed copper coil heat exchanger is used to transfer heat from the water in the large storage tank to the potable hot water. This copper coil heat exchanger is shown in Figure 17. The tank and heat exchanger were used to transfer heat from the water in the large storage tank to the potable hot water. The small tank was not hooked up. The large coil is used to ensure relatively good heat transfer from the water in the large tank.

Figure 17: Small stainless steel tank and copper coil heat exchanger

A drain water heat exchanger is used on the house to recover heat from the drain water from the fixtures on the on the main floor. A photo of the copper heat exchanger is shown in Figure 18. This unit recovers heat that normally would flow down the drain. If there is insufficient heat in the potable hot water after passing through the waste water heat exchanger and the solar storage tank heat exchanger, the water temperature is raised by an instantaneous electric heater.

Figure 18: Copper waste water heat exchanger for the house

A picture of the instantaneous water heater used during the monitoring period is shown in Figure 19.

Figure 19: Instantaneous water heater

To provide space heating for the house, a fan coil incorporating a water to air heat exchanger is located adjacent to the large storage tank in the basement. A picture of the fan coil is shown in Figure 20. The fan coil is shown on the left. It takes hot water from the large storage tank and uses the hot water to provide space heating through a forced air system. The fan on the forced air system is a brushless direct current motor. The fan coil can also take cooled water from the pilings beneath the house and use this cooled water for space cooling.

Figure 20: Fan coil

2.4 Roof Water Collection System

To reduce water consumption, the house has low flow shower heads, a front loading clothes washer, a water efficient dishwasher, and water efficient landscaping.

To further reduce purchased water consumption, water is collected from the roof and stored in membrane storage tanks beneath the basement floor. A cross section of the house showing the location of the water storage tanks is shown in Figure 21.

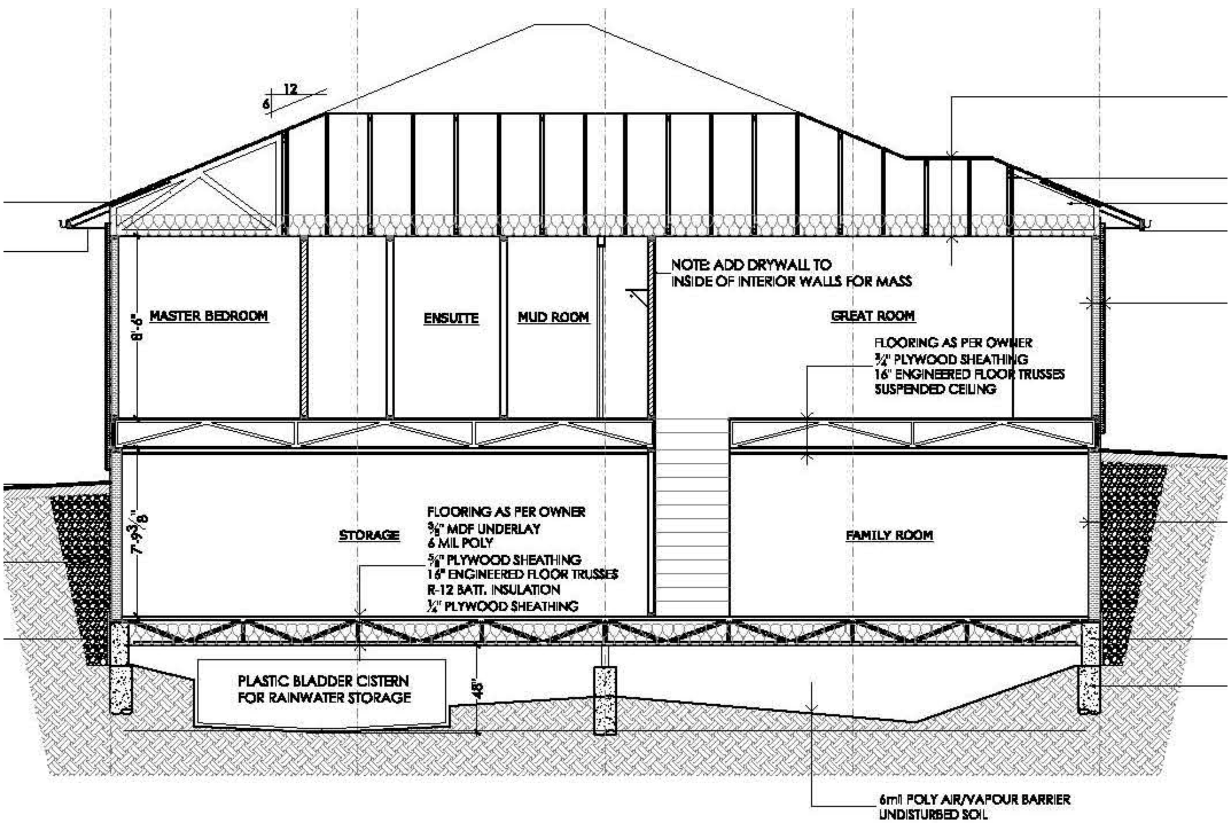

Figure 21: Cross section of the house

Figure 21 shows the location of the plastic bladder cisterns (19,000 litres total volume) for rainwater storage in the crawl space. The water collected from the roof is used for two purposes: toilets and exterior landscape watering, neither of which uses require potable water.

A photo of the pump that is used to lift water from the cistern to the end uses is shown in Figure 22.

Figure 22: Water pump to supply the toilets and the exterior landscaping

2.5 Roof Slope for Future Photovoltaics

Because of the relatively high cost of a photovoltaic system (approximately $50,000), no attempt was made to use a grid connect PV system. The roof slope on the south side of the house, however, is suitable to add photovoltaic panels at a later date when costs are lower. An electrical wire was put in place into the attic to facilitate the future hookup of such a roof mounted PV system.

2.6 Appliances

Appliances chosen for the house are Energy Star rated where applicable. The major appliances have the following Energuide Ratings:

Appliance	kWh/year
Dishwasher	242
Clothes Washer	247
Refrigerator	372
Freezer	479
Electric Range	453
Clothes Dryer	937

A voltage lowering device called the Green Plug ™ is used on the upright freezer to further reduce consumption. (The Green Plug was tried on the Refrigerator, but was not successful. When the Green Plug was used, a rapid cycling noise was heard coming from the refrigerator. It is likely that the refrigerator already incorporates a voltage lowering device.)

To assist the occupants to determine instantaneously their use of electricity, an innovative device called The Energy Detective™ is used. This device, which is connected to the main electrical panel, has a readout device that can be plugged into any outlet in the house. It gives an instantaneous readout of the electricity use in the home in both kilowatts and $/hour. Studies on the device have shown that it can reduce electricity use by about 10% to 15% compared with a group of homes that do not use the device.

2.7 Lighting

Almost all of the light fixtures in the home use compact fluorescent lamps. Figure 23 shows the kitchen/dining area fixtures with compact fluorescent lamps installed.

Figure 23: Light fixtures in the kitchen/dining area

Halogen lamps were used over the kitchen cabinets (as shown in Figure 24), as compact fluorescent lamps were not available in this style. Light-sensing light emitting diode (LED) lamps were used on the risers of the staircase between the main floor and the basement.

Figure 24: Halogen lamps over the kitchen cabinets

2.8 Indoor Air Quality

The three basic approaches being used to ensure good indoor air quality are to reduce avoidable interior sources of off-gassing, to provide clean outside air, and to use a continuous mechanical ventilation system with heat recovery. The use of a buried ground tube to preheat ventilation air was considered, but potential problems with condensation and mould growth in the buried tube led the design team to avoid this approach.

An innovative ceramic-topped but flexible floor tile is used in a large part of the living area of the main floor (see Figure 24).

An air to air heat exchanger (heat recovery ventilator) with low energy brushless direct current motors is being used. On low speed the wattage draw of the unit is 55 watts. The unit is located near the east wall to minimize energy losses in the ducts between the air exchanger and the outside. A continuous air flow of about 30 litres/second is used in the house, which has four occupants, two adults and two children under the age of nine. The flow rate can be increased for short periods of time using timer switches located in the kitchen and bathrooms.

2.9 Commissioning

The following commissioning was done:

1. Building envelope air tightness
2. Commissioning of space heating system and controls
3. Commissioning of monitoring system
4. Commissioning of the pump for the roof rainwater collection
5. Commissioning of toilet water consumption

3.0 MONITORING

3.1 Monitoring Plan for Energy and Indoor Environmental Quality

A computer based data logging system manufactured by National Instruments is used for continuous measurements of temperatures, solar radiation, energy flows, water flows, carbon dioxide levels, and relative humidity in the house. The system is web-enabled for off-site data access.

A schematic of the monitoring points for the house is shown in Figure 25.

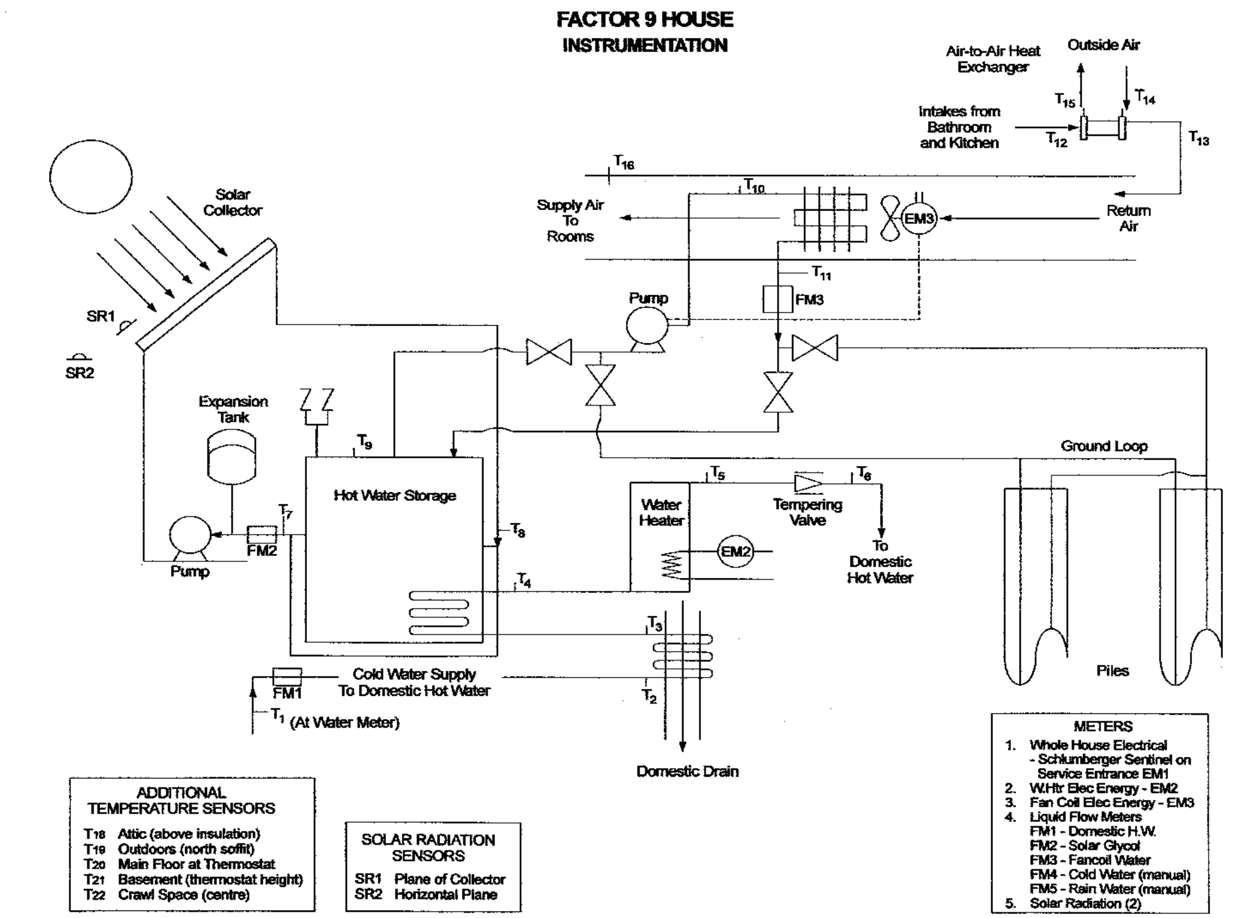

Figure 25: Monitoring points

Continuous measurements were made of carbon dioxide levels in the house, along with the interior relative humidity. In addition, spot measurements of volatile organic compounds, and radon were taken.

3.2 Monitoring Results

3.2.1 Outdoor Conditions

A graph of the outdoor temperature measured at the house for the period from May 26, 2007 to June 23, 2008 is shown in Figure 26. This temperature was measured on the north side of the house under the soffit.

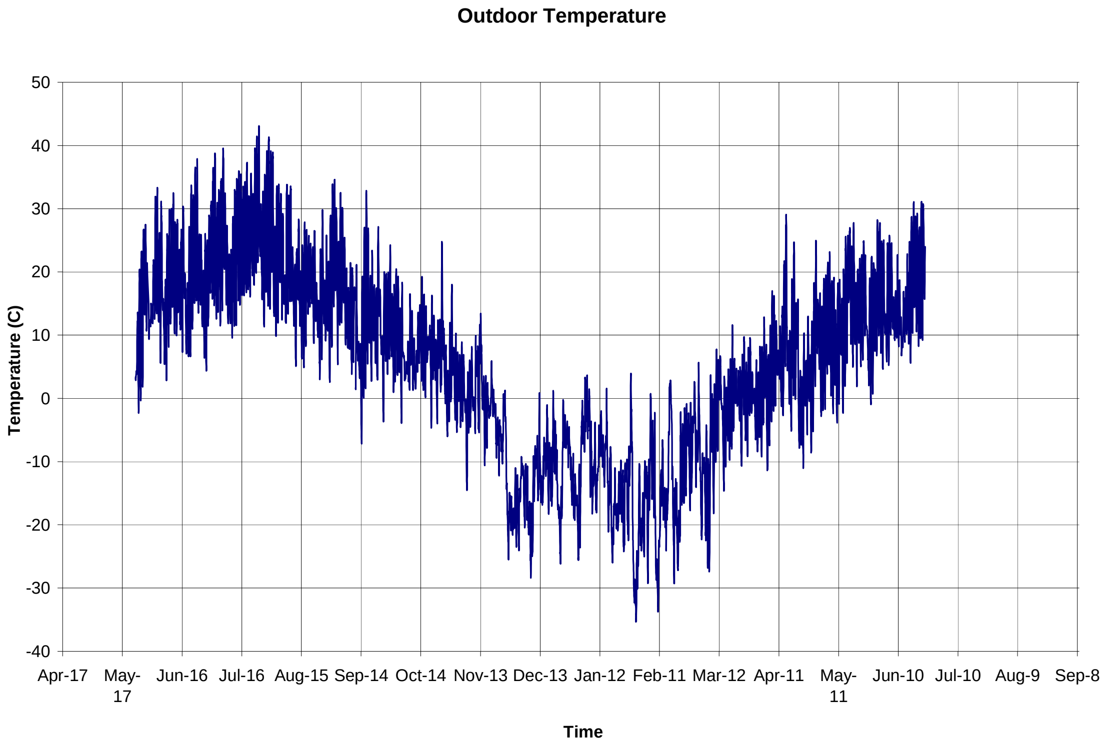

Figure 26: Outdoor air temperature measured at the Factor 9 Home

Over the monitoring period, the peak outdoor temperature reached was +43.0 C on July 24, 2007 at 17:00. The minimum outdoor temperature reached was -35.2 C on January 30, 2008 at 7:00.

Over the 12 month period from June 1, 2007 to May 31, 2008, a total of 5844 heating degree days (base 18 C) accumulated and a total of 199.2 cooling degree days (base 18 C) accumulated. This data for heating and cooling degree days was taken from the Environment Canada web site data for the Regina airport.

These values are compared to the long term averages in the following table.

Table 1: Long Term Averages

	June 1, 2007 to May 31, 2008 Values	Long-Term Average (1971-2000)	Ratio of Measured to Long-Term Average
Heating degree days (base 18 C)	5844	5661	1.032
Cooling degree days (base 18 C)	199.2	145.9	1.365

3.2.1.1 Solar Radiation

Solar radiation values were measured on two planes—the horizontal, and the vertical facing 26 degrees East of South. New photovoltaic based sensors (Li-Cor) were used. These had been factory calibrated.

The hourly horizontal radiation is shown in Figure 27.

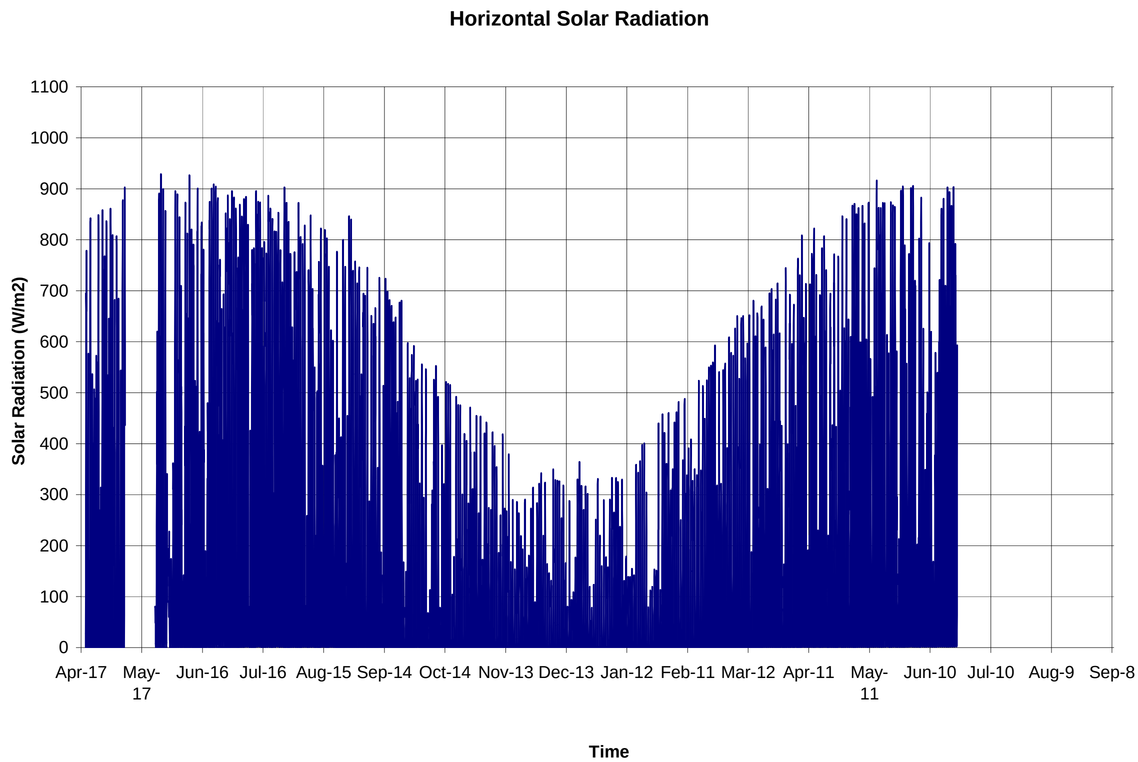

Figure 27: Solar radiation measured on the horizontal

As can be seen from the figure, the peak solar radiation on the horizontal occurs in the summer period, and the lowest daytime peak solar radiation values occur in the winter. The horizontal solar radiation value peaked at a value of 929 watts/m^2 on May 26, 2007. As can be seen, the solar radiation values during the daytime were lowest in the winter months and peaked in the summer period. During the months with snow, the solar radiation sensor, which was mounted at the height of the eaves-trough, was not always clear of snow. Thus the horizontal solar radiation values shown in the graph will slightly underestimate the annual solar radiation during winter months.

The vertical solar radiation values are shown in Figure 28. The sensor was oriented in line with the vertical solar panels on the back of the house. The back of the house faces 26 degrees east of south.

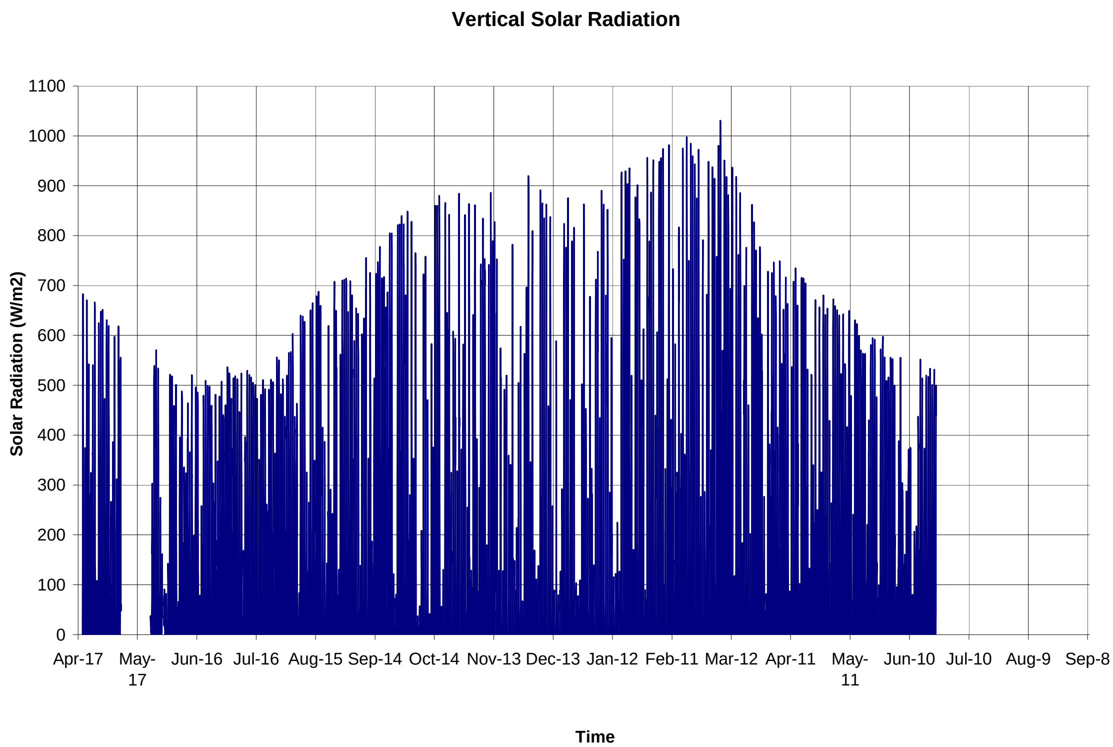

Figure 28: Solar radiation on the vertical south face (26 degrees E of S)

With the vertical orientation, the incident solar radiation was lowest in the summer period.

The peak hourly solar radiation on the vertical surface of 1031 watts/m^2 occurred on March 6, 2008 at 12:00 noon. At that time of the year, the moisture in the atmosphere is lower and the solar transmittance of the atmosphere is high.

Over the 12 month period from June 1, 2007 to May 31, 2008, the cumulative incident solar radiation values as measured by the photovoltaic solar radiation sensors were as follows for the two orientations:

Table 2: Cumulative annual solar radiation on the horizontal and vertical sensors over a one year monitoring period

Orientation	Measured solar radiation values (June 1, 2007 to May 31, 2008) gigajoules/ m^2	Ratio Vertical/Horizontal
Horizontal	4.57	
Vertical	3.92	0.86

To determine the cumulative annual solar radiation values, the hourly values in watts per square metre were summed and converted to gigajoules per square metre. As can be seen, the measured solar radiation value for the horizontal orientation was 4.57 GJ/m2. For comparison, the long term data from the RETSCREEN computer program is 5.22 GJ/m^2. The measured value amounted to 87.5% of the RETSCREEN long term value.

The solar radiation measured on the vertical surface was 3.92 GJ/m^2. For comparison purposes, the RETSCREEN long term value for this surface is 5.44 GJ/m^2. The measured value amounted to 72.1% of the RETSCREEN long term value.

The optimum tilt angle with respect to horizontal for greatest annual solar radiation collection in most locations in the world is equal to the latitude angle, which is 50.4 degrees in Regina. For house space heating, however, a tilt angle of about 70 degrees results in a value which is near the optimum. Had the solar panels been mounted at a 50.4 degree angle, the available annual solar radiation would have been 6.66 GJ/m^2, according the RETSCREEN long term data. At an angle of 70 degrees, the available annual solar radiation would have been 6.30 GJ/m^2 according to the RETSCREEN long term data.

For appearance reasons, the solar heating panels on the Factor 9 home were mounted on the vertical south face of the house.

3.2.2 Interior House Conditions

The temperatures measured on the main floor of the house at the room thermostat location in a hallway are presented in Figure 29. The main floor temperature was not set back regularly during the day or night. The maximum indoor temperature of 27.4 C was measured at midnight on July 24, 2007. The outdoor temperature peaked at 43.0 C at 17:00 hr on July 24. The house does have a cooling system consisting of plastic pipes embedded in the concrete piles and grade beam. This chilled water is circulated through a fan coil, which distributes the cooling to the house via an air system.

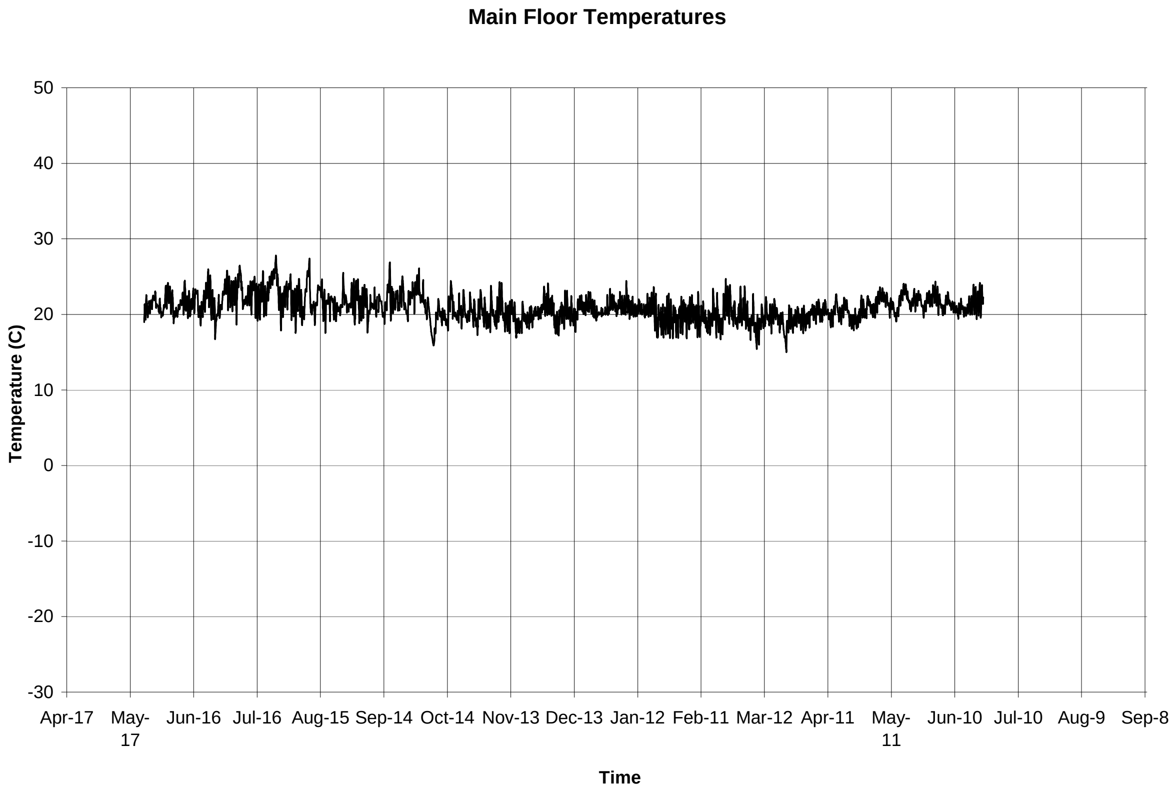

Figure 29: Main floor temperature in the Factor 9 Home

The minimum main floor temperature measured was 15.7 C at 10:00 on March 22, 2008.

The temperatures in the basement are shown in Figure 30. The basement area of the house was not finished during most of the monitoring. No one lived or slept in the basement.

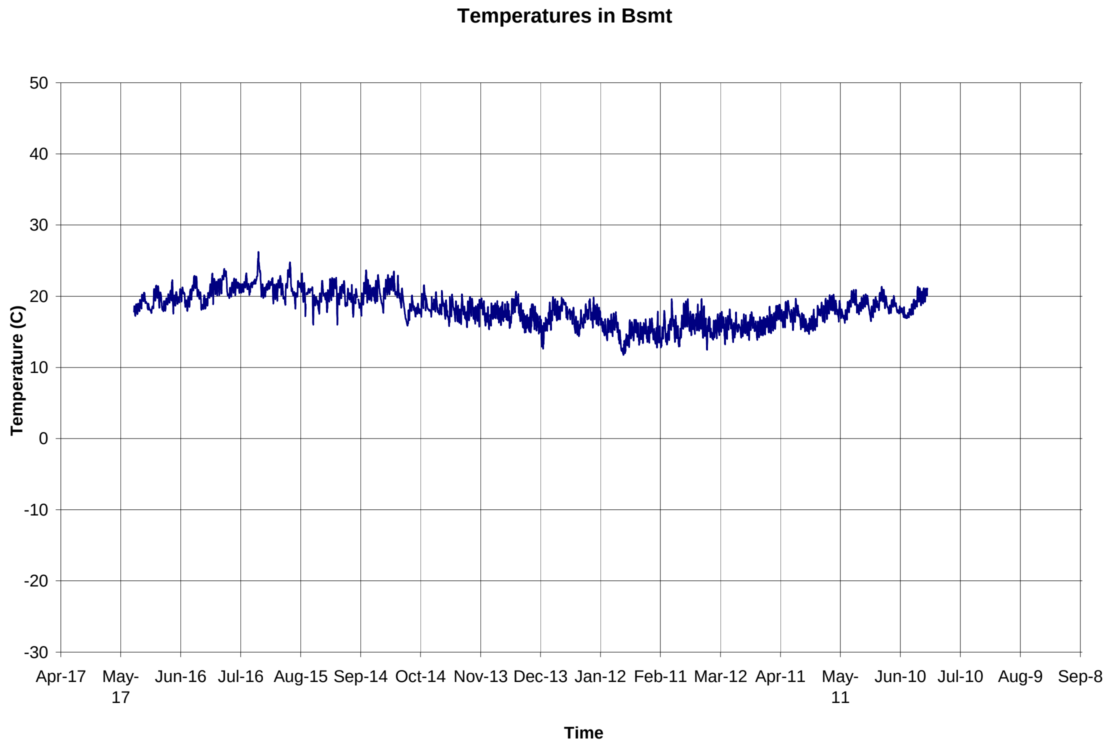

Figure 30: Temperatures in the basement

The peak temperature measured in the basement was 26.2 C at 22:00 on July 24, 2007. The coldest temperature measured in the basement was 12.3 C at 11:00 on January 24, 2008.

3.2.3 Temperature in the Crawl Space

The house has a wooden truss floor in the basement with an accessible crawl space. The two water storage tanks which collect water from the roof are located in the crawl space.

A graph of air temperature in the crawl space is shown in Figure 31. The drop in temperature in the crawlspace in September 2007 was caused by closing off the floor for the crawl space.

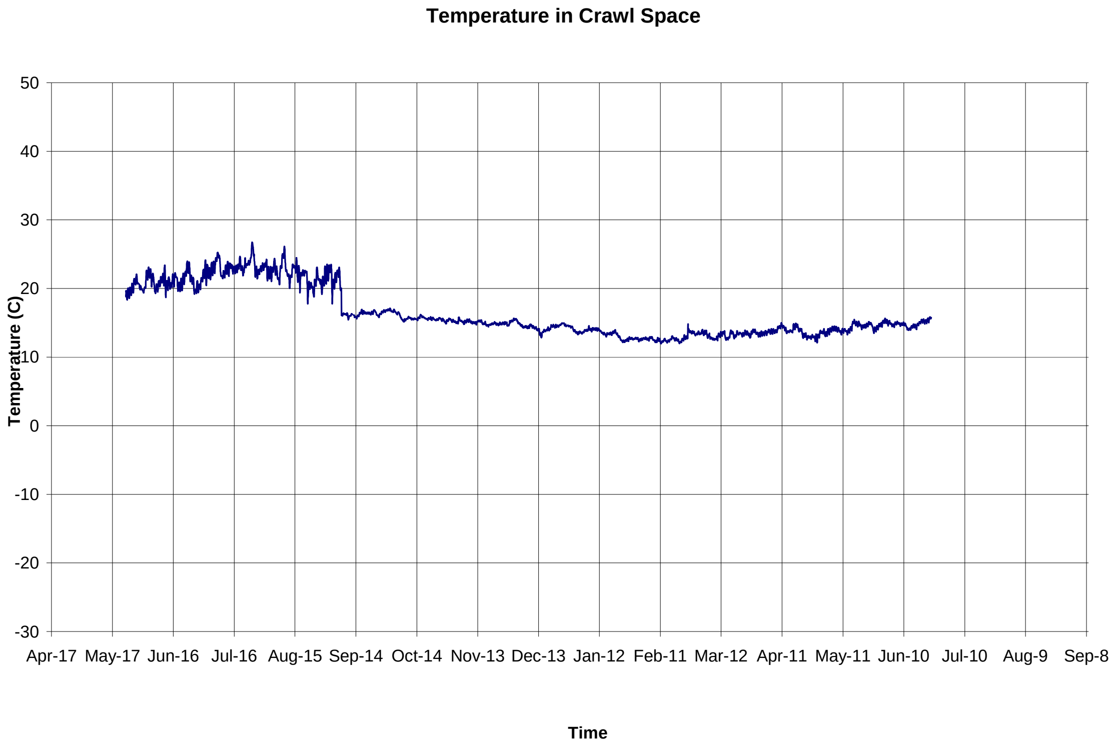

Figure 31: Temperature in the crawl space

There is no insulation in the wood floor of the basement, and thus the temperature in the crawlspace is relatively close to the temperature in the basement. The two plastic water tanks in the crawl space (19,000 litres) tend to stabilize the temperature in the crawl space.

3.2.4 Temperature In The Attic

Figure 32 shows the temperature measured in the attic.

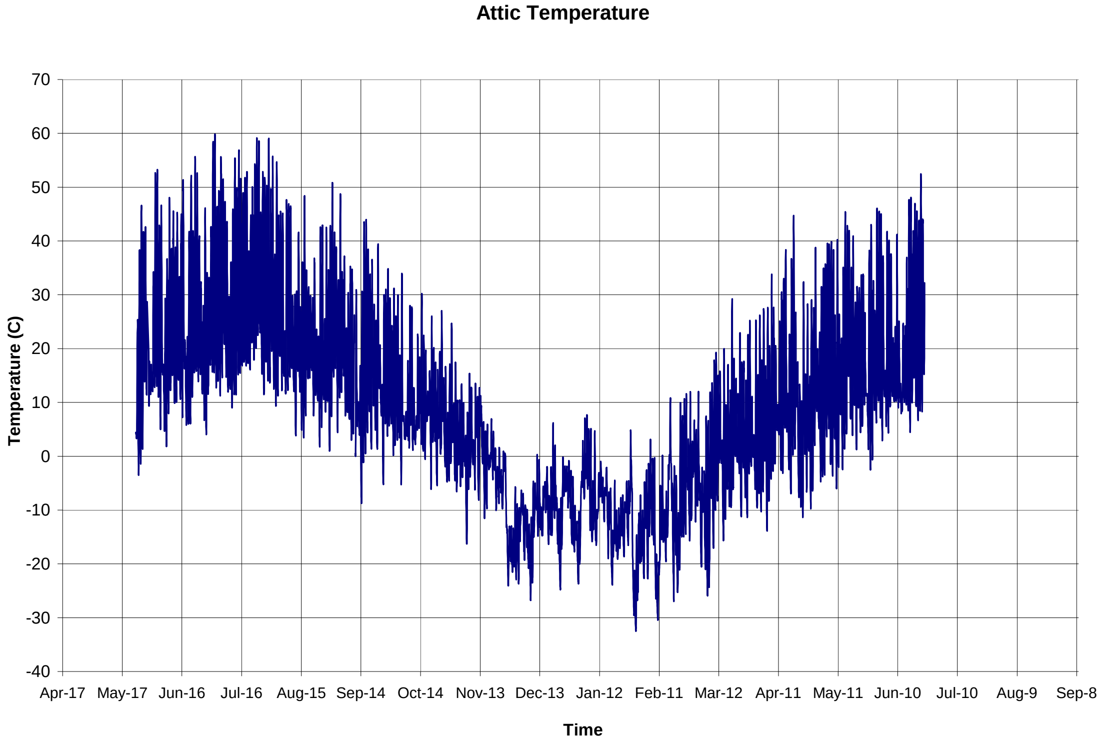

Figure 32: Attic temperatures

The attic temperature varied from a high of +59.8 C on July 2, 2007 at 15:00 to a low of -31.5 C on January 30, 2008 at 10:00.

The roof has brown asphalt shingles, oriented strand board sheathing, and wood trusses.

RSI 14.0 blown glass fibre insulation (R80) is placed on the top of the ceiling, along with a sealed air/vapour barrier. (The air/vapour barrier for the ceiling was a Membrain[TM] by Certainteed. Gypsum board is used on the ceiling.

3.2.5 Relative Humidity In The House

The relative humidity sensor is located in the exhaust air duct for the heat recovery ventilator. The relative humidity values over the monitoring period are shown in Figure 33.

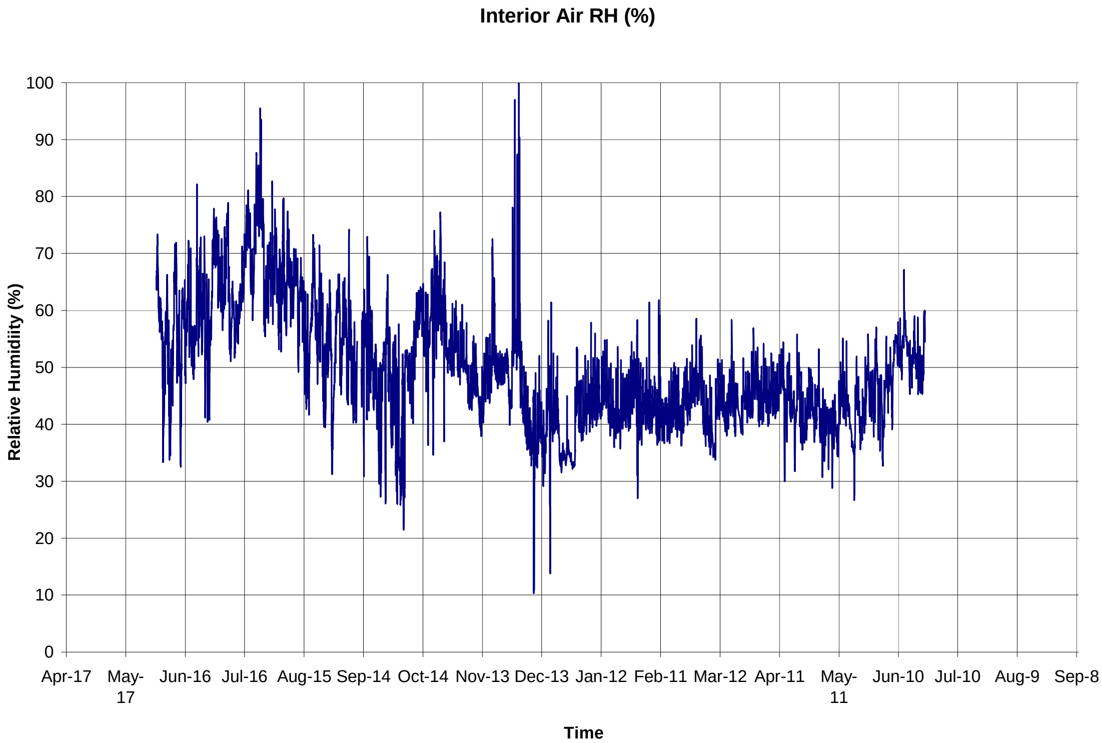

Figure 33: Relative humidity in the house

The lowest relative humidity value recorded was 10.9% at December 9, 2007 at 04:00. This low value is not representative of house conditions. At that time the HRV was turned off, and outside air infiltration into the HRV duct caused the relative humidity at the sensor to drop. A low relative humidity value on December 17 also occurred at a time when the HRV was not running.

The highest RH value was 100%, which occurred on December 1, 2007. A water leak in the cistern piping caused the interior RH to spike. The leak was quickly repaired.

For most of the heating season, the relative humidity value was above 30%, which is the Health Canada guideline. The house has triple glazed windows on the north, east and south with two low emissivity coatings and argon gas fill. The south windows are double glazed with Sungate 500 solar glazing. These windows have a higher thermal resistance than conventional windows, and allow the higher relative humidity values without condensation problems.

In July of 2007, the interior humidity in the house reached a value of 96%. A moist front of air from the south greatly increased the outdoor humidity, and also affected the interior humidity in the house.

3.2.6 Carbon Dioxide Readings

A plot of the carbon dioxide readings for the house is shown in Figure 34.

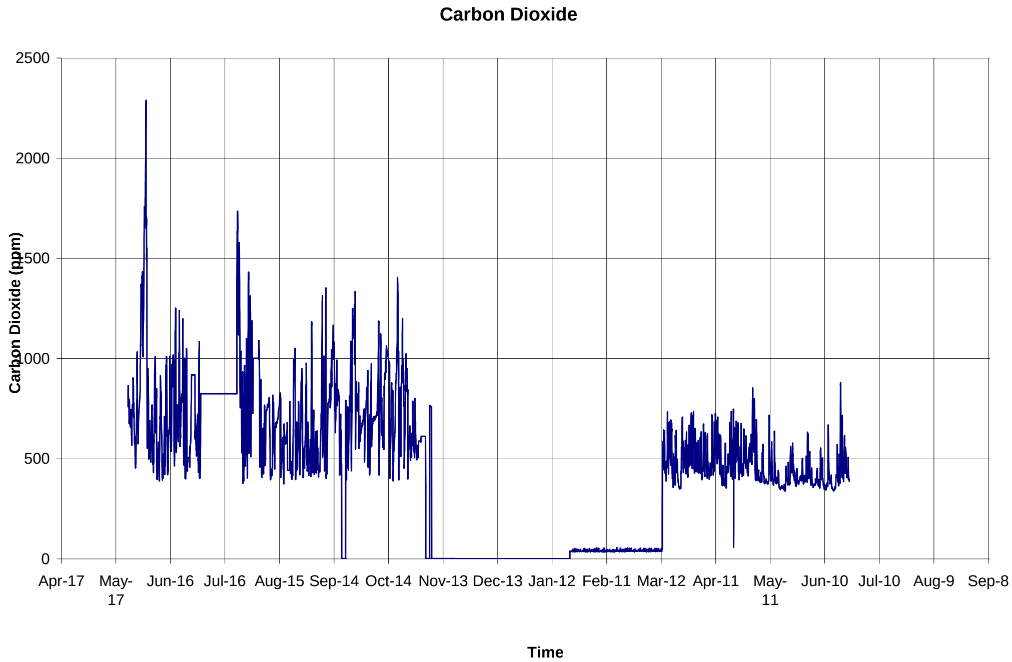

Figure 34: Carbon dioxide readings in the house

The carbon dioxide sensor had some reading problems during the monitoring period. In July 2007 the sensor froze at a reading of about 800 ppm. From early November to March 12, the sensor failed, and the readings were not available. The company no longer supports the device, but an alternative repair agency was eventually found, and the sensor was re-installed on March 12. (A faulty diode was the problem.)The sensor periodically gives a false reading. Note that around April 25, 2008 the readings fell to about 50 parts per million. This reading is not possible, as outdoor carbon dioxide readings typically are about 380 ppm. The quoted accuracy for the sensor is ±100 ppm.

The peak carbon dioxide reading occurred on June 2, 2007 at 14:00 with a reading of 2289 ppm. This high level occurred during a contractors' open house at which a large number of visitors were present.

Health Canada has a residential guideline for carbon dioxide of 3500 ppm. However, ASHRAE recommends a more stringent level of less than 1000 ppm. As can be seen, during most of the monitoring period carbon dioxide levels were less than 1000 ppm.

3.2.7 Ventilation

A plot of the measured outside air ventilation flows through the heat recovery ventilator (HRV) is shown in Figure 35. The flows were measured using averaging flow grids placed in the supply and exhaust ducts. The flow grids were connected to pressure transducers that produced voltage signals that could be read by the data logger.

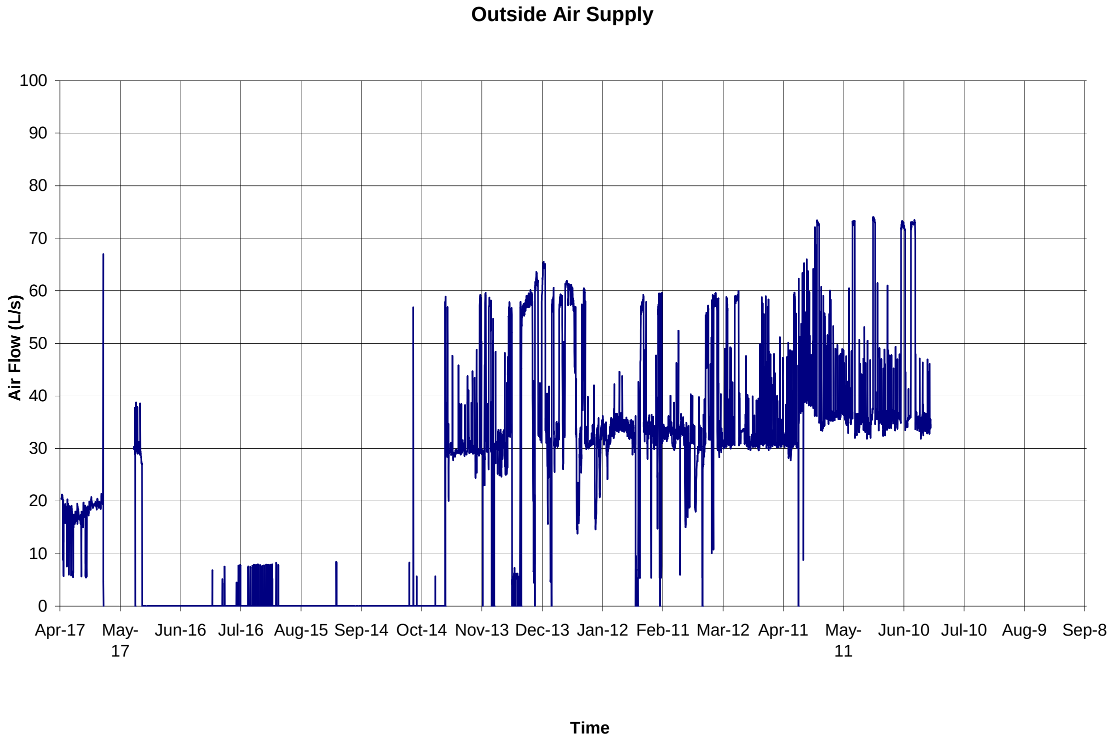

Figure 35: Outside air flow through the heat recovery ventilator

Up until about November 1, the HRV was run only a small amount. Prior to November 1, windows in the house were mostly left open to provide ventilation. After November 1, the outside air flow rate was set at about 30 litres/second as a base rate, with flows increasing for short intervals. (There are speed controls in each bathroom and the kitchen to allow the ventilation rate to rise to a higher value if desired.) Around the end of April, the outside air flow was increased to about 35 L/s.

The ASHRAE ventilation code recommends a ventilation rate of about 8 L/s per person in the absence of strong indoor air pollutions sources. For a 4 person family, the rate would be 32 L/s.

A plot of the exhaust air flow through the HRV is shown in Figure 36.

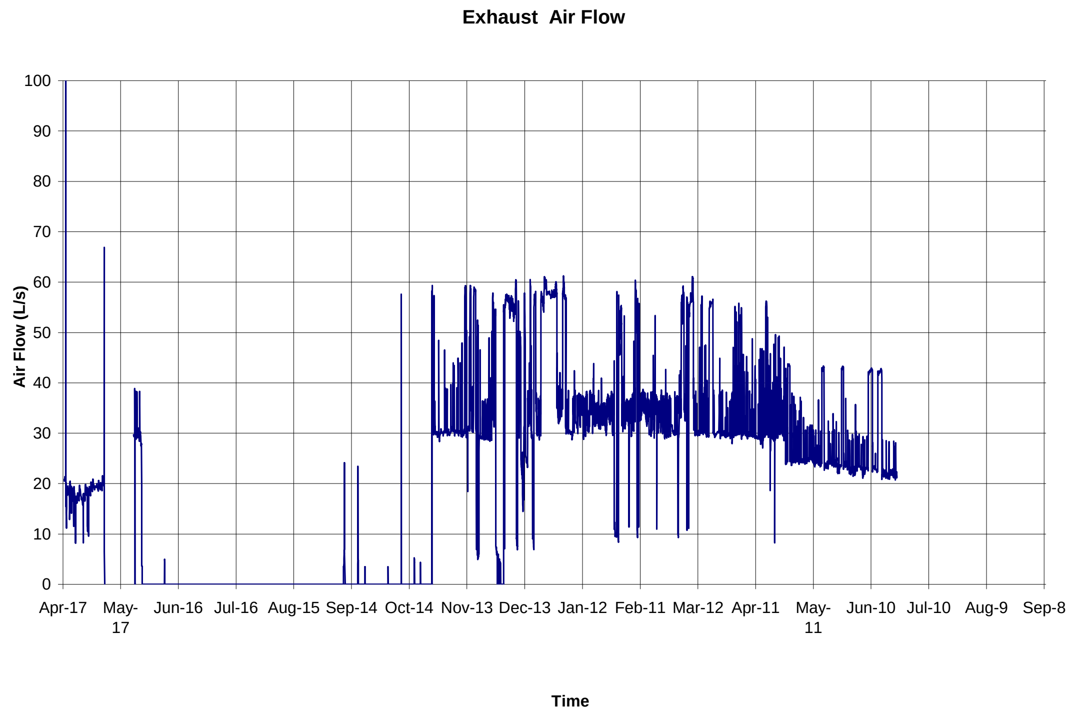

Figure 36: Exhaust air flow through the heat recovery ventilator

As can be seen by comparing the outside air flow and the exhaust air flow charts, the two flows were normally on at the same times. A value of 30 L/s was the base rate of flow for the time when the HRV was operating continuously. The base air flow was reduced to about 25 L/s around the end of April. The homeowner did this to see if the radon gas levels would decrease if the house were slightly pressurized. The radon gas level did decline a small amount after the exhaust flow was reduced and the supply flow increased. Because of the relatively modest humidity levels in the house, it is very unlikely that this increase pressurization would contribute to condensation problems.

3.2.8 Measurement of Volatile Organic Compounds

A passive charcoal sampler (3M) was used to sample the volatile organic compounds in the house. The dates tested were April 28 and April 29, 2008. In the time just prior to the sampling, painting of the largest room in the basement was done.

The Total Volatile Organic Compound (TVOC) reading for the house was measured over that two day interval at 5.4 milligrams/cubic metre of air.

Canada does not currently have a guideline for indoor TVOC values. However, the European value that is sometimes quoted is a guideline of 0.3 milligrams/cubic metre of air.

This relatively high reading for TVOC was no doubt strongly related to the extensive painting that occurred in the basement just prior to the measurements.

Additional measurements of TVOC are recommended.

3.2.9 Measurements of Radon Gas

Radon values were measured using a factory calibrated digital readout device—the Safety Siren Pro 3™ Radon Detector. Over the period from April 6, 2008 to June 22, 2008 the weekly radon readings measured on the main floor of the house varied from a low of 41 to a high of 70 becquerels per cubic metre (Bq/m^3). The current Canadian guideline for radon is 200 Bq/m^3 (5.4 picocuries per litre.) Thus the radon gas levels were well below the Canadian guideline. Regina does have relatively high radon gas levels in homes, based on a previous survey of Canadian homes. After Winnipeg, it had the second highest radon gas levels in homes.

3.2.10 Energy Use

3.2.10.1 Total Purchased Energy

The purchased electrical energy consumption for the house amounted to 8969 kWh for the period from June 1, 2007 to May 31, 2008. A graph of the energy consumption is presented in Figure 37. The graph shows manual readings taken weekly.

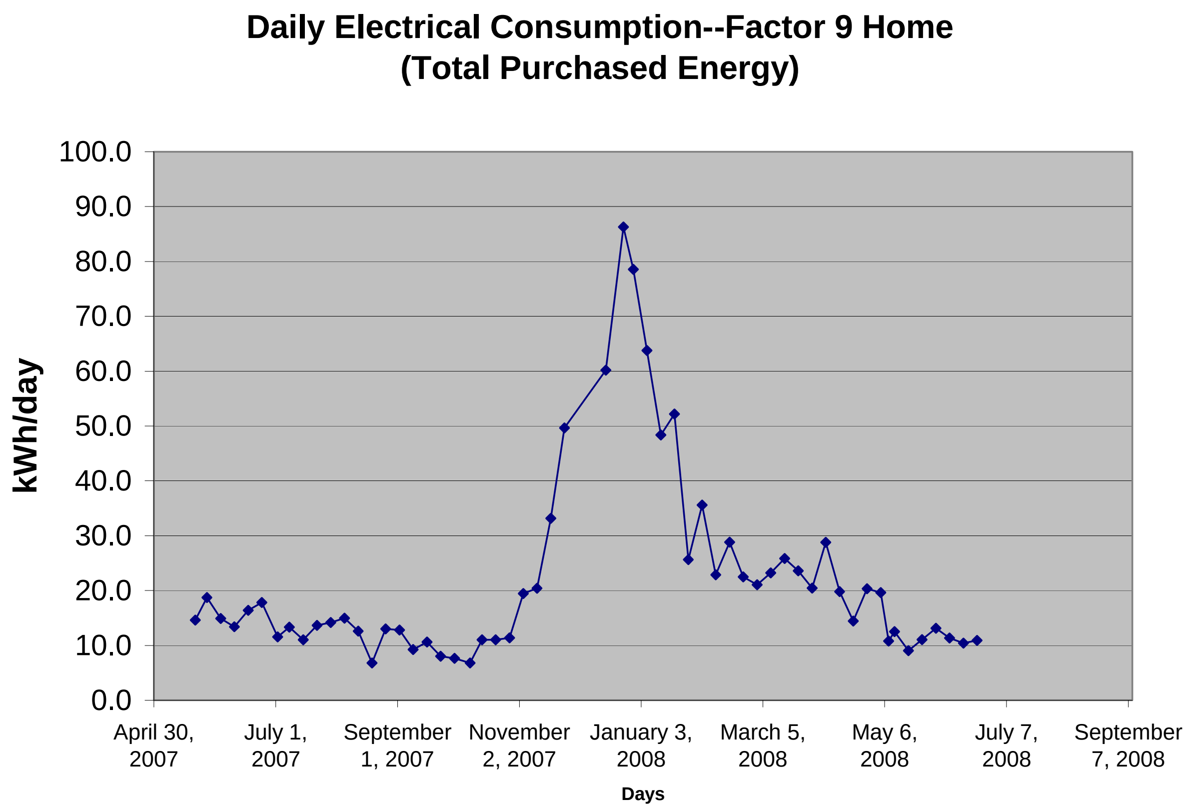

Figure 37: Purchased electricity consumption for the Factor 9 Home

As can be seen from Figure 37, the peak daily electricity consumption for the house was 86.3 kWh/day [3.6 kW] for the one week period ending December 25, 2007. This peak consumption is much smaller than the design heat loss for the house as calculated by the HOT-2000 computer program (10.5 kW at -34 C), as the HOT-2000 program calculation of the design heat loss assumes no passive solar contribution and no active solar heating contribution.

The second biggest electrical load after space heating is the domestic hot water load. The house has an active solar heating system with 20.4 square metres of vertical solar thermal panels along with a 2350 litre storage tank. This active solar heating system provides some domestic water heating along with some space heating. A graph of the solar tank temperature over the monitoring period is shown in Figure 38.

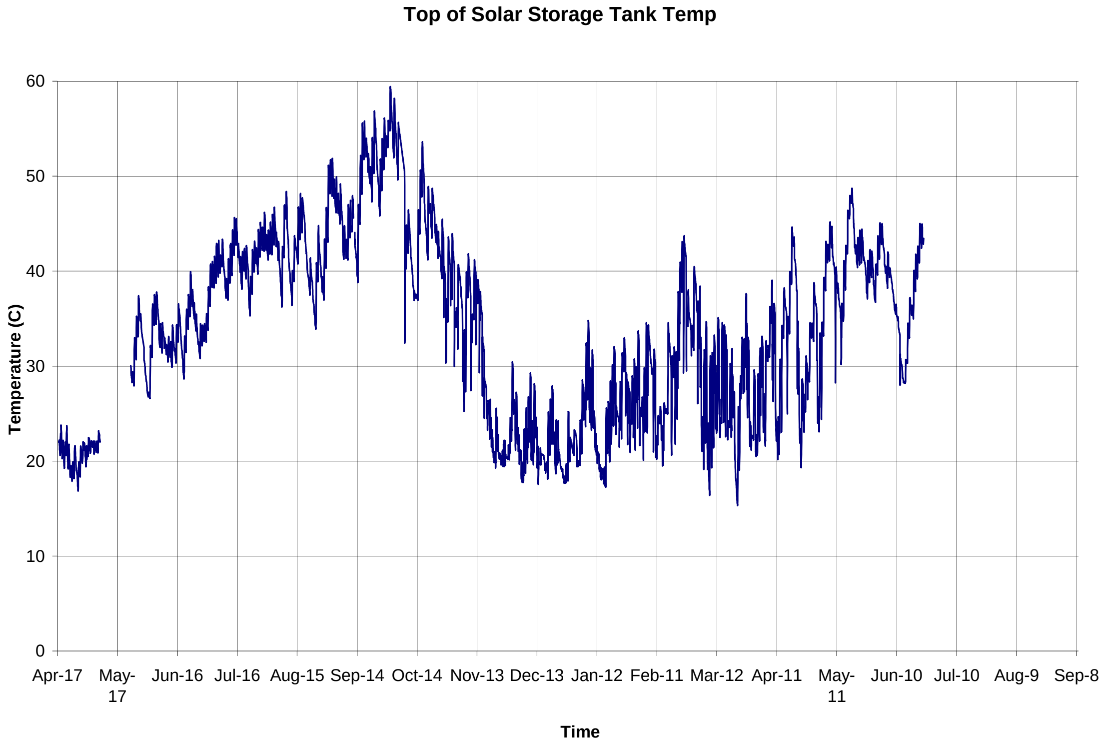

Figure 38: Temperature at the top of the 2350 litre solar thermal storage tank.

As can be seen, the tank temperature reached a peak of 59.1 C on September 30, 2007, and a low of 15.8 C on March 22, 2008. Even at the low temperature of 15.8 C, the solar system was able to add some useful heat to the domestic hot water, as the incoming water temperature at that time was about 6.0 C.

The auxiliary energy used for domestic water heating is presented in Figure 39. This energy is added via an instantaneous water heater.

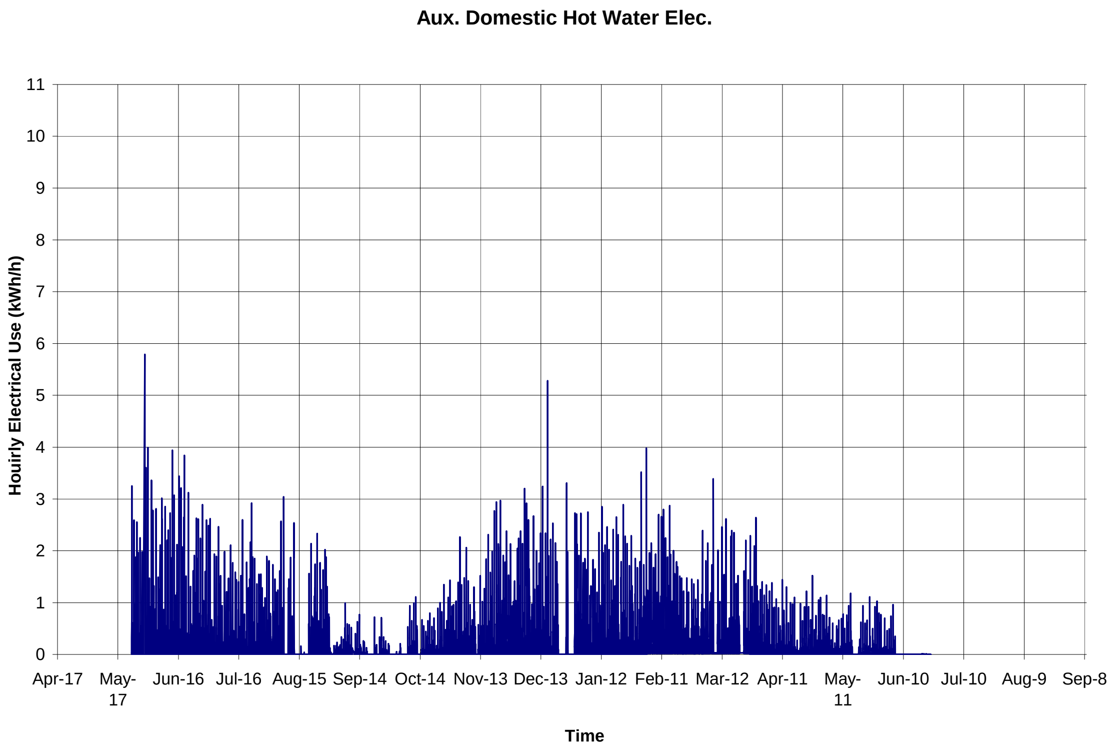

Figure 39: Auxiliary electrical energy for domestic hot water

Note from Figure 39, that the auxiliary electrical energy for domestic hot water fell to a very small value in late September, as the large tank reached temperatures over 50 C. During the winter months, periods when there was no water use in the house are evident by the "gaps" in the data. The auxiliary heater for the domestic hot water used during the monitoring period is an instantaneous device with a maximum capacity of 11.8 kilowatts, and there is no tank loss during periods when the hot water is not being drawn. A conventional 151 litre electric tank with standard insulation (approximately 25 mm of glass fibre) would have a standby heat loss of about 100 watts or 876 kWh per year.

The measured auxiliary electrical energy for domestic hot water amounted to 1294 kWh for the 12 month monitoring period.

A graph of the domestic hot water consumption over the monitoring period is shown in Figure 40.

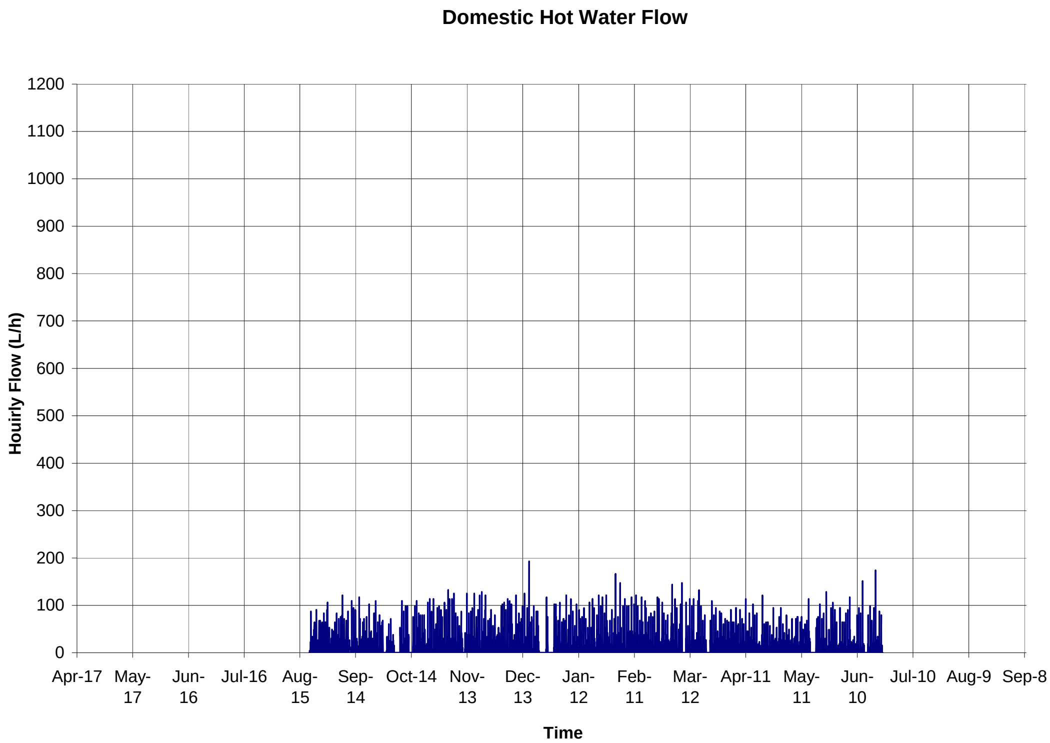

Figure 40: Hourly domestic hot water flow

The data shown in Figure 40 is for the period from August 20, 2007 to June 23, 2008. Prior to August 20, there was a problem with the contact closure on the pulse output from the water meter, which caused it to over-estimate the domestic hot water flow. (Contact bounce was the problem.) This problem was solved using a software fix in the National Instruments Fieldpoint system. The manual output from the meter worked satisfactorily, however, during the entire monitoring period, and was read approximately at weekly intervals. Over the one year monitoring period, the volume of domestic hot water used was 73.4 cubic meters based on manual readings of the domestic hot water meter.

A graph of the minimum water temperature entering the house is shown in Figure 41. This temperature point was measured at the inlet of the potable water supply to the basement. During each hourly interval, the minimum water temperature measured was recorded. During times when no water was drawn, the temperature recorded would be close to the air temperature in the basement. When the potable water supply was running, the minimum temperature recorded would drop significantly, as the incoming water temperature was almost always colder than the basement air temperature.

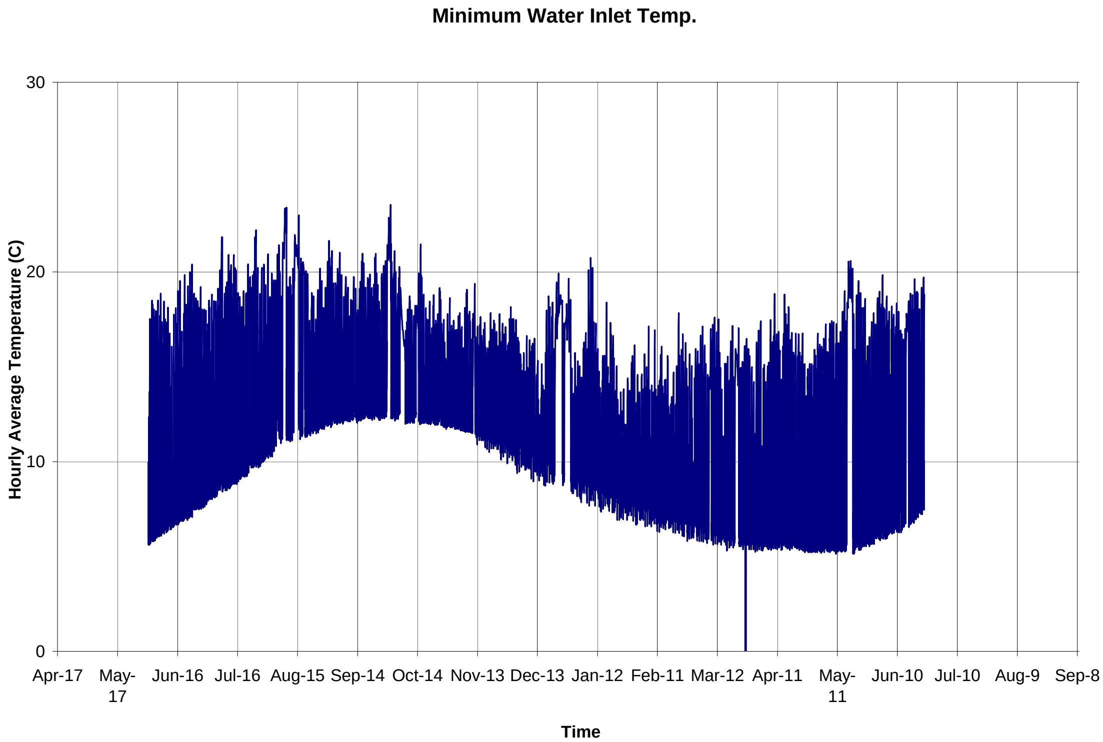

Figure 41: Minimum entering potable water temperature

As can be seen from the graph, the lower boundary of the curve represents the temperature of the cold potable water entering. The lower part of the graph is approximately sinusoidal in shape. The minimum entering water temperature over the monitoring period was 5.2 C on May 11, 2008. The maximum entering water temperature was 12.4 C on September 28, 2007. Gaps in the graph represent periods when the house water usage was zero.

3.2.10.2 Drain Water Heat Recovery Unit

The drain water heat recovery unit recovers heat that would otherwise be flushed down the drain. The unit works best when coincident flows on the drain water side and the potable water side occur, such as during a shower. A plot of the hourly average temperatures of the potable water entering the drain water heat recovery unit is shown in Figure 42. A plot of the hourly average temperature of the potable water leaving the drain water heat exchanger is presented in Figure 43**.** As can be seen by comparing the graphs, there is a noticeable rise in temperature of the potable water as it passes through the drain water heat exchanger.

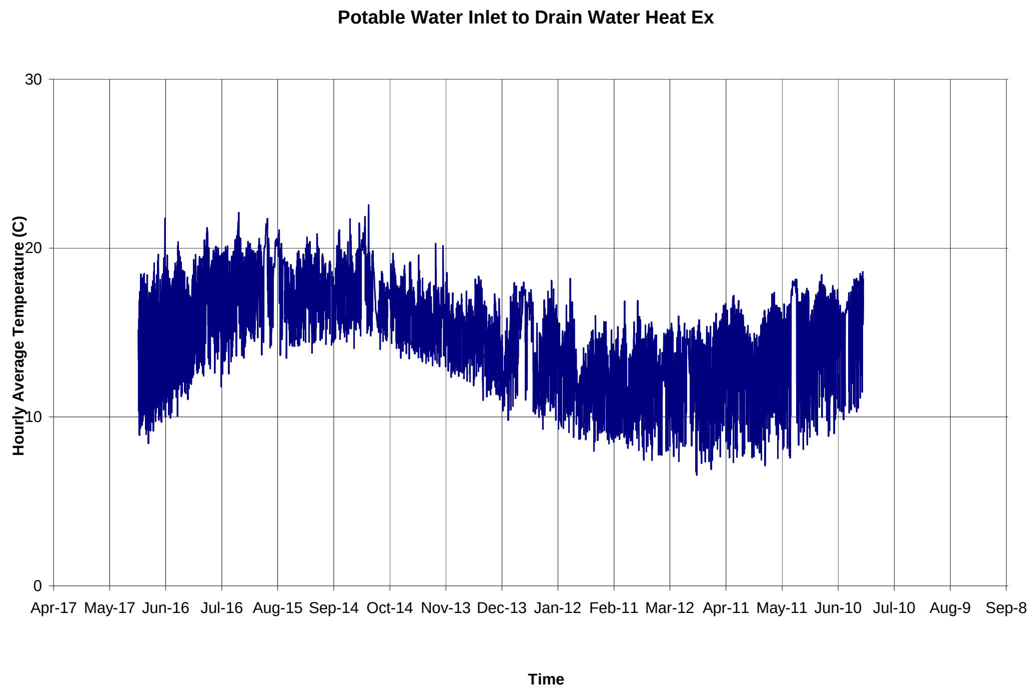

Figure 42: Hourly average temperatures of the potable water entering the drain water heat exchanger

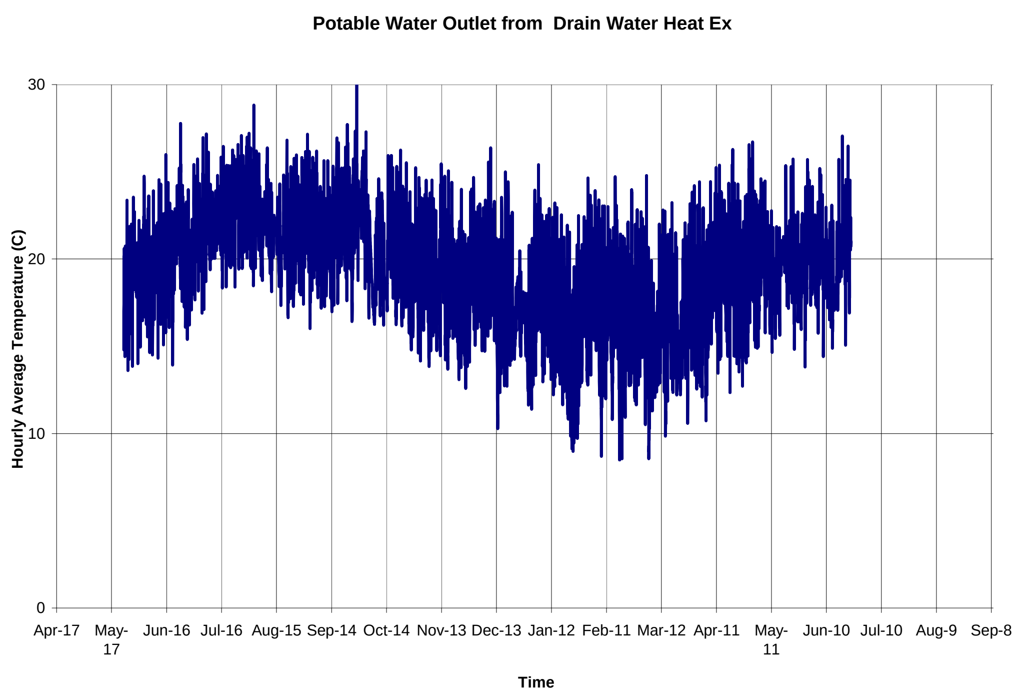

Figure 43: Hourly average temperatures of the potable water leaving the drain water heat exchanger

The amount of energy gained by the potable water as it passed through the drain water heat exchanger was measured by taking the product of the water flow times the specific heat of water times the temperature rise. These values were summed and stored for each hour. A graph of the hourly energy recovery is shown in Figure 44.

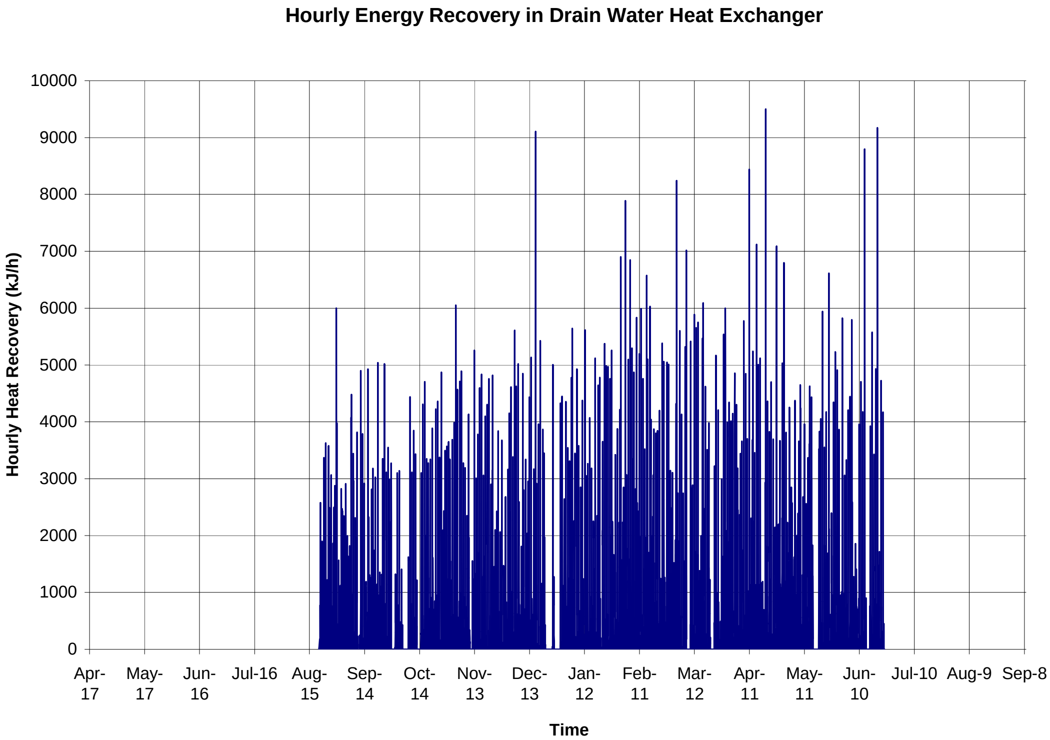

Figure 44: Hourly heat recovery values for the drain water heat exchanger

For the one year monitoring period, the energy gained in the drain water heater was 772 kilowatt hours (based on a linear extrapolation of the data from August 20, 2007 to June 1, 2008).

The volume of domestic hot water heated over the 12 month period from June 1, 2007 to May 31, 2008 amounted to 73.4 cubic metres (73,400 litres) or 201 litres per day. This amount was higher than the original estimate of 150 litres per day used in the computer simulation for the house. (The HOT-2000 default value is 225 L/day.) As mentioned earlier, there is a family of 4 persons in the house (two adults and two children under the age of 10).

To heat 73.4 cubic metres of water from an average temperature of 8.8 C to 50 C, the amount of heat required is 3514 kilowatt hours (assuming no losses). The auxiliary electric heat required was 1294 kWh or 36.8%. The contribution of the drain water heat exchanger was 773 kWh or 22.0%. The contribution of the solar thermal system amounted to 3514 -1294-773 = 1447 kWh, or 41.2% of the total water heating load.

As mentioned earlier, additional insulation on the storage tank would help to increase the contribution of the solar thermal system to the domestic hot water load.

3.2.10.3 Appliance Energy Use

A number of the appliances in the house had electrical submeters.

The submeters were Kill-a-Watt™ units that provided consumption figures in kilowatt hours. Unfortunately, the electrical meters would lose the consumption values when the electricity was turned off. During the monitoring period, there were 15 sets of readings out of 52 weekly readings that were not useful because of power outages in the new subdivision where the house was located. To extrapolate to the annual kWh readings, only the readings from the weeks with valid readings were used. These values were averaged and then projected to a one year time interval. Newer Kill-a-Watt meters are now on the market that have a battery and memory that hold values during a power outage.

The measured values for the appliances that were submetered are shown in Table 3.

Table 3: Appliance energy consumption data

Appliance	Electrical Energy Consumption during 366 monitoring period (kWh/year)	ENERGUIDE RATING (kWh/year)	Ratio of actual consumption to ENERGUIDE Rating
Refrigerator (No Freezer compartment) Kenmore	302	372	0.81
Upright Freezer	537	479	1.12
Clothes Washer Front loading Frigidaire	26.4 (excluding hot water usage)	Not rated for electricity consumption only. 247 kWh/year including hot water	
Dishwasher Asko	75.0	Not rated for electricity consumption only. 242 kWh/year including hot water	
Heat Recovery Ventilator*	315	Not rated	
Electric Range	296	372	0.80
Clothes dryer Frigidaire	Not measured	937	

* The Heat Recovery Ventilator was not run continuously in the summer period of 2007. On low speed the energy consumption is 55 watts, or 482 kWh/year

3.2.10.4 Lighting and Miscellaneous Loads

For budgetary reasons, there were no submeters used on the lighting and miscellaneous loads.

An estimate of the electrical energy used for appliances, lights and miscellaneous electricity use can be gathered by subtracting the auxiliary energy used for hot water from the total energy consumption of the house during the non-space heating season.

For the period from June 3 to September 2, 2007, the appliances, lighting and miscellaneous electricity usage amounted to 9.7 kWh/day, or 3542 kWh extrapolated to a one year period.

In the HOT-2000 run, a value of 9.7 kWh/day was used as the electrical consumption for the lighting, appliances and miscellaneous electricity use (excluding space heating and water heating.) Thus the estimate for this parameter in the HOT-2000 run was in good agreement with the measured consumption.

3.2.10.5 Use Of An Instantaneous Electrical Energy Readout

A device that gives an instantaneous readout of the electrical energy used in the house is shown in Figure 45.

Figure 45: The Energy Detective ™ instantaneous readout device

The device can display the instantaneous electricity consumption as well as the cost in dollars per hour. The cost of the unit was about $175.00 Canadian. The system consists of two current clamps that are placed on the main electrical panel, a sending unit that connects to one 15 ampere breaker, and the readout device (which can be plugged into an electrical outlet connected to the same side of the electrical panel as the sending unit) which is shown in the above figure. By providing an instantaneous readout of energy use, it is a useful tool for the occupants in reducing unnecessary electrical consumption. The occupants of the house kept the readout device on the kitchen countertop.

3.2.10.6 Water Consumption

A plot of the potable water consumption purchased from the city is presented in Figure 46. Over the one year monitoring period, the total purchased water consumption was 171 m^3 or 171,000 litres.

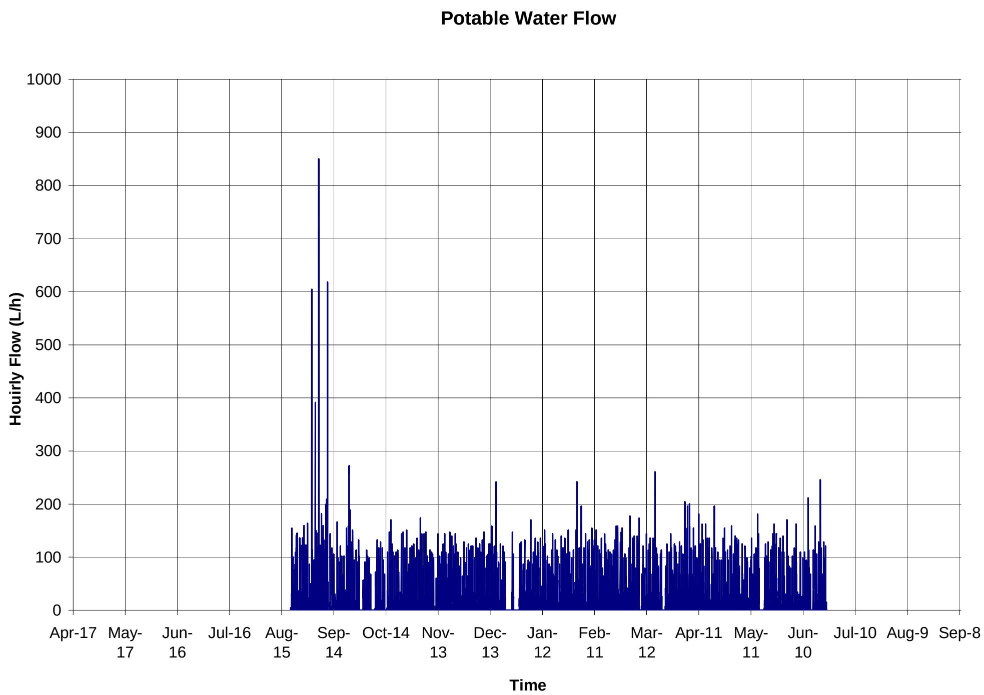

Figure 46: Potable water flows to the house

The relatively large flows (>200 L/hr) occurred when water was added to the cistern to help with flushing the toilets, and also when the lawn at the back of the house was being watered.

For budgetary reasons, flow meters were not used to quantify the amount of roof water that entered the cisterns. The water which was pumped from the cisterns was measured using a manual meter.

A graph of the water pumped from the cisterns over the monitoring period is shown in Figure 47.

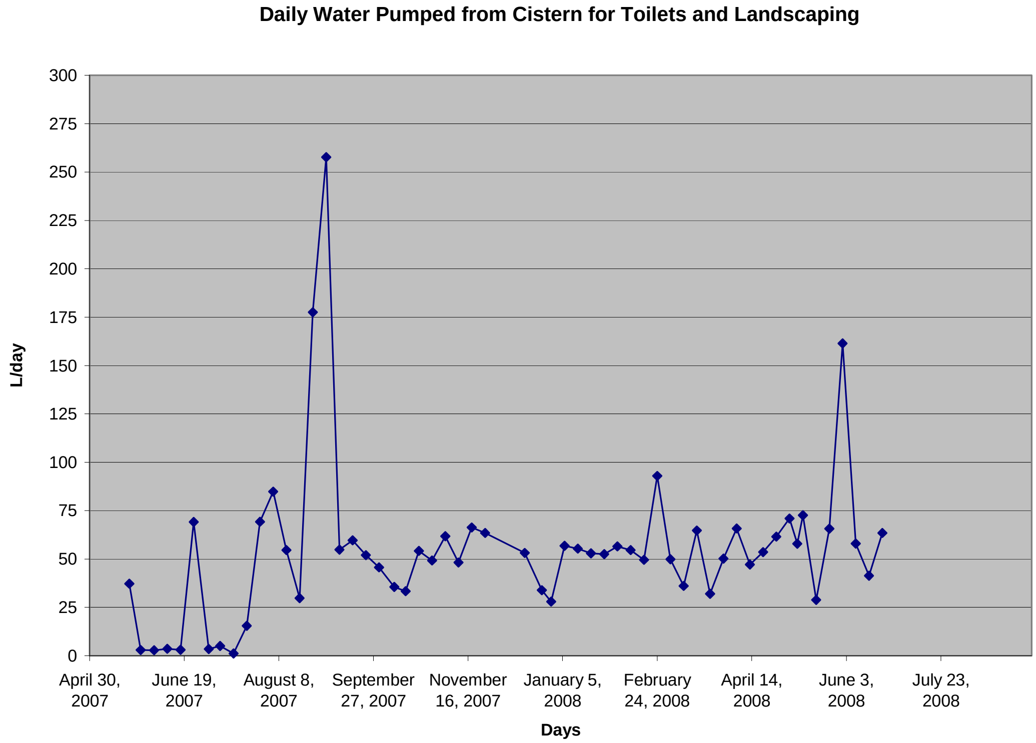

Figure 47: Daily water consumption of water removed from the cistern
(based on weekly manual measurements of the meter)

As shown in Figure 47, there were peak daily flows greater than 150 L/day on several occasions. These high flows were likely associated with exterior watering of the landscaping.

Over the one year monitoring period, the water pumped from the cisterns for the use of toilets and exterior landscaping was equal to 20.0 m^3. The volume of the cisterns is 19 m^3 . During the winter months, all of the cistern water was used for toilets only. For the period from November 4, 2007 to March 30, 2008, the average daily use of the cistern water was 52.1 L for toilet flushing. The toilets used in the house have an average flush volume of 3.69 Litres. Thus the average number of flushes per day was about 14.1 over that time period.

Older toilets in Canada (pre-1985) have flush volumes of approximately 20 litres per flush or 13 litres per flush (1985 or later) while some cities mandated 6 litre toilets after 1996. The toilets in the Factor 9 Home, with an average flush volume of 3.69 litres, have dramatically reduced water consumption. The two types of toilets used were the Gerber Avalanche™ and the Toto Drake™. The homeowners expressed a preference for the Gerber toilet.

4.0 COMPARISON OF ENERGY USE WITH THE TARGET

The total purchased energy use target for the house at the beginning of the project was set at 30 kilowatt-hours per square metre of floor area (including the basement area) per year assuming average weather data for the year. This value represents a reduction of 91% from the value of 331 kWh/m^2 per year as measured in a study of 1970 to 1973 homes constructed in Regina. (Hedlin, Orr, 1977)

The uncorrected electrical energy consumption for the Factor 9 Home for the one year monitoring period (June 1, 2007 to May 31, 2008) was 8969 kWh, or 29.8 kWh/m^2, which is slightly better than the target of 30 kWh/m^2 based on the total floor area of 301m^2 for the house.

Two corrections need to be made to the energy consumption data: one correction is for weather during the monitoring period that does not match the long term weather data. The second correction is for the energy use of the data logging equipment and sensors, as these items would not normally be used in a conventional house.

For the period from June 1, 2007 to May 31, 2008, the heating and cooling degree days as measured by Environment Canada were as follows. In the following table they are compared with the long term average values:

Table 4: Comparison of heating and cooling degree days during the monitoring period with the long term averages

	June 1, 2007 to May 31, 2008	Environment Canada Long term average (1971-2000)	Ratio of Measured to Long Term Average
Heating degree days (base 18 C)	5844	5661	1.0323
Cooling degree days (base 18 C)	199.2	145.9	1.3653

As can be seen from the table, the heating degree days during the monitoring period were 3.23% higher than the long term average, and the cooling degree days were 36.5% higher than the long term average. The month of July 2007 was exceptionally warm in Regina, with 130.5 cooling degree days, as compared with the long term average of 33.8 cooling degree days for that month.

Both the heating degree days and the cooling degree days were higher than normal during the monitoring period. These higher values contribute to increased energy consumption.

To correct for the increase in the annual heating degree day values over the long term average, the following approach was used. The purchased space heating electricity consumption is equal to the total purchased energy consumption minus the auxiliary purchased water heating consumption and the lighting, appliances, and miscellaneous electricity consumption. For the one year monitoring period, the values were as follows:

Table 5: Summary of annual purchased electricity consumption (June 1, 2007 to May 31, 2008)

	Energy consumed over the monitoring period (kWh)	Percentages
Total purchased electricity	8969	100%
Auxiliary domestic hot water heating electricity	1234	13.8%
Lights, appliances and miscellaneous electricity	3542	39.5%
Auxiliary energy for space heating (Total – domestic hot water – lights, appliances and misc.)	4193	46.7%

To correct for the non-standard heating degree days, a reduction of 3.23% in the annual auxiliary energy for space heating can be applied. This is equal to 136 kWh for the monitoring period.

It is difficult to apply a correction for the additional cooling degree days during the monitoring period. The additional energy used for cooling consisted only of the use of a fan coil and the pump that circulates water through the pilings and the grade beam and is considered negligible.

The monitoring equipment and the sensors used an average of 34 watts or 298 kilowatt hours during the one year monitoring period. During the cooling season, this energy consumption contributes to the cooling load for the house and is undesirable from a purchased energy standpoint. In the heating season, the heat released from the equipment contributes to the space heating and is not an energy penalty for the house, given that additional electrical space heating was needed.

As can be seen from the graph of total energy consumption versus time (figure 37), the heating season (time when the purchased energy consumption rises substantially) for the Factor 9 Home starts approximately in November and ends in May. Thus for about six months of the year (June to October) the heat released from the monitoring equipment is undesirable. To correct for the monitoring energy use, half of the monitoring energy or 149 kWh is subtracted from the annual total energy use.

If the two corrections for heating degree days (136 kWh) and the monitoring equipment (149 kWh) are applied, the one year purchased electricity consumption falls to 8684 kWh or 28.9 kWh/m^2.

During the one year monitoring period, the family took a number of trips away from the home. As is evident from Figure 46, there were a number of periods when no potable water consumption occurred. The total number of days when the house was unoccupied during the one year monitoring period was 35. However, the house indoor temperature was not set back substantially during the times that the family was away, as can be seen from Figure 29. Space heating is the largest energy use in the home (46.7%), followed by lights, appliances and miscellaneous energy (39.5%) and auxiliary domestic hot water (13.8%). Thus, the space heating load and part of the lighting, appliances, and miscellaneous energy use occurred during the absences from the home.

The fireplace was used occasionally. Unfortunately, the amount of wood used in the fireplace was not measured directly. In subsequent monitoring, it would be desirable to avoid the use of the fireplace during monitoring. The homeowners used discarded wood pallets in the fireplace. The amount of wood used was less than a 'half-ton load,' according to the homeowner. Dry wood has an energy content of about 18.6 Megajoules/kg. Assuming that about 500kg of wood were burned, the energy content of the wood was 9.3 Gigajoules or 2,584 kWh. The seasonal efficiency of the fireplace, which is relatively well sealed and has glass doors, is approximately 50%. Assuming that level of efficiency and 500kg of wood consumption, the useful energy supplied to the house was about 1,292 kWh.

If that level of useful energy input from the wood heating is added to the electricity consumption for the house, the one year energy consumed increases to 9,976 kWh or 33.1 kWh/m^2.

The house energy consumption target of 30 kWh/m^2 was met by the actual consumption.

5.0 COMPARISON OF WATER USE WITH THE TARGET

The water consumption target for the Factor 9 Home is a 50% reduction in purchased water compared with conventional homes. Conventional homes in Canada use 343 litres per person per day, according to the Atlas of Canada based on 1998 figures. (http://atlas.nrcan.gc.ca/site/english/maps/freshwater/consumption/domestic/1)

This water consumption number is approximately in agreement with some measured data for houses in Saskatoon, Saskatchewan (Dumont, unpublished data). Thirty houses were monitored for four years (1977-1981). The average annual water consumption was 356 litres per person per day, or 3.8% higher than the 343 litres per person per day figure quoted in the Atlas of Canada.

For a 4 person family consuming 343 litres per person per day, the annual consumption would equal 500.7 cubic metres.

The Factor 9 Home over the one year monitoring period had a measured consumption of purchased water equal to 171 cubic metres. This volume represents a reduction of 66% in water consumption compared to the Canadian average. Thus the home readily met the target of a 50% reduction.

It should be noted, however, that the landscaping at the front of the house has not been completed during the monitoring period. However, it is anticipated that the 50% reduction target would have been achieved even when the higher outdoor water use for the front landscaping is accounted for.

During the one year monitoring period, the total precipitation as measured by the Environment Canada weather station in Regina amounted to 192.4 mm. The long term average for Regina for that period is 388.2 mm. Thus the period of monitoring was one in which the total precipitation was roughly one-half of the long term average. If the normal long term amount of precipitation had occurred, less purchased water would have been needed for the toilet flushing and outdoor landscaping.

6.0 LESSONS LEARNED

1. A very high energy performance home in a cold climate has been successfully demonstrated. The measured energy consumption of the house (33.1 kWh/m^2) was about 10% higher than the energy target (30 kWh/m^2) for the house for a one year period.. Conventional 1970-1973 vintage homes had a measured annual energy consumption of 331 kWh/m^2 per year. The average home in Canada uses 8760 kWh per year for lights and appliances. (CREEDAC, 2001). The Factor 9 Home used 8,684 kWh of electricity plus a quantity of wood equal to approximately 1,292 kWh of useful space heating.

2. The participation of the homeowners was a substantial contribution to the achievement of the energy and water conservation goals. The use of The Energy Detective™ to allow the occupants to determine their instantaneous use of electricity was of considerable value in minimizing the energy use.

3. The homeowners did a substantial amount of the work on the house and were able to achieve discounts through their professional contacts. Thus, it is difficult to put a precise number on the incremental cost of the energy and water efficiency features. The incremental construction cost for the energy and water

efficiency measures for the home was roughly $37,000, or 10% extra. The home includes a number of upgrades that increase the durability of the home, including a piling foundation in the Regina clay soils, exterior insulating brick cladding, and upgraded asphalt shingles. The water savings are $488 per year based on current water prices in Regina. The house does not use any natural gas. The energy savings compared with a new home of similar size located in Regina (that is heated with natural gas) are estimated at $952 per year based on reference data in the CREEDAC database of homes built between 1998 and 2000. The combined energy and water savings amount to $1440 a year based on current energy prices in Regina. The rate of return on the incremental costs for the energy and water saving features of the home is thus 3.9% per annum based on current energy prices. This would be equivalent to a simple payback period of 26 years. In a number of Canadian provinces, substantial cash grants are now available to help reduce the incremental cost of the energy efficiency measures. These cash grants would improve the economics.

4. Several additional energy efficiency measures are recommended to further reduce the energy consumption of the house. Insulation should be added to the basement floor to isolate the floor from the crawl space. A relatively inexpensive way to add insulation is to place heavy duty aluminum foil on the base of the wood trusses. If RSI 1.8 insulation is added to the floor in the crawl space, an annual energy saving of about 1,225 kWh could be achieved. This additional insulation would bring the annual consumption down to a value of 29.1 kWh/m^2 or better than the target value of 30 kWh/m^2. In addition, the basement air temperature would be raised to a more comfortable level during the heating season. A shiny surface facing down has a metric R value of RSI 1.8 (R10). In addition, further insulation should be added to the solar storage tank to reduce heat gain to the basement in the summer time and to improve the annual performance of the solar thermal system.

5. The Factor 9 Home incorporated several features—an active solar space heating system and a drain water heat exchanger—that were not able to be simulated using a single commonly available computer programs. Two separate programs—HOT-2000 and RETSCREEN—were used. HOT-2000 was used to calculate the monthly space heating loads, and RETSCREEN was used to simulate the contribution of the active solar space heating system. RETSCREEN did not have an active solar space heating module; to simulate the space heating load, the monthly space heating loads generated in HOT-2000 were converted to domestic hot water loads in RETSCREEN. A commonly available computer program that was able to compute both the space heating loads and the contribution of the active solar space heating system would simplify considerably the simulation of such houses.

7.0 RECOMMENDATIONS FOR FURTHER STUDY

A number of follow-up investigations are recommended.

1. The radiant barrier on the bottom of the floor trusses should be installed and the house energy consumption measured for an additional heating season.

2. The insulation on the storage tank should be further upgraded to improve the output of the solar thermal system.

3. Additional tests on the total volatile organic compound readings in the house should be conducted.

4. Further measurements of the purchased water consumption of the house should be conducted once the exterior landscaping is completed.

8.0 LIST OF REFERENCES

Hedlin, C.P. and Orr, H.W., 1977, “A Study of the Use of Natural Gas and Electricity in Saskatchewan Homes,” Proceedings, 91st Annual EIC Meeting (National Research Council of Canada, Division of Building Research, NRCC 16898)

9.0 ACKNOWLEDGMENTS

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Instrumentation Programming and Debugging	Tara Morin and Kelly Winder, SRC

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