Residential Hybrid Heating System

Whitehorse, Yukon

Final Report V.2

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March 15th, 2006

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1 INTRODUCTION

Lessoway Moir Partners was retained by the Energy Solutions Centre to collect, analyse and archive performance data of a hybrid geothermal-solar residential heating system in Whitehorse, Yukon. The scope of work included preparation of interim performance reports to document the performance of the heating system over a complete year of the operation[1]. The first interim report was issued to ESC on August 24, 2005[2] and reported on the performance of the system from the inception of the monitoring in December of 2004 to the end of July 2005. The format and content of certain sections has been modified to reflect comments made by ESC[3] and the homeowner Steve Duncan[4]. The report also includes analysis of performance data taken up to the end of December 2005.

It is intended that this report will provide information to those in the local commercial and residential heating industry on the feasibility of hybrid geothermal-solar heating systems in the Northern Canadian climate.

2 BACKGROUND

The 2700 ft^2 house, located in the Porter Creek subdivision of Whitehorse, Yukon, was constructed in 2003. The house is well-insulated (R30 walls, R44 to R48 roof) and has triple glazed, low-e, argon-filled windows. The heating system in the house is unique in that it combines multiple heating sources to satisfy the space and hot water heating demand. The heating system consists of the following components:

1. Geothermal loop
2. Solar Panels
3. Solar Wall
4. Heat Recovery Ventilator (HRV)

The components operate both separately and simultaneously based on the occupant's demands and outdoor climate conditions as dictated by the heating system sequence of operations (Ref. Appendix A – Sequence of Operations).

2.1 Geothermal Loop

The Geothermal Loop component of the heating system is comprised of:

1. Four 1000 ft closed loops of HDPE pipe buried in the homeowner's backyard in four parallel 170' long trenches approximately 20' apart. The loops are buried at depths of 8 ft, 9 ft, and 10 ft below grade in an area of approximately 170 ft by 70 ft.
2. A 20/80 by volume mixture of methanol to water is fed through the loop to a water-to-water heat pump located in the mechanical room in the house.

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[1] LMP File: 0303009001. LMP proposal to ESC, June 10, 2003.

[2] LMP File: 0303009001. *Performance Review of a Geothermal Hybrid Residence in Whitehorse, Yukon*, August 24, 2005.

[3] Handwritten comments by Doug McLean of ESC, September 2005, on copy of LMP report: *Performance Review of a Geothermal Hybrid Residence in Whitehorse, Yukon*, August 24, 2005.

[4] Handwritten comments by homeowner Steve Duncan, November 2005, on draft copy this report.

3. The 6 ton heat pump provides refrigerant to a coil within an air handling unit, which in turn provides ventilation and space heating to the home. (Ref. Appendix B - Heating Schematics).
4. The heat pump also provides refrigerant to the desuperheater located in the primary water storage tank. The desuperheater raises the water temperature of the primary water storage tank serving as a heat exchanger, facilitating heat transfer to the hydronic heating system which also passes through the tank. The hydronic heating system combined with the air handling unit provides the space heating to the home.
5. The primary water storage tank also serves to preheat the domestic hot water via the desuperheater from the heat pump and the loop from the solar panels.
6. In the cooling season, the geothermal loop serves as a sink to dissipate heat. Unwanted heat is transferred from the coil in the air handler, via the heat pump to geothermal loop. The geothermal loop also accepts excess heat from the solar panel loop via a water storage tank. The loop in turn rejects the heat to the ground.

A schematic of the Geothermal Loop component operation during heating season is provided below.

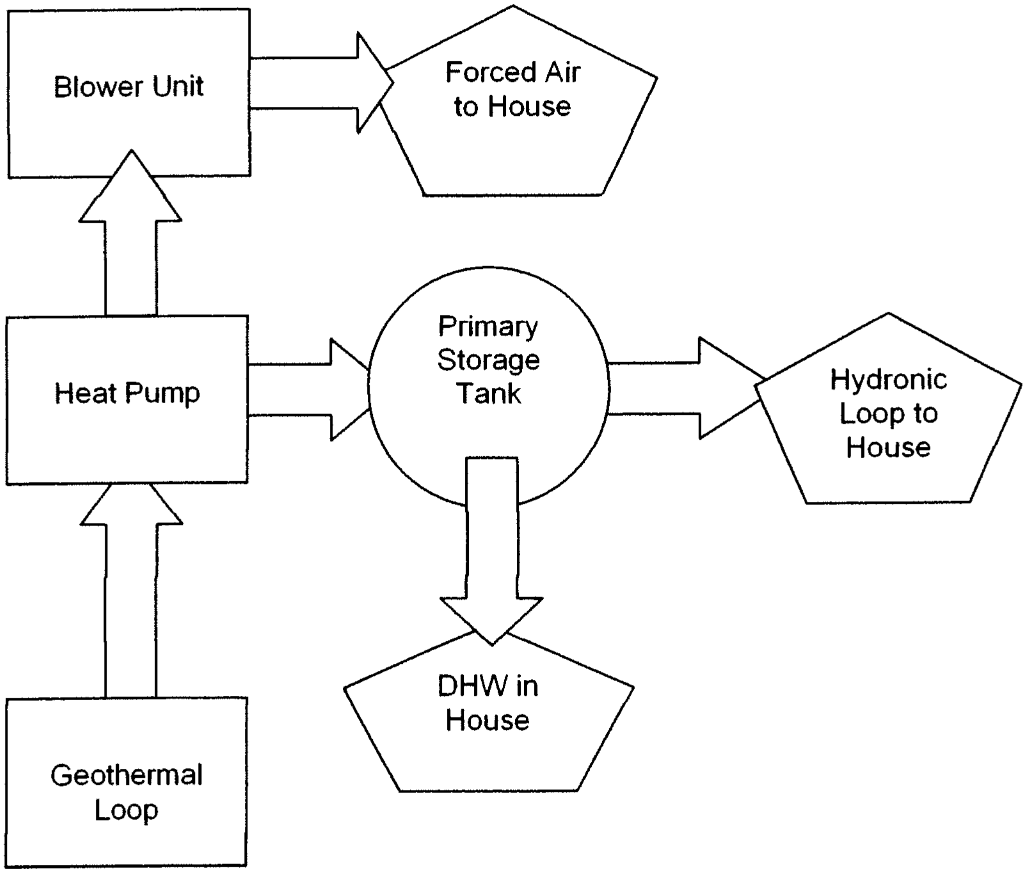


Figure 1: Geothermal Loop Heating Season Operation

2.2 Solar Panels

The solar panel component of the system includes:

1. Four solar panels, each consisting of thirty evacuated tubes for a total of 120 tubes. The 87" x 80" x 6 1/4" panels, are mounted on the south facing roof of the house at a fixed angle of approximately 30 degrees from the vertical.
2. A 50/50 by volume mixture of propylene glycol and water passes through the solar panels to a coil within the primary water storage tank in the mechanical room of the house. This storage tank, as described in the geothermal loop operation provides domestic water and a portion of the space heat to the home when solar heat is available.
3. An auxiliary water storage tank serves to transfer excess heat generated by the solar panels. In the winter, the excess heat is transferred to the ground loop and eventually the heat pump. The heat pump in turn transfers the geothermal heat and excess solar to the forced air component of the space heating. In the summer this heat is dissipated to the ground via the geothermal loop.

A schematic of the Solar Panel component operation during the heating season is provided below.

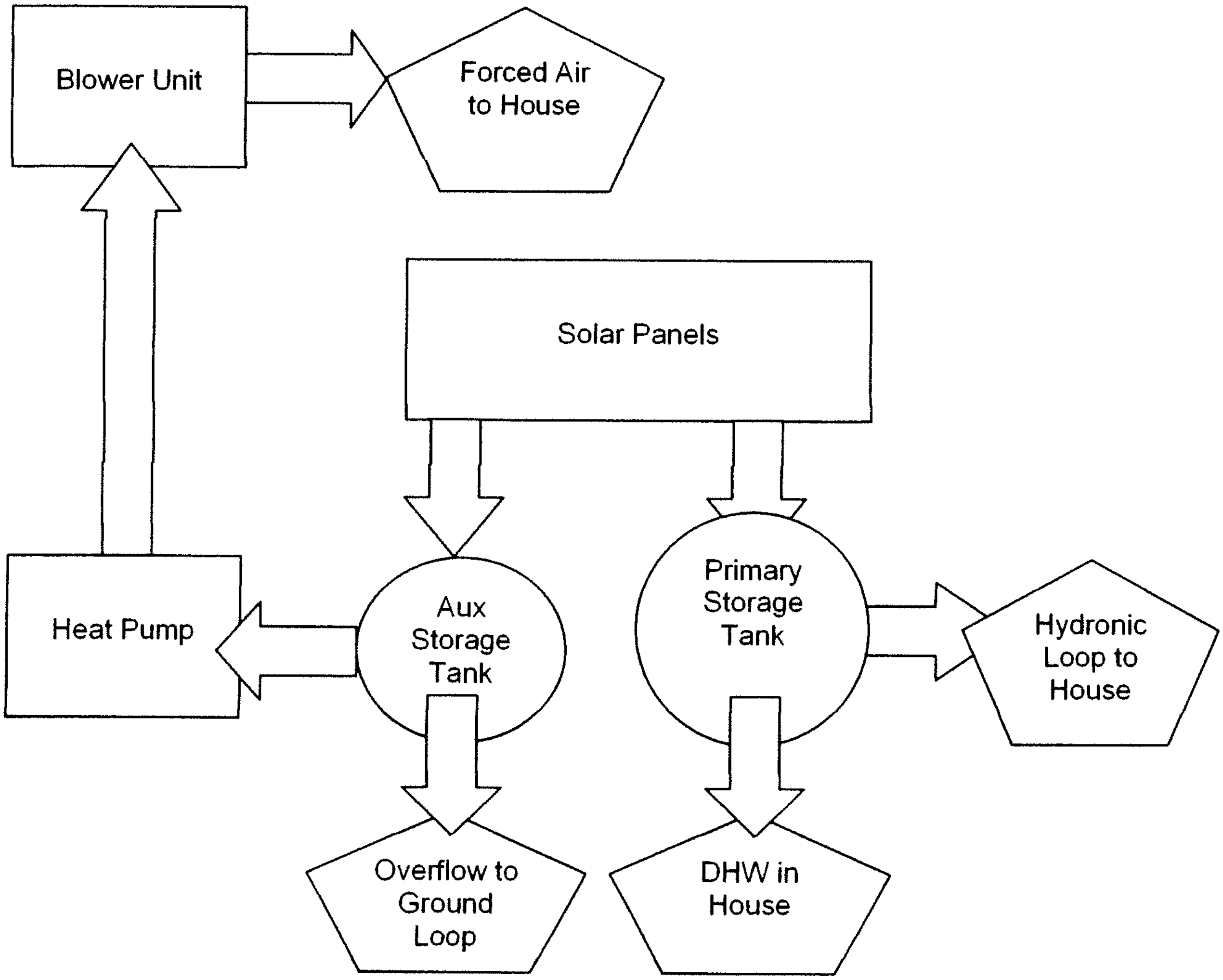


Figure 2: Solar Panel Loop Heating Season Operation

2.3 Heat Recovery Ventilator

A HRV is located in the mechanical room of the house and operates in the heating season to preheat outdoor air before it is introduced into the air handling unit. The unit is a dual core heat exchanger, recovering heat from the air exhausted from the home to preheat fresh air entering the home. The operation of the HRV is dependent on the outdoor air temperature, inside air temperature, and solar wall air temperature.

A schematic of the HRV component operation during the heating season is provided below.

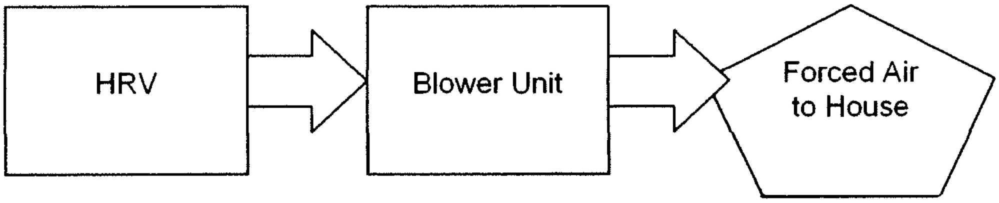


Figure 3: HRV Heating Season Operation

2.4 Solar Wall

A solar wall located on the south facing exterior wall transfers solar energy to preheat the outdoor air before it is introduced into the home. Outdoor air enters the solar wall from the bottom of the wall and through perforations on the surface of the wall. The air rises by natural convection to a discharge at the top. The discharge of the solar wall is ducted to the HRV and the air handling unit. When preheated outdoor air is required, a combination of control dampers adjusts to direct the air to the HRV and then to the air handling unit. Where it is directed is dependant on the outdoor air temperature, inside air temperature and solar wall discharge temperature. When preheated air is not called for, the solar wall is bypassed completely and fresh air is introduced through a separate outdoor air hood.

A schematic of the solar wall component operation during the heating season is provided below.

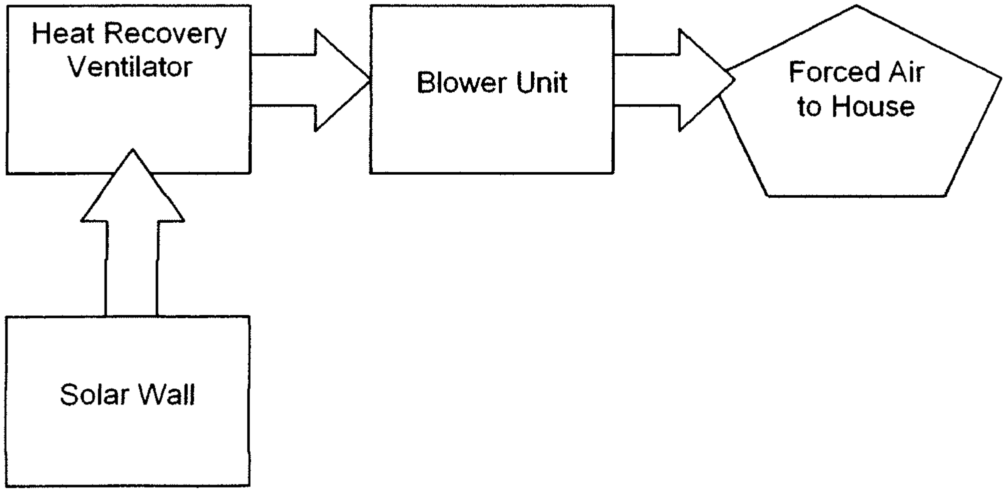


Figure 4: Solar Wall Heating Season Operation

2.5 Electric Heat

The homeowner has incorporated some redundancy in the system to accommodate any down time for the system components.

- A domestic hot water tank is connected in series with the primary water storage tank outlet to permit electric heat into the domestic hot water system if needed.
- A 4 kW immersion type electric heater is available in the primary water storage tank to substitute or supplement the heat contributions of the geothermal and solar loops.
- Similarly, in the blower unit, an electric coil is available to provide space heating in the event that one of the system components (i.e. heat pump, geothermal loop, solar panels, pumps) requires service.

Under normal operation, the breakers for these electrical heating elements are removed so that no electric heat is being put into the system. These elements serve strictly as a backup and under normal use, no electricity is being consumed directly to generate heat. It should be noted, however, that electricity is required to run the heat pump, heating fluid pumps, and blower. Further discussion on electrical use follows.

2.6 Propane

A small propane fireplace is installed in the home. The fireplace provides minimal heat to the space and is used primarily for its aesthetic appeal. For the purposes of this study the heat provided by the propane fireplace will not be considered.

3 Data Measured

Parameters demonstrating the performance of the hybrid heating system being measured are as follows:

3.1 Geothermal Loop

- *Geothermal Loop Supply Temperature*
- Geothermal Loop Return Temperature
- Geothermal Loop Flow Rate

3.2 Solar Panels

- Solar Loop Supply Temperature
- Solar Loop Return Temperature
- Solar Loop Flow Rate

3.3 Heat Recovery Ventilator

- HRV SA
- HRV RA
- HRV EA
- HRV OA *(inlet air from solar wall or outside)*

3.4 Solar Wall

- OA Temperature
- Solar Wall discharge
- HRV Inlet Air Temperature
- HRV SA Temperature
- HRV Air Flow

The data logger has recorded each of these parameters every 10 to 15 minutes since the inception of the monitoring process. The daily, weekly, and monthly averages were tabulated for each of the parameters. Daily values are stored electronically at LMP, while weekly averages are provided in Appendix C – Weekly Averages of Monitored Data. Monthly averages are presented later in this report and are used for discussion. Where data was missing an estimate was made. This was done by extrapolating the border points on the missing interval and assuming a linear rise or fall over the time interval. For the purposes of our study and the limited time where data points were missing, this estimating technique was sufficient.

4 Performance

For the purpose of this study it is worthwhile to view each component as contributors to the overall heating system. The heat input, from the geothermal loop, the solar loop, the HRV, and solar wall collectively satisfy the heat demand for the space.

$$Q_{Total} = Q_{Geothermal\ Loop} + Q_{Solar\ Panel} + Q_{HRV} + Q_{Solar\ Wall}$$

Q_{Total} = Total Heat input to home [Btu/hr]
$Q_{Geothermal}$ = *Geothermal heating contribution* [Btu/hr]
$Q_{Solar\ \mathrm{Pamel}}$ = Solar Panel contribution [Btu/hr]
Q_{HRV} = HRV contribution [Btu/hr]
$Q_{Solar\ Wall}$ = Solar Wall *contribution* [Btu/hr]

For each of the components, geothermal, solar, HRV etc., the heat input into the system has been tabulated. Daily heat contributions were determined from the values provided by the data logger. Weekly and monthly averages were tabulated to more clearly observe the changing performance of each component over the monitoring period. To obtain a more clear understanding of the system performance, monthly averages of the heat contributions by each of the system components are presented below.

4.1 Geothermal Loop

The supply and return temperatures of the geothermal loop was monitored, allowing us to determine the heat supplied from the geothermal loop. The flow rate of the loop was known from the equipment data. Heat output values from the loop were tabulated based on the following calculation:

$$Q_{Geothermal\ Loop} = m_{Geothermal\ loop}\ c_p\ (T_{LWT} - T_{EWT})\ k$$

$Q_{Geothermal}$ = Geothermal heating contribution [Btu/hr]

$m_{Geothermal}$ = Geothermal loop fluid mass flow rate [kg/s]

c_p = Specific heat of loop fluid [J/kg·K]

T_{LWT} = Geothermal leaving water temperature [°F]

T_{EWT} = Geothermal entering water temperature [°F]

k = unit conversion factor

The average monthly heat contribution seen from the geothermal loop is summarized in Figure 5 below.

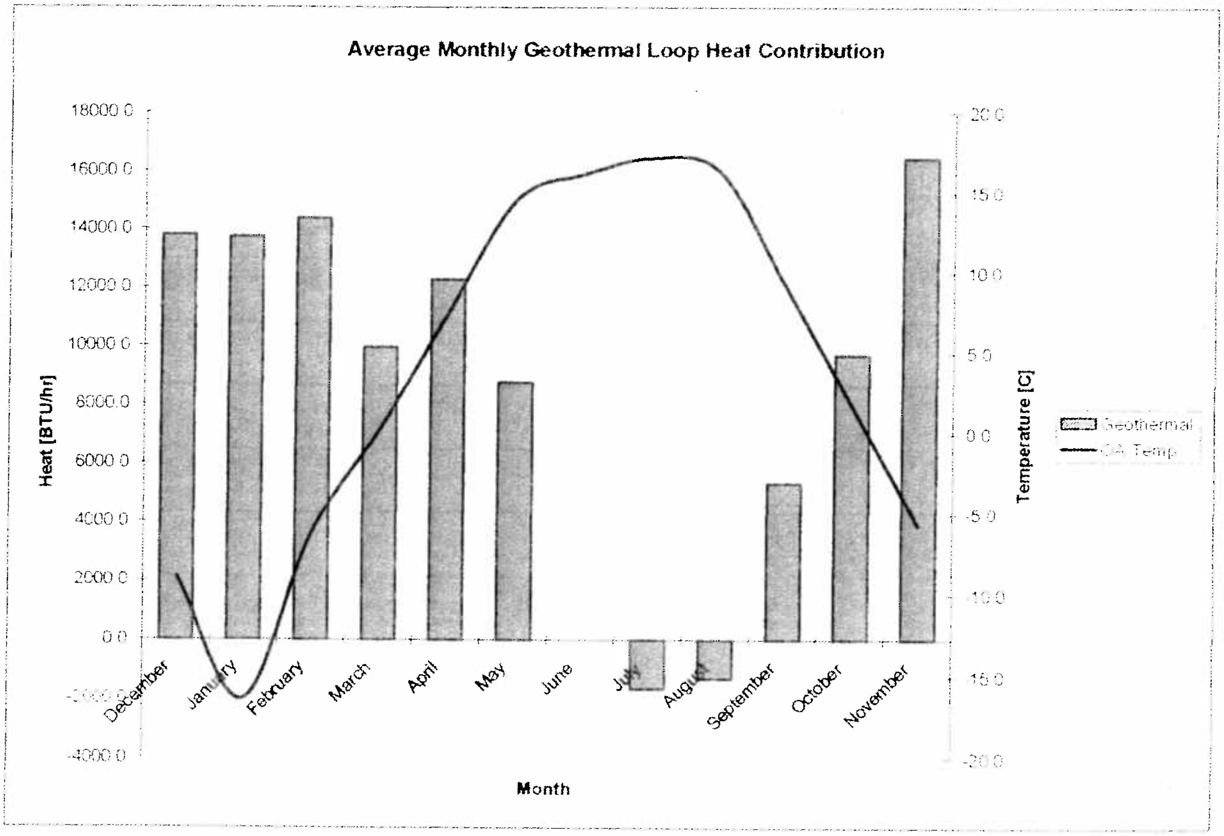


Figure 5: Average Monthly Geothermal Loop Heat Contributions

4.2 Solar Panels

The temperature of the water entering the solar panels was monitored along with the temperature of the water leaving the panels. The flow rates through the panels were also recorded allowing for the amount of heat gained by solar energy to the house to be determined:

$$Q_{Solar\ Panels} = m_{Solar\ loop} \cdot c_p \, (T_{LWT} - T_{EWT}) \cdot k$$

$Q_{Solar\ Panels}$ = Solar Panel heating contribution [Btu/hr]
$m_{Solar\ loop}$ = Solar Panel loop fluid mass flow rate [kg/s]
c_p = Specific heat of loop fluid [J/kg·K]
T_{LWT} = Solar panel leaving water temperature [°F]
T_{EWT} = Solar panel entering water temperature [°F]
k = unit conversion factor

The average monthly heat contribution seen from the solar panels is summarized in Figure 6 below.

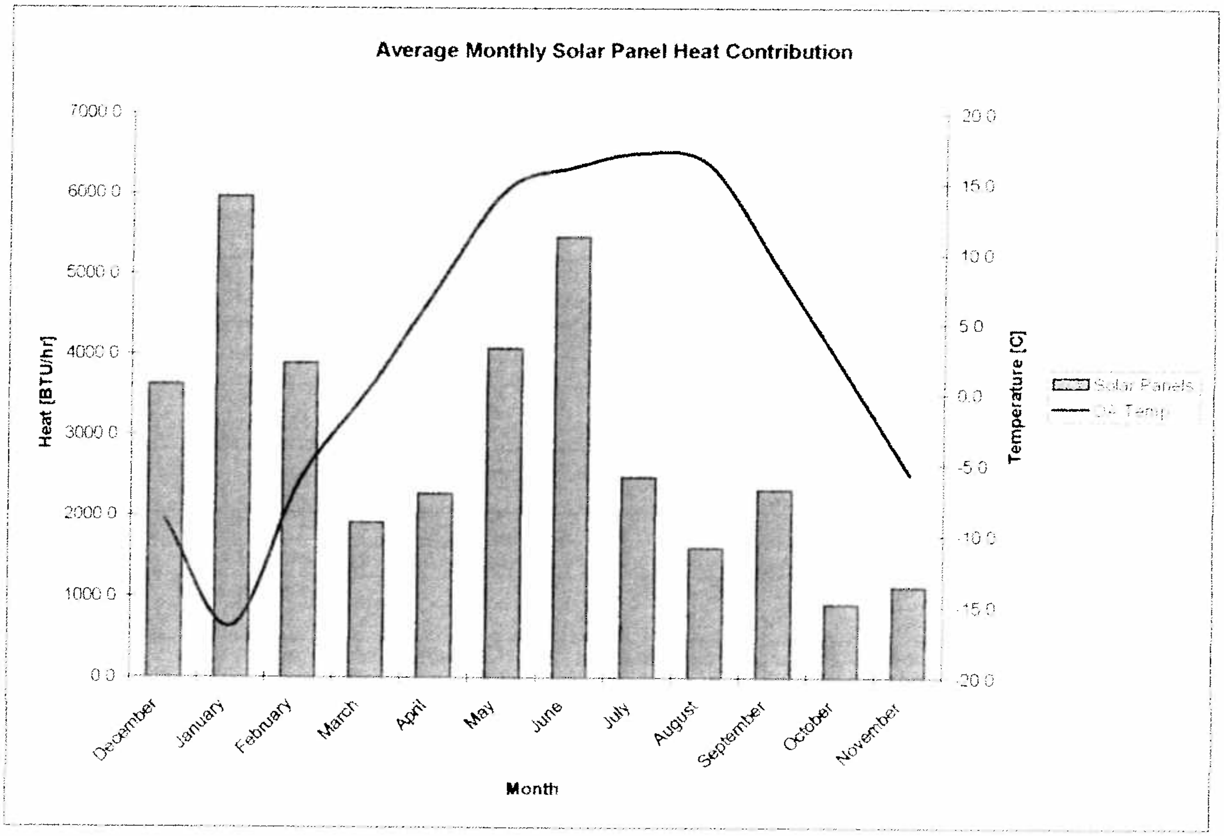


Figure 6: Average Monthly Solar Panel Heat Contributions

4.3 Heat Recovery Ventilator

The Heat Recovery Ventilator (HRV) raised the incoming OA temperature by acting as a counterflow air to air heat exchanger, 'recovering' the heat from the exhaust air leaving the building. The HRV efficiency varied between 70% and 80% during the heating season. Knowing the airflow through the heat exchanger and the temperature raise which resulted, the amount of heat 'recovered', or *contributed to heating the house* was determined by:

$$Q_{HRV} = V_{HRV} \cdot 1.08\,(T_{SA} - T_{SWD})$$

Q_{HRV} = HRV heating contribution [Btu/hr]

V_{HRV} = HRV air flow rate [cfm]

T_{SA} = HRV supply air temperature [°F]

T_{SWD} = Solar Wall discharge air temperature [°F]

The average monthly heat contribution seen from the HRV is summarized in Figure 7 below.

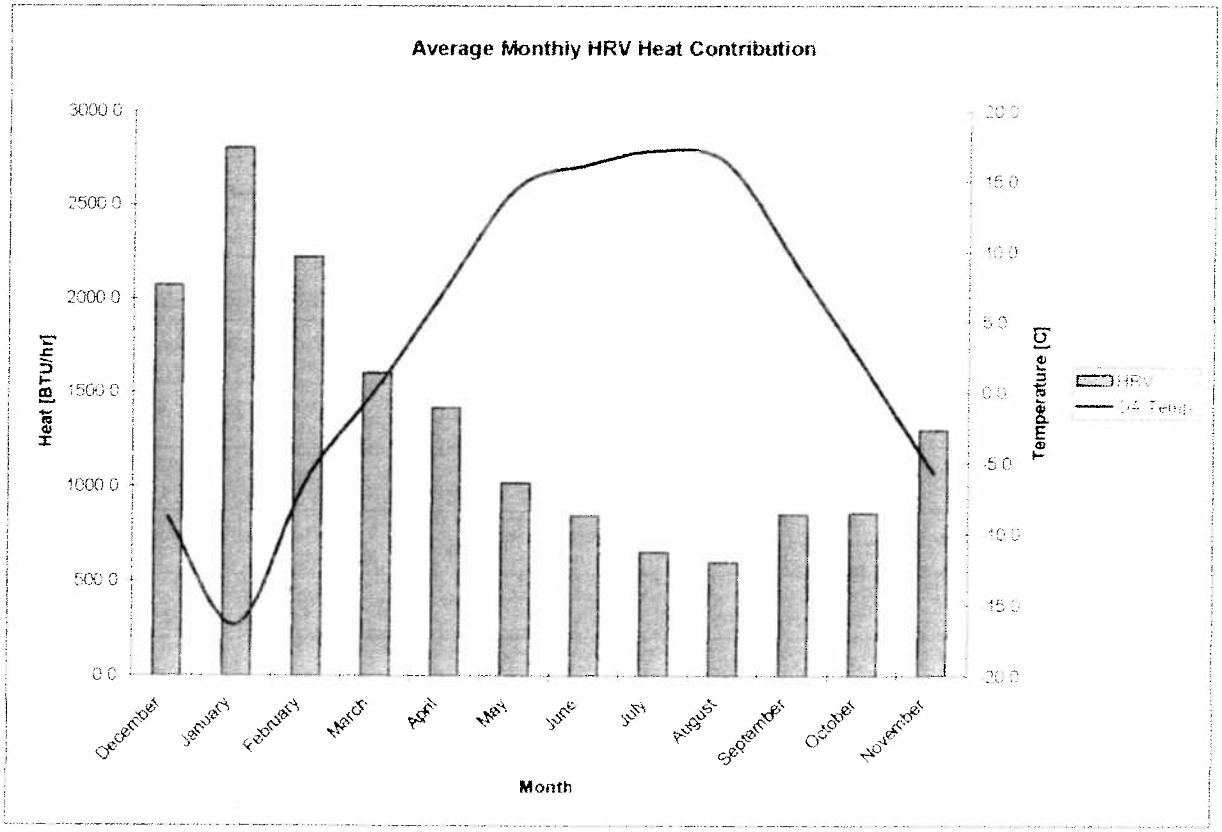


Figure 7: Average Monthly HRV Heat Contribution

4.4 Solar Wall

During the heating season, the solar wall increased the incoming air temperature to the HRV by between 2°C and 8°C (Ref. Performance Review Aug 2005, Figure 2B). The amount of heat that the solar wall provided was calculated according to the following:

$$Q_{solar\ wall} = V_{HRV} \cdot 1.08 \cdot (T_{SWD} - T_{OA})$$

$Q_{solar\ wall}$ = Solar Wall heating contribution [Btu/hr]

V_{HRV} = HRV air flow rate [cfm]

T_{SWD} = Solar Wall discharge air temperature [°F]

T_{OA} = Outside air temperature [°F]

The average monthly heat contribution seen from the solar wall is summarized in Figure 8 below.

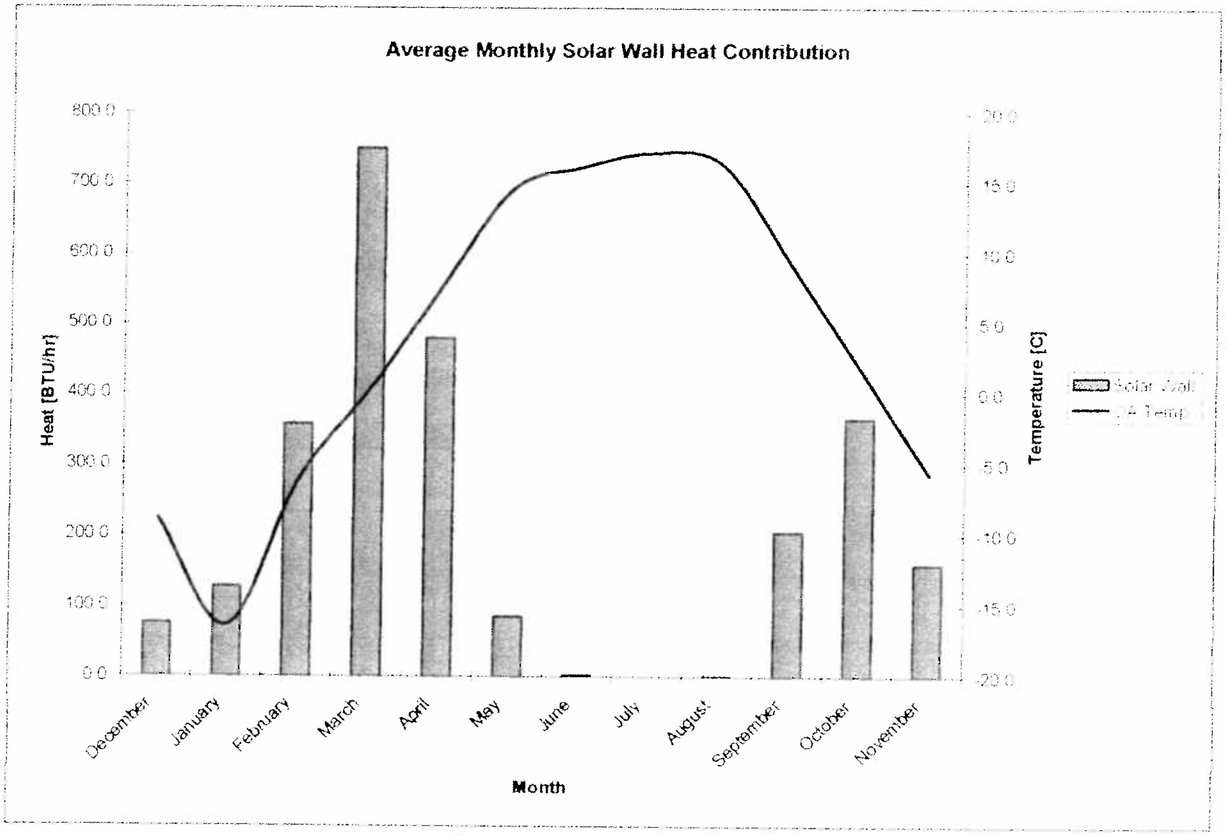


Figure 8: Average Monthly Solar Wall Heat Contribution

5 Analysis

For the purposes of this analysis, the geothermal loop, solar panel, HRV and solar wall will be referred to as the hybrid heating system. An average monthly total heat output from the hybrid system can be tabulated from the monitored data. It is possible to compare this with an estimate of the amount of heat input required by the home each month.

5.1 Comparison of House Heat Demand and Hybrid System Supply

The estimate of home heating requirements is comprised of two parts; domestic hot water demand and heat loss due to transmission and infiltration losses.

Monthly domestic hot water demand was estimated to be 2440 Btu/hr (Ref. Appendix D – Heat Demand Calculations). This heat demand is assumed to be constant throughout the entire year.

The estimated heat loss due to transmission and infiltration losses was determined to be 38,000 BTU/hr (Ref. Appendix D – Heat Demand Calculations). This value represents the peak heat loss on the building on the coldest day of the year. The peak demand can be scaled to provide a heat loss value based on the average monthly outdoor air temperature. It carries throughout the year with outdoor air temperature.

The total heat demand of the home is the sum of the domestic hot water load and the heat loss. A comparison of the total estimated heat demand and total actual heat supply of the home is provided in Table 1 below, as well as in Figure 9.

Month	OA [C]	DHW Load [Btu/hr]	Heat Loss [Btu/hr]	House Demand [Btu/hr]	Hybrid Supply [Btu/hr]	Differnece [Btu/hr]
December	-8.8	2440	15079.4	17519.6	18924.3	1404.7
January	-16.3	2440	19006.5	21446.7	22402.8	956.1
February	-6.1	2440	13655.2	16095.4	18369.3	2274.0
March	0.3	2440	10312.8	12753.0	13986.1	1233.1
April	7.5	2440	6539.2	8979.4	9727.9	748.4
May	14.6	2440	2842.9	5283.1	4895.3	-387.7
June	16.2	2440	1998.1	4438.4	2948.7	-1489.6
July	17.2	2440	1478.6	3918.8	1266.3	-2652.6
August	16.4	2440	1896.2	4336.4	950.2	-3386.2
September	9.2	2440	5632.0	8072.2	7320.7	-751.5
October	1.8	2440	9520.2	11960.4	13128.7	1168.4
November	-5.7	2440	13431.2	15871.4	17599.9	1728.5

Table 1: Comparison of House Heat Demand and Hybrid System Supply by Month

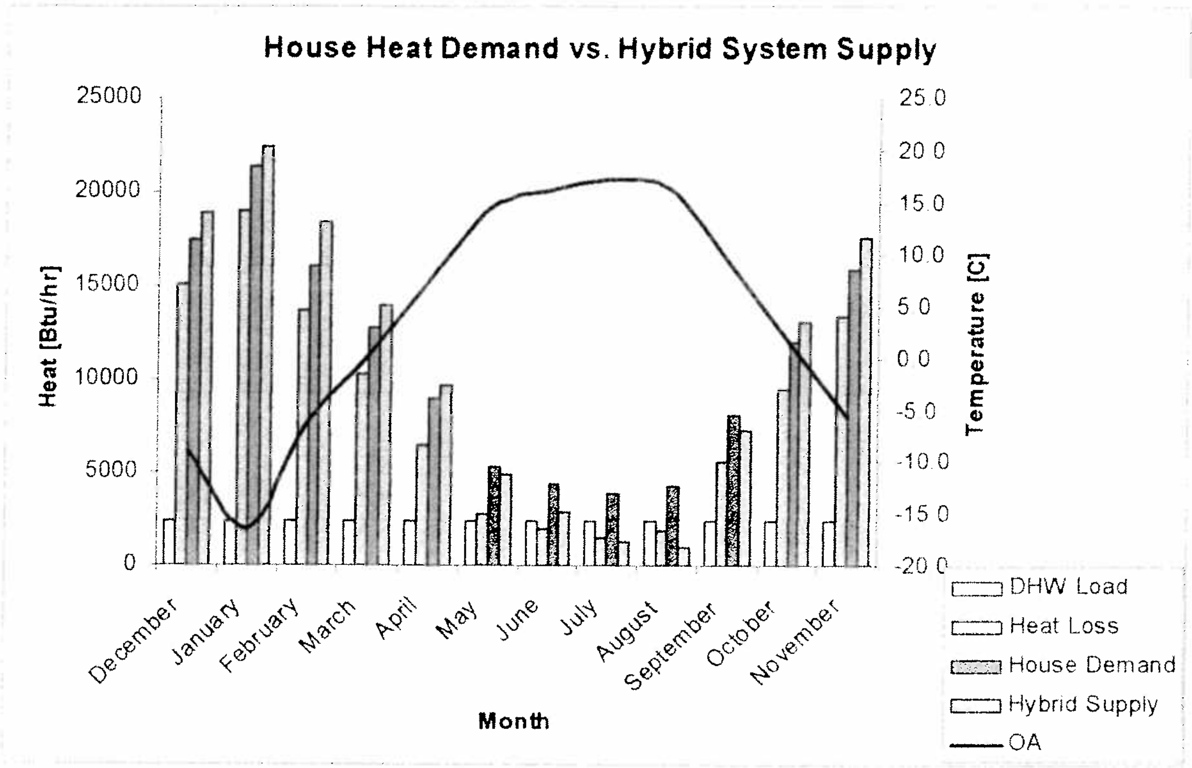


Figure 9: House Heat Demand Compared to Hybrid System Supply

It is important to note that the house's heat loss is calculated based on a set point temperature of 20 °C. From June to August the average outside air temperature remains below this set point resulting in a positive house heating demand calculation. Figure 5 shows the geothermal system supplied heat to the ground (cooling to the house) during these months which indicates that there was no space heating demand. Therefore, either the set point was actually lower during these months, or internal sources of heat (from occupants, lighting, kitchen equipment, etc.) contributed enough heat to equal the heat loss from the house's envelope. The DHW load remains the same throughout the year and during these summer months when the geothermal system is providing space cooling whatever is not provided by the solar system for heating domestic hot water is made up with electric heating.

What can be concluded from Figure 5 and Figure 9 together is that the hybrid system supplied ample heat to the home throughout the year. Further evidence that this is true comes from the building occupants who report that the system provided hot water and maintained the desired thermostat temperature set points in the home throughout the year.

5.2 Contributions of Hybrid System Components

Satisfied that the system is capable of serving the space, how the components contribute to the system will be considered. Figure 10 demonstrates the contribution of each of the components during the heating season.

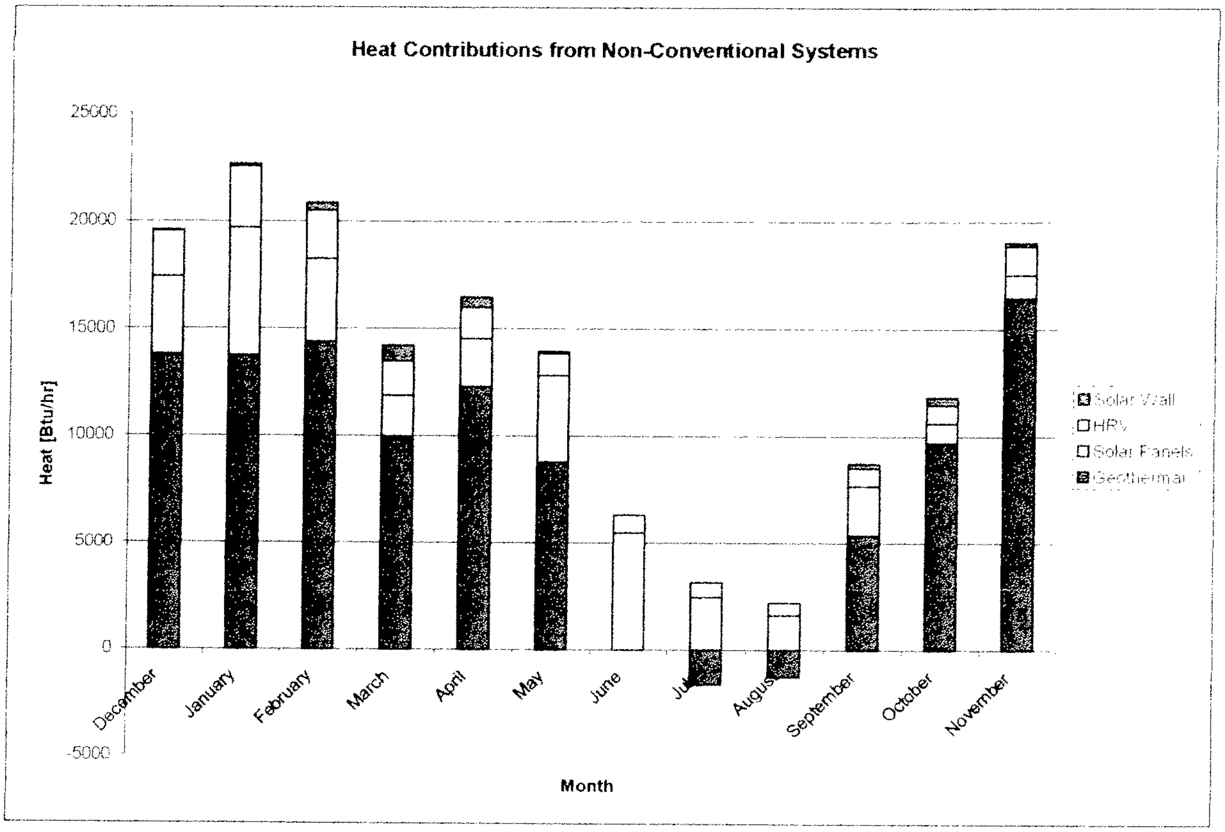


Figure 10: Heat Contributions from the Non-Conventional Components

5.2.1 Geothermal Loop

The geothermal loop provided the largest contribution to the hybrid system providing a majority heat during the heating season. From December through February, the coldest months of the year, the geothermal loop provided an average of approximately of 14,000 BTU/hr with a maximum output of close to 16,500 Btu/hr. This average equates to approximately 75% of the average heating load on the home during those same months

A lower and more varied heat output was seen during the shoulder months of May and September where the loop provided monthly averages around 9,000 BTU/hr. The large fluctuations represent the varied heating demands during this period of the year. The geothermal pumps run on heat demand thus its contribution follows the broad temperature swings experienced in the Northern Canadian spring and fall months. Further variance can be accounted for in the increase in solar gain experienced in the space as the days grew longer. This diminished the need for geothermal heat input to meet the design set points. If the heat pump was not calling for as much heat, because the variable solar gains were accommodating the space, the loop would return the heating fluid at a temperature closer to the supply. This would result in a lower and more varied heating input seen from the geothermal loop.

5.2.2 Solar Panels

In this heating system, the solar panels serve a dual purpose. They provide heat to the space and also assist in heating the domestic water. In observing the total output from the solar panels, a significant contribution to the total heat load on the building was realized. Providing an average between 2000 and 3500Btu/hr during the heating season (December to April), the solar panels can be seen as an integral part of the hybrid heating system in excess of satisfying the domestic hot water load.

Note that the heat contribution in December and January is higher than might be expected due to a significant difference between entering and leaving temperatures on a few days of the month, resulting in high average contributions. For example, January 13th had a T_{EWT} =7.0 °C and a T_{LWT} = 13.6 °C resulting in a one day heat contribution of over 20500 Btu/h. Five similar days in January resulted in the high monthly average of 6000 Btu/h instead of what otherwise would have been closer to 1900 Btu/h.

In practice, the solar heating system is not as effective in winter as the data suggests due to the thermal lag in the system. The glycol heat transfer fluid is cold and takes much longer to heat up in the winter, reducing the heat contribution from the solar panels significantly. Further, there are fewer hours of sunshine in winter and less solar radiation during those hours compared to the summer months.

5.2.3 Heat Recovery Ventilator

The average efficiency experienced by the HRV during the heating season was 75%. That is to say, on average 75% of the heat in the exhaust air was recovered and used to heat the incoming fresh air to the space.

With both the solar wall and HRV it should be recognized that all contributions to heating are achieved without the production of pollutants and little or no power being consumed. Once the equipment is in place, the contributions will be made year after year with no consumables expended (other than minimal electricity needed to run the HRV).

5.2.4 Solar Wall

The solar wall contribution to heating the house is in the order of hundreds of BTU/hr. The reason being that the solar wall preheats the outside air (OA) entering the building. Because the OA component in a residence is so minimal, only 150 cfm, the capacity of this component of the hybrid system to make a significant impact is limited in this case.

The largest heat gains occurred in the late winter months, up to 8°C average in March and April, when longer days and more direct sunlight were experienced. This is compared to a 2°C average temperature rise seen during the darker winter months of January and February.

Due to the limited sunlight during parts of the heating season, and the low fresh air requirements for residences, the overall heating contribution from the solar wall was minimal.

6 Hybrid System Cost Comparison with Conventional Heating Methods

A rudimentary cost comparison between the subject hybrid system and conventional heating system demonstrates the financial advantages of the hybrid system. Using the Degree Day method as outlined by ASHRAE, a value for the total heat input into the home was calculated.

From this theoretical value of annual total heat required, an estimate for providing heat strictly with oil, and strictly with propane was made. Estimates were based on the current market cost per litre for oil and propane. The industry average equipment efficiencies were also factored in.

While no fuel is consumed in the hybrid system, there is a consumable cost in the electrical power needed to run the heat pump. It is necessary that this be considered as it is a consumable that is required to run the system. The amount of power needed to run the heat pump was not monitored throughout the year. This is valuable information however, and in December an ammeter (Amprobe model A70FL) was installed temporarily to determine the power use of the heat pump. Unfortunately one month of data was not enough to compare to the whole building's power load as the utility company does not provide accurate monthly residential usage, only averages with periodic adjustments.

In order to provide an estimate, it was assumed that the unit was running 15% of the time during the 6 month heating season. The hybrid cost reflects the cost of electricity consumed by the heat pump for one year based on this assumption. The results are summarized in Table 2 below. Detailed calculations are provided in Appendix E – Annual Energy Cost Calculations.

System Type	Annual Energy Cost	
Oil	$	2,624
Propane	$	2,544
Hybrid	$	839

Table 2: Annual Operating Cost Comparison of Different Heating Systems for Subject Home

7 Recommendations

There were several instances of missing or unreliable data produced by the monitoring system. An assessment should be made to ensure all data monitors are working accurately.

If a cost comparison between the hybrid system and the conventional oil or propane systems is desired, the electrical power consumed by the heat pump and hot water overflow (to estimate the heat supplied by solar panels to the ground loop) should be monitored for a one-year period.

It may also be of interest to the homeowner, the community and local building science industry to monitor the impact the geothermal loop is having on the surrounding ground temperature. It would lead to realizing the capacity of sites such as this one and perhaps even dissuade sceptics of this technology. Potential studies would involve monitoring the ground temperature at one or multiple locations at the geothermal loop location. Temperatures would be taken at multiple depths above and below the heating loops. This information could determine how much heat is being drawn from and rejected to the ground. Further review would be required to decide exactly how many and at what depths temperatures would have to be monitored in order to produce meaningful data.

APPENDIX A

Sequence of Operations

Duncan Residence

Sequence of Operations

Solar Water Heater

1. The Jace will provide controls for the solar water system. When the water in tank 1 is 15°F cooler than the collector temperature, the circulating pump will be started. Once the pump is started, it's speed will be modulated to maintain a 15°F temperature rise through the solar collector, speeding up when the temperature differential is greater than the 15° setpoint, and slowing down when the differential is less than setpoint. The pump speed will not be decreased below an adjustable setpoint.
2. When the first tank reaches 130°F, the Jace will modulate a three-way bypass valve to divert the return water through tank 2.
3. The Jace will monitor the temperature of tank 2. When the temperature in tank 2 rises to 90°F in the winter, or 70°F in the summer, the ground loop pump will be started. Summer and winter mode will be determined by a time schedule.
4. The Jace will monitor the BTU's gained from the solar water system. Both instantaneous and totalized data will be available. This data will be stored in a temporary log buffer.

Space Heating System – The heating system consists of a WaterFurnace geothermal heatpump, a Lennox blower, and in-slab heating. A solar heater serves the water source for the slab heating, and will be operated as a supplemental system, running whenever the solar system can collect enough heat.

1. The heat pump will be controlled by the Harmony 3 control system, provided by others. The Harmony 3 control system will provide 4 air system zones for controlling the space temperature. The master bath zone is shared with the master bed zone and will have a damper to shut off the air supply when the bed zone is calling for cooling. The other zones are the main floor living areas, lower floor living areas, and the lower floor storage.
2. The Jace will monitor the space temperature in the basement slab zone. On a call for heating, the basement slab zone circulating pump will be started. The zone three-way valve will be modulated to maintain a supply temperature setpoint. The hot water supply temperature setpoint will be reset based upon space temperature (setpoint of 70°F). If the tank T1 water temperature is not above a minimum setpoint, the pump will locked out. After the pump runs for 10 minutes, a contact-closure signal will be sent to the Harmony 3 system, which will in turn energize the heat pump.
3. The Jace will monitor the space temperature in the master bath zone. On a call for heating, the master bath slab zone circulating pump will be started. The three-way zone valve will be modulated to maintain supply temperature setpoint. to the slab coil. The hot water supply temperature setpoint will be reset based upon space temperature. If the tank T1 water temperature is not above a minimum setpoint (115°F, adj.), the pump will be locked out.

4. The garage is heated with baseboard radiation. When the space temp in the garage drops below setpoint (40°F), the circulating pump will be energized. Upon receipt of a pump status signal, the Jace will modulate the three-way diverting valve to maintain the garage temperature setpoint. If the water in tank T1 drops below 120°F, the circulation pump will be locked out. If the garage space temp drops below 35°F, the Jace will override the lockout, and energize the pump regardless of the tank T1 water temperature.

Ventilation

1. The HRV unit will run continuously to provide exhaust from the kitchen, bedroom #2, ½ bath, laundry, master bath, and lower bath. Supply air from the HRV will be sent to the return duct of the Lennox blower.
2. The Jace will start the HRV in low speed. If the return air humidity, as sensed by the Jace, rises above setpoint, the HRV will be commanded to high speed. When the return air humidity drops below setpoint by a deadband, the HRV will be commanded to low speed.
3. The control system will monitor manual override buttons in each washroom. Upon receiving an override signal, the HRV will be set to high speed for an adjustable length of time, initially set at 15 minutes.
4. The fresh air will enter the HRV through a solar wall pre-heat system. If the outside air temperature rises above 10°C, or the supply air from the HVR is above 25°C, the solar wall intake damper will close, and the direct OA damper will open, thus bypassing the solar wall. The system will operate in this mode until either the outside air temperature or the HRV supply air temperature drop below setpoint by a programmed deadband.
5. The kitchen exhaust fan and dryer exhaust fan will have a hard-wired interlock with the fresh air intake isolation damper (D3). The position of dampers D3 will be monitored by the Jace, and when it is fully opened, damper D1 will open, and D2 will close.
6. The garage will have a ventilation system to exhaust humid air. When the garage space humidity rises above setpoint, the Jace will energize the garage exhaust fan.

Domestic Water

1. A desuperheater will operate on its own controls to provide heating for the domestic hot water tank T1 through a heat exchanger.
2. The mixing valve serving the two outside hose bib's will be modulated to maintain a supply temperature setpoint of 70°F, as sensed by the control system. While the outdoor hose is not in use, the mixing valve will have a tendency to modulate toward the hot water side, caused by the stagnant water in the pipe gradually losing heat over time. The Jace will limit the position of the mixing valve to prevent a slug of excessively hot water from discharging after a period of non-use. The maximum position will be calculated using the cold water supply temperature, and tank T1 temperature, to deliver water at a temperature no higher than a user adjustable setpoint (initially set at 80°F).

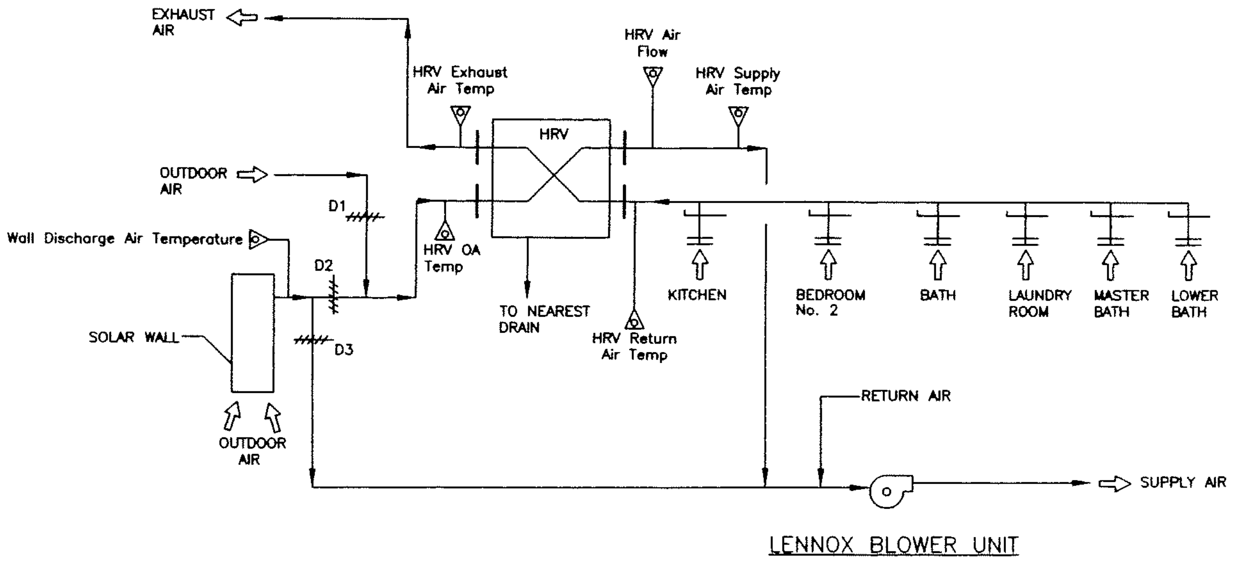
3. The water service entry will have a recirculation system, which will be energized according to an occupancy schedule. The pump will be off in occupied mode, and on in unoccupied mode.
4. The domestic hot water recirculation pump will be energized when the house is in occupied mode. A tempering valve will be modulated by the Jace to maintain hot water supply temperature at 120°F.

Alarms

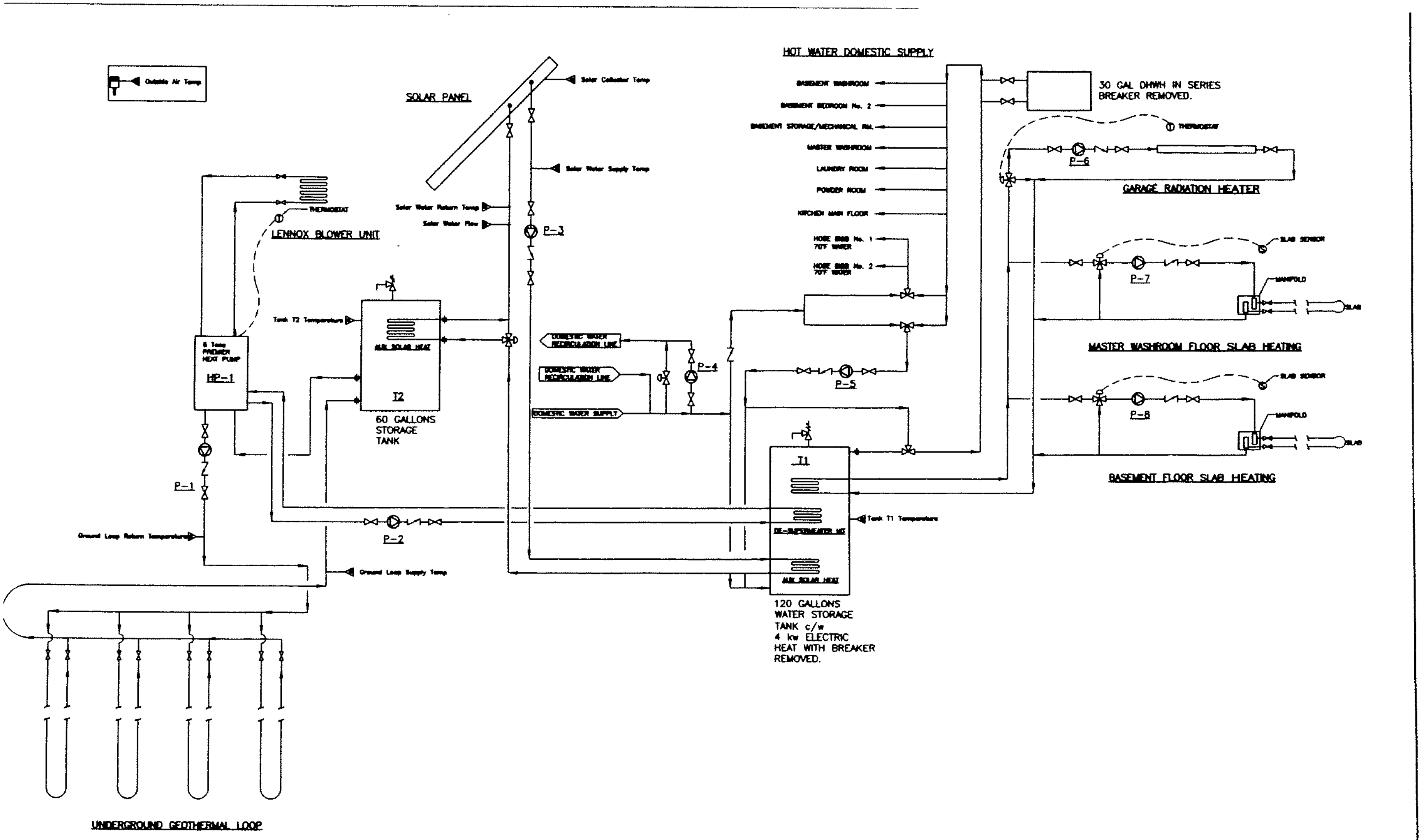
1. The Jace will monitor the system and generate the following alarms:
    a. Solar Heater Pump Fail
    b. Solar Collector High Temp Alarm
    c. Solar Collector Low Temp Alarm
    d. Tank T1 High Temp Alarm
    e. Tank T2 High Temp Alarm
    f. Ground Loop Pump Fail
    g. Basement Slab Zone Pump Fail
    h. Master Bath Slab Zone Pump Fail
    i. HRV Fan Fail
    j. Garage Exhaust Fan Fail
    k. DHW High Supply Temp
    l. DHW Recirc. Pump Fail
    m. Basement Space Temp High
    n. Basement Space Temp Low
    o. Main Floor Space Temp High
    p. Main Floor Space Temp Low
    q. Master Bath Space Temp High
    r. Master Bath Space Temp Low
    s. Garage High Humidity
    t. HRV Exhaust Air High Humidity

APPENDIX B

Schematics



LESSOWAY MOIR PARTNERS	Project Duncan's Residence	Project No. 0303009001	Date 06/11/03
	Client Energy Solutions Centre/ Duncan's Ltd.	Scale NTS	Drawing No. SCH–2
	Title Ductwork Schematic	Drawn by RDD	



LESSOWAY
MOIR
PARTNERS

Project
Duncan's Residence

Client
Energy Solutions Centre/ Duncan's Ltd.

Title
Piping Schematic

Project No.
0303009001

Scale
NTS

Drawn by
RDD

Date
06/11/03

Drawing No.
SCH-1

APPENDIX C

Weekly Averages of Monitored Data

Weekly

Week Number	Starting on Sunday	OA [C]	Solar Wall [Btu/hr]	HRV [Btu/hr]	Solar Panels [Btu/hr]	Geothermal [Btu/hr]
1	11-Dec-04	-3.1	42	1523	3829	14416
2	18-Dec-04	-2.5	82	1801	1916	12844
3	25-Dec-04	-20.9	101	2892	5141	14194
4	1-Jan-05	-13.1	99	2554	5506	14228
5	8-Jan-05	-23.4	159	3104	13775	14993
6	15-Jan-05	-21.1	147	3343	4520	13139
7	22-Jan-05	-10.3	161	2300	1689	12928
8	29-Jan-05	-13.8	284	2478	2932	13675
9	5-Feb-05	-12.0	305	2272	3677	14416
10	12-Feb-05	-12.0	602	2441	4145	14416
11	19-Feb-05	-2.5	376	1923	4008	14416
12	26-Feb-05	2.0	659	1717	2953	11565
13	6-Mar-05	2.7	965	1334	1469	7679
14	13-Mar-05	0.2	986	1545	1962	11300
15	20-Mar-05	-3.2	598	1877	1827	12388
16	27-Mar-05	1.5	1014	1682	1895	7903
17	3-Apr-05	3.2	1014	1544	1347	8222
18	10-Apr-05	3.7	334	1650	1966	7829
19	17-Apr-05	7.0	509	1251	2638	15177
20	24-Apr-05	13.5	0	1164	3340	18782
21	1-May-05	10.0	380	1277	3035	18305
22	8-May-05	15.9	0	977	2373	15858
23	15-May-05	13.7	0	902	4322	4671
24	22-May-05	13.5	0	978	5821	0
25	29-May-05	15.2	0	1043	5759	0
26	5-Jun-05	14.8	13	875	5624	0
27	12-Jun-05	17.7	0	672	5492	0
28	19-Jun-05	15.3	0	943	5488	0
29	26-Jun-05	16.9	0	650	4565	0
30	3-Jul-05	17.0	0	665	3704	0
31	10-Jul-05	18.3	0	563	3240	-2499
32	17-Jul-05	17.0	0	729	1433	-3797
33	24-Jul-05	16.2	0	685	1511	-1215
34	31-Jul-05	14.1	0	608	917	1858
35	7-Aug-05	19.9	0	467	1384	-7564
36	14-Aug-05	16.4	0	589	1280	-3179
37	21-Aug-05	12.7	2.6	694	2046	1832
38	28-Aug-05	10.8	223.2	789	2141	3096
39	4-Sep-05	10.9	17.8	797	3234	6178
40	11-Sep-05	10.5	129.2	931	3650	5758
41	18-Sep-05	9.1	143.9	867	1852	3634
42	25-Sep-05	5.7	443.1	771	737	6153
43	2-Oct-05	5.0	443.9	688	895	3179
44	9-Oct-05	2.7	309.0	792	925	10072
45	16-Oct-05	1.4	403.7	841	758	10469
46	23-Oct-05	-1.0	242.3	1025	838	15349
47	30-Oct-05	-6.2	226.7	1382	1418	16641
48	6-Nov-05	-9.4	153.6	1535	1123	16317
49	13-Nov-05	-3.4	161.5	1135	1088	16064
50	20-Nov-05	1.3	201.2	926	987	15486
51	27-Nov-05	-14.7	220.0	1693	1083	15761

APPENDIX D

Heat Demand Calculations

Residential Heat Loss Calculations
File #:0303009001
Date: December 2005

								Den		Entry		Master Ensuite		Master Bedroom		Living Room		Dining Room	
HEATING LOADS								Area or Quantity	BTU/HR		BTU/HR		BTU/HR		BTU/HR		BTU/HR		BTU/HR
			U	x	Temp	=	Factor												
Glass			0.21		118		24.7800	32	793			13	315	44	1,098	95	2,342	88	2,181
Wall			0.0317	x	118	=	3.7406	215.5	806	176.8	661	824	3,082	278	1,040	178	684	175	655
Door			0.49	x	118	=	57.8200			71	4,105							21	1,214
Roof			0.0203	x	118	=	2.3954	150	359	152	364	172	412	210	503	336	805	178	426
Infiltration:	Volume x (.24*.069*118*.35)					=	0.6800	1345.5	915	1418	964	1,740	1,183	2,121	1,442	4,032	2,742	1,795	1,221
Windows	1.08	x	0.56	x	118	=	71.3664												
Mandoors	1.08	x	2	x	101	=	218.1600												
OH Doors	1.08	x	2	x	101	=	218.1600												
Basement wall (per foot of perimeter)							59.0000												
Basement Floor (per sq.ft.)							2.0000												
Slab on Grade perimeter with insulated foundation wall (ft.)							60.0000												
Slab on Grade perimeter with un-insulated foundation wall (ft.)							60.0000												
							Totals		2,873		6,095		4,992		4,083		6,552		5,696
							Totals + 10%		3,161		6,704		5,491		4,491		7,208		6,266

Square footage
CFM based on ASHRAE STD 62 CFM/ sq.ft. of: 0.2000

Total 56,125

Residential Heat Loss Calculations
File #:0303009001
Date: December 2005

	Kitchen		Bedroom 1		Rec Room		Bedroom 2		Storage Room 1		Storage Room 2		Bath	
HEATING LOADS		BTU/HR		BTU/HR		BTU/HR		BTU/HR		BTU/HR		BTU/HR		BTU/HR
Glass	13	330	20	501	60	1,487	20	501						
Wall	78	290	240	898	81	303	245	918	261	976	338	1,262	54	202
Door														
Roof	117	280												
Infiltration:	1,182	804	1,958	1,331	2,304	1,567	1,600	1,088	1,872	1,273	2,025	1,377	540	367
Windows														
Mandoors														
OH Doors														
I														
Basement wall (per foot o			29	1,711	16	944	30	1,741	29	1,711	38	2,213	6	354
Basement Floor (per sq.ft			131	262	208	416	89	177	121	242	113	225	42	84
Slab on Grade perimeter v														
Slab on Grade perimeter v														
		1,704		4,703		4,717		4,424		4,202		5,077		1,007
		1,874		5,173		5,188		4,866		4,622		5,585		1,108

Square footage
CFM based on ASHRAE !

Total

occupants	2.5	people	assumed
use	500	L/person/day	GL study
Percentage hot water	30%		assumed
total HW/day	375	L/day	Occ*Use*Perct
Flow rate	0.068	GPM	unit conversion
DWS temperature	5	C	assumed
DHW temperature	45	C	assumed
DWH Load	2440	Btu/hr	m*cp*delta T

APPENDIX E

Annual Energy Cost Calculations

Heating Energy Estimation

Print Date: 09/03/2006

Project: **Steve Duncan's House**
Date Prepared: 05-Oct-05
Prepared by: Gerard MacDonald
location: Whitehorse, YT
LMP Project Number:

ASSUMPTIONS:

1 E = CD*(86.4*Qls*DD)/(k*DT)
ref: ASHRAE Fundementals handbook, 1989, SI ver, pg F28.2
where:
E= fuel or energy consumption for estaimte period, kJ
CD = correction factor for heating effect vs. kelvin degree days
Qls = design heat loss incl. inflitration and ventilation, W
DD= Kelvin degree days, C
k = correction factor for heating system
DT = design temperature difference, C

2 Use degree day data for Whitehorse, YT

3 fuel oil consumption = E/fuel oil heating value

4 Day loss and hours assume ventilation system off at night, therefore outdoor air off so night heat loss lower.

5 existing building, furnace, 24/7 operation, minumum O/A via infiltration and washroom E/A fans

6 fuel oil = # 2 diesel fuel oil

INPUT DATA: (input yellow)

Heating Degree days - Environment Canada Climatic Norms

Jan DD	1141.8	July DD	127.9
Feb DD	880	Aug DD	177.7
Mar DD	784.2	Sep DD	322.4
Apr DD	531.5	Oct DD	538.3
May DD	353.9	Nov DD	841.5
Jun DD	193.3	Dec DD	1054.2
		Total DD:	6946.7

Correction factor CD:	0.8	
heat loss day	9,964 W	
heat loss night	9,964 W	118716462
ave occupied hours	24 hrs	
ave unoccupied hours	0 hrs	
correction factor k:	0.65	
Delta Temp	62 C	
Fuel Oil heating Value, mJ/L	38.2 mJ/L	ref. ASHRAE 1989, F15.6, table 6

OUTPUT: Monthly Fuel oil Consumption

Jan	511 L	July	57 L
Feb	394 L	Aug	79 L
Mar	351 L	Sep	144 L
Apr	238 L	Oct	241 L
May	158 L	Nov	376 L
Jun	86 L	Dec	472 L

Total Annual Fuel consumption 3,108 L

Heading Energy Estimation

Print Date: 09/03/2006

Project: **Carcross Tagish First Nations Admin bldg Addition**
Date Prepared: 03-Apr-03
Prepared by: Lee Fleming
location: Carcross, Yukon
LMP Project Number:

ASSUMPTIONS:

1 E = CD*(86.4*Qls*DD)/(k*DT)
ref: ASHRAE Fundementals handbook, 1989, SI ver, pg F28.2
where:
E= fuel or energy consumption for estaimte period, kJ
CD = correction factor for heating effect vs. kelvin degree days
Qls = design heat loss incl. infiltration and ventilation, W
DD= Kelvin degree days, C
k = correction factor for heating system
DT = design temperature difference, C

2 Use degree day data for Whitehorse, Yk

3 fuel oil consumption = E/fuel oil heating value

4 Day loss and hours assume ventilation system off at night, therefore outdoor air off so night heat loss lower.

5 existing building, furnace, 24/7 operation, minumum O/A via infiltration and washroom E/A fans

6 fuel oil = # 2 diesel fuel oil

INPUT DATA: (input yellow)

Degree days - Environment Canada Climatic Norms

Jan DD	1141.8	July DD	127.9
Feb DD	880	Aug DD	177.7
Mar DD	784.2	Sep DD	322.4
Apr DD	531.5	Oct DD	538.3
May DD	353.9	Nov DD	841.5
Jun DD	193.3	Dec DD	1054.2
		Total DD:	6946.7

Correction factor CD:	0.8	
heat loss day	9,964 W	
heat loss night	9,964 W	118716462
ave occupied hours	24 hrs	
ave unoccupied hours	0 hrs	
correction factor k:	0.65	
Delta Temp	62 C	
Propane heating Value, mJ/L	25.2 mJ/L	Ontario Gas Association

OUTPUT: Monthly Fuel oil Consumption, litres

Jan	774 L	July	87 L
Feb	597 L	Aug	121 L
Mar	532 L	Sep	219 L
Apr	360 L	Oct	365 L
May	240 L	Nov	571 L
Jun	131 L	Dec	715 L

Total Annual Fuel consumption 4,711 L

Propane

Cost Comparison Spreadsheet

Heat Load on Building	34000	[Btu/hr]
Degree Days	6947	DD
Heat Required/year	131215	[MBH]

Oil

Cost	$ 2.80	[$/Gal]
Heat Value	140	[MBH/Gal]
Gal/year	820	[Gal/year]
Cost/year	**$2,624.31**	[$/year]

Propane

Cost	$ 1.90	[$/Gal]
Heat Value	98	[MBH/Gal]
Gal/year	1243	[Gal/year]
Cost/year	**$2,543.97**	[$/year]

Hybrid System

Cost	$ 0.12	[$/KWhr]
KW	10.8	[KW]
KW/year (6 months operation)	6998	[KW/year]
Cost/year	**$ 839.81**	[$/year]

System Type	Annual Energy Cost	
Oil	$ 2,624.31	
Propane	$ 2,543.97	
Hybrid	$ 839.81	