THERMAL ENERGY USE OPTIMIZATION

BAIE-D'URFE PUBLIC WORKS BUILDING

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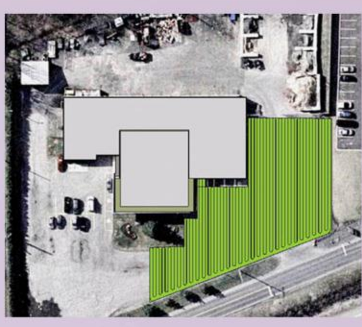

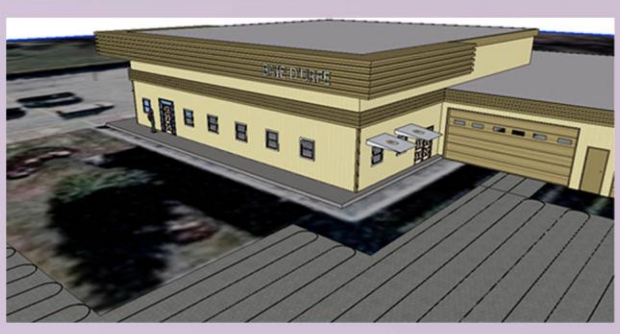

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LIST OF VARIABLES

q = the heat loss (W)

U = the conductance of the material ($W/m^2°C$)

A = area (m^2)

ΔT = the temperature difference between the outside and inside of the building (°C)

A_L =effective area

A_{es} =exposed area

AUL =unit leakage area (depends on construction type)

IDF = infiltration driving force

Q_i = infiltration rate

q = heat transferred from the soil to the heat transfer fluid in W

h = average convective heat transfer in W/m^2K

A_p = pipe cross sectional area in m^2

D_o = pipe outer diameter in m

D_i = pipe inner diameter in m

L= total pipe length in m

K_{pipe} = pipe thermal conductivity in W/mK

T_{soil} = soil temperature in K

T_{bo} = outlet temperature of the heat transfer fluid in K

T_{bo} = inlet temperature of the heat transfer fluid in K

Re_D = Reynolds number

Pr = Prandtl number

K_f = heat transfer fluid thermal conductivity in W/mK

m = heat transfer fluid flow rate in kg/s

μ = heat transfer fluid dynamic viscosity in Pa/s

Tavg = the average temperature of the soil

A_t = the difference between the extreme and average temperatures

α = the thermal diffusivity of the soil in m^2/s

t_o = the length of the temperature variation cycle, in this case fixed to 1 year

q_{ground} = required heat transfer from the soil to the heat transfer fluid in W

q_{ground} = required heat to be delivered to the building in W

COP = coefficient of performance of heat pump system

1. EXECUTIVE SUMMARY

With energy prices on the rise, many people are looking at ways to become more energy wise. The town of Baie-d'Urfé has expressed interest in investing in a more efficient heating and cooling system to try to reduce their energy footprint. There are currently plans for renovations and retrofits to the town building. Alternative design scenarios are presented, which the town can choose to implement alongside of their renovation plans. The alternatives include different combinations of replacing the large windows with more energy efficient ones, replacing the large windows with an insulated wall and small operable windows, and installation of a ground source heat pump.

Geothermal energy uses the heat from deep within the earth's core to directly heat a fluid which is being pumped to the building. Ground source heat pumps work by extracting heat from a shallow ground source with a cooler temperature and transferring it to a sink with a higher temperature. It can be used effectively for both heating and cooling buildings. Along side of the GSHP, a permeable pavement system had to be designed to keep the moisture content of the soil above 12.5%. The windows that are currently in place are all single paned with no insulation factor. Replacement of the windows with more modern, efficient windows could improve the insulation to the building envelope by a huge factor because most heat is lost through windows and doorways. Improving the air tightness of the building includes adding insulation by transforming the north façade into a sealed wall and fixing the holes in the building.

It was determined that the building is currently losing 29.37 kW due to infiltration, the windows, and the holes. The best recommendation to alleviate this significant loss is to replace the large single pane windows with an insulated wall and small operable windows. This results in an energy savings of 15%. This savings is supplemented by the use of a ground source heat pump to supply the heating and cooling needs to the building. An economic analysis was performed and it was determined that these changes have a payback period of 4.5 years.

2. INTRODUCTION

a. Problem Statement

In Canada, heating and cooling of buildings constitutes over 17% of the nation's energy use (OEE, 2011). By increasing the efficiency of buildings through retrofits and improved design, this significant use of energy can be decreased, which can lead to economic savings and environmental benefits. Retrofits applied to aging infrastructure allows for the integration of new energy efficient technologies and design principles, which can significantly reduce energy consumption.

The Baie-d'Urfé Public Works Building, built in 1967, was originally conceived to serve as a car dealership and garage. As such, large windows are featured along its front façade, mainly facing north, with numerous garage doors. Additionally, the ventilation and heat distribution system layout is ineffective and leads to significant heat losses and poor climate control. With large temperature gradients throughout the building and holes in the building envelope, proposed renovations and energy efficient retrofits are necessary to lower high heating and cooling loads and increase thermal comfort.

b. Objective & Scope

The primary project objective will be to reduce the energy consumption for heating and cooling purposes of the public works building in the Town of Baie-d'Urfé. Project costs and subsequent economic savings are extremely important parameters in the selection of a final design. Subsequent benefits of improving thermal energy efficiency of the building include improving climate control, increasing comfort of workers and clients, and demonstrating environmental leadership.

In order to meet the main objective, an energy audit has been conducted to assess the source of large heating and cooling loads. From previous rankings and assessments, geothermal ground source heat pumps, and improvements to the building envelope have been selected to be designed and optimized for thermal energy savings (Busgang, et al. 2011).The scope of this project will include the parameters for the geothermal system (e.g. refrigerant type, pipe length, configuration, etc.), along with various building envelope design options.

3. ENERGY AUDIT

An energy audit is the process by which the energy use of various components is evaluated and areas of improvement are identified. In a building energy audit, the audit will focus on components such as the building envelope, lighting, heating and ventilation. The preliminary energy audit was completed in previous work, where an analysis of utility bills allowed the seasonal and base loads to be isolated. These results are summarized in Table 1 and Figure 1 (see Appendix B for energy audit graphs).

Table 1. Energy breakdown for a yearly period

TYPE OF LOAD	ENERGY TYPE	ENERGY CONSUMPTION (kWh/PER YEAR)	ENERGY COST ($/YEAR)	TOTAL ENERGY COST ($/YEAR)	% OF TOTAL ENERGY COST	TOTAL ANNUAL CONSUMPTION (kWh/YEAR)
BASE LOADS	Electric	124920	12669.48	12774.33	0.4687772	124920
	Natural Gas	0	104.85			
SEASONAL LOADS (SUMMER)	Electric	4575	439.895	439.895	0.0161427	4575
	Natural Gas	0	0			
SEASONAL LOADS (WINTER)	Electric	45720	3682.245	14036.1	0.5150801	401348
	Natural Gas	355628	10353.855			
TOTAL						530843

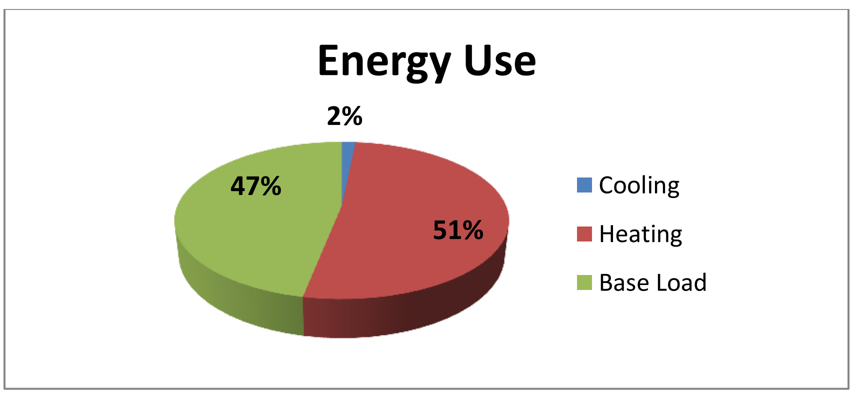

Figure 1. Energy breakdown graph

Additional measurements and analysis were done for this energy audit. First, the building ventilation plans, shown in Figure 2, were analyzed to determine how heating and cooling was being distributed in the building. This analysis identifies potential heat losses or gains due to an inefficient supply and identifies potential connections for future systems. For the ventilation and air conditioning ducts, shown in blue, the plans show that the ventilation is limited to a small section of the office space. For heating distribution, the plans indicate that distribution grills are located along exterior walls in the floor slab, with a majority located along the large exterior windows. The warm air, identified in red, cools as it travels the length of the building. This results in heat loss and poor heat distribution throughout the building. It is also unknown if this heating systems extends to the other parts of the building.

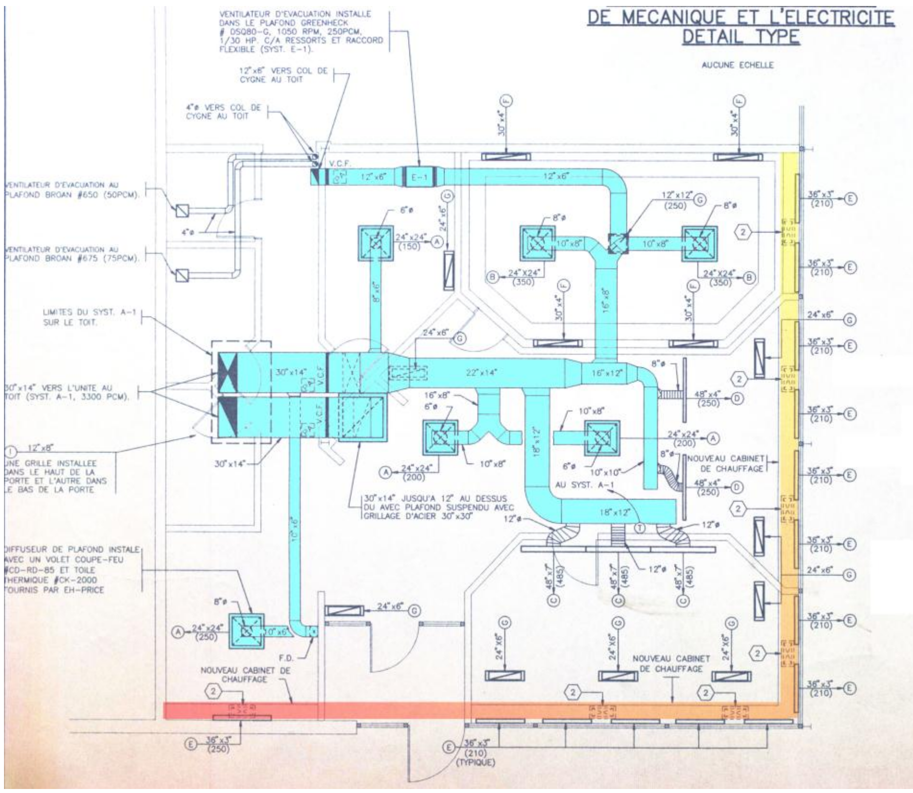

Figure 2 - Existing Ventilation & Heating Distribution System

4. PROPOSED OPTIONS

The objective of reducing energy consumption of the public works building can be done from two different approaches. First it is possible to make the supply of energy more efficient, in other words reducing the amount of electricity or gas required to provide the same amount of heating and cooling for the building. The second approach is to reduce the amount of energy required to heat the building by ensuring that the heat supplied stays in the building longer. If less heat escapes the building, then less heat needs to be supplied, effectively reducing the energy consumption of the building. There are various solutions that can fulfill the project objectives and they fall under one of these two approaches.

Previously a series of possible solutions were quickly investigated. In the energy supply approach these included: solar, wind, biomass, hydro, and geothermal energy and heat pump systems. On the energy demand side possible solutions included: landscaping, solar awnings, insulation, and improvement to the building envelope through a green roof, window replacement, and increase in air tightness. The team has selected two options by means of a Pugh Chart (see Appendix C), where building envelope improvements (increasing air tightness and window replacement) and a ground source heat pump system were selected to be designed. For more explanation for the selection of these options as well as for more information on the technical aspects of all the options refer to the previous report: Thermal Energy Use Optimization Baie-d'Urfé Public Works Building.

The chosen options, a ground source heat pump and building envelope improvements, are now investigated in more detail

a. Improvements to Building Envelope

The envelope of a building consists of all of the materials separating the interior of a building with its exterior. This includes various building components such as the exterior walls, the roof, the windows and the doors (Thumann et al. 2003; Osso et al., 1996). Optimizing heat transmission through these components can significantly reduce a building's energy consumption.

i. Insulation

The insulation of a building is the main barrier which protects the interior of the building from the hot or cold exterior. All materials are assigned an R (or U) value. This value represents the amount of heat transfer which is capable of occurring through the material. Not all materials are created equal when it comes to their thermal insulating properties, for example a wall with a thick layer of insulation can provide greater thermal comfort than a window. This is because the U-value of insulating materials is much lower than that for glass.

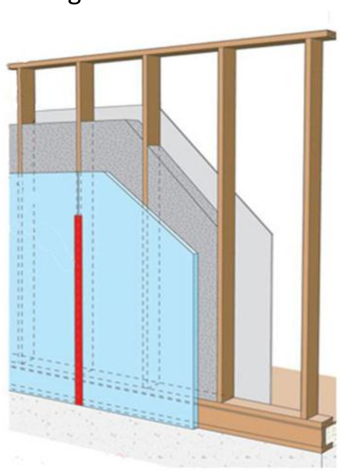

Figure 3. Typical wall construction (buildingscience.com, 2009)

There are many kinds of insulating materials available on the market. Some examples include Styrofoam, cellulose, fibreglass, polyurethane, etc. Different materials are applied in different ways. Some of the materials are rigid, like Styrofoam, and are simply placed in the desired location. Others, like polyurethane, can be blown or sprayed in place in thicknesses of the clients choosing. Some of the more insulating materials are also fire hazards, so choosing an appropriate insulation is often difficult. It is important that a material be well insulated and not a safety concern. The best insulating material is a vacuum. This is because there is no air movement in the wall. The best insulation is the one which restricts the air movement from the outdoors to the inside of the building and vice versa (Ching, 2011).

Generally, walls have four layers, not including structural elements, the façade, usually made from bricks or plaster, plywood, or some other structural material like steel, an insulation layer, usually made from fibreglass, cellulose, or polyurethane foam, and finally, drywall is the innermost layer. Each material for each layer has its own U-value. However, the only layer that provides enough insulation for a cold climate like Montreal's is the insulation layer (Ching, 2011) .

ii. Air Leakage

Air leakage is the uncontrolled air infiltration between the interior and exterior of the building through joints, cracks, holes, etc. It occurs due to a pressure differential between the outside and inside, and creates a flow of air through various points of entry in the building envelope (Busgang et al., 2011).

Since the temperature difference is greatest in the winter for this climate, the effects of air leakage are more significant for heating requirements due to higher pressure and air flow. This air leakage can be a significant source of heat loss or gain, which was estimated to contribute 10% of a building's energy usage by the US Department of Energy (DOE, 1996). Another estimate indicates that as much as 40% of a building's heating requirements can be attributed to infiltrating cold air (Harvey, 2006).

From a visual inspection of the building, holes, cracks, and poor weather sealing were found in the building envelope (see Appendix D). In addition, there are many aging windows and doors, leading to the conclusion that this building has low air tightness. Therefore, with a high degree for potential improvement, increasing air tightness is an important practical solution to minimize energy demand of the public works building (Busgang et al., 2011).

iii. Window Optimization

Windows represent a huge source of potential energy inefficiency in a building. Non-solar heat flow is the heat flow resulting from a temperature differential between indoor and outdoor temperature. The effect of this type of heat flow is significant for heating requirements since in winter the temperature differential is often so great. The rate of non-solar heat flow is referred to as the U-value (DOE, 1997). This is the most important factor in choosing a window and it is dependent on many factors. These factors, in turn, are dependent on climate, cost, building use, and desired air tightness.

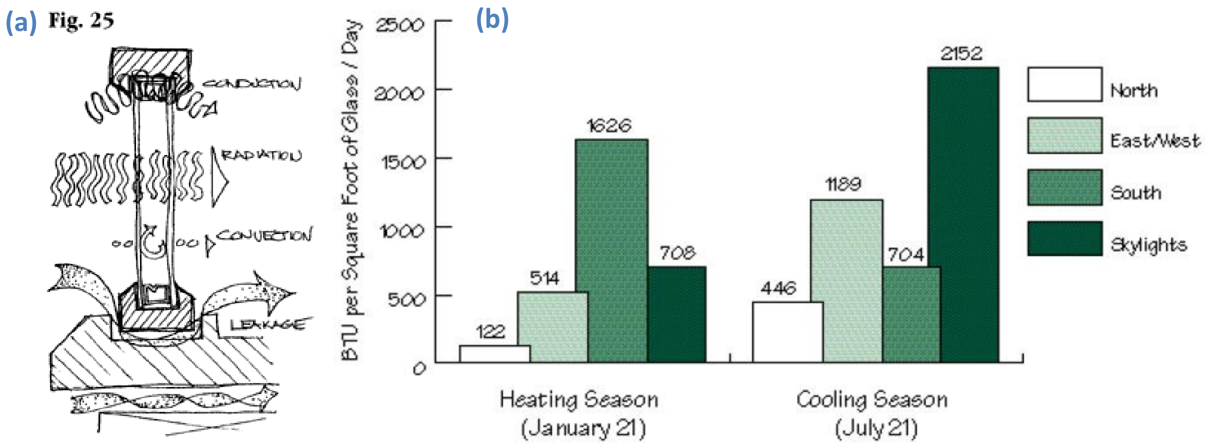

Figure 4. (a) Left: Schematic Heat Transfer Through a Window (NRCan, 2009), (b) Right: Heat gains with varying window orientations (ASHRAE, 1993)

In the public works Building, there are presently large single pane, aluminum framed windows located primarily on the North side of the building. The orientation, size, type of window and frame are all parameters in consideration when trying to minimizing heat losses or gains.

- The building is not presently taking advantage of solar heat gains from the south façade.
- There are high solar heat gains in the summer for east and west facing windows with comparatively low gains in the winter.
- With the majority of large single-pane windows facing north, solar heat gains in the winter are almost negligible (Busgang et al., 2011).

Number of Window Panes – Windows can be single, double or triple paned. This terminology indicates the number of glass panels within the window, also referred to as its glazing. By increasing the number of window panes, solar heat gains can be reduced, as well increase impact and sound resistance (DOE, 1996; NRCan, 2009).

Glass Coating – Coatings for energy efficiency are referred to as low-emittance or low-E coatings. This type of coating is a microscopically thin metal (or metal oxide) deposit on the glazing surface which limits radiative heat transfer. It allows short wave solar energy to pass through while reflecting long wave infrared energy, responsible for heating, back to the exterior surroundings. This process reduces both solar heat gains in the summer and heat losses in the winter. This coating can also be applied between panes to increase the insulating value of the window and a northern low-E coating is recommended for cold climates (DOE, 1996; NRCan, 2009).

Window Frames – Window frames are often made of wood, metal, fiberglass, vinyl, or composites. Certain materials are more conductive than others however proper insulation can prevent any significant heat losses or gains. Other considerations include structural strength, maintenance, weather resistance, and cost. Aluminum frames are relatively poor thermal insulators, but have low maintenance and good durability and weather resistance (NRCan, 2009; DOE, 1996).

Window Functionality– Windows can be fixed or operable. As the name implies, a fixed window cannot be opened and is generally more airtight, which leads to a reduction in heat loss or gain (NRCan, 2009). However, well-placed operable windows can reduce ventilation requirements (DOE, 1996).

b. Improvements to Building Heating System

i. Heat Pumps

Heat pumps are systems, which for heating purposes, extract heat from a source of lower temperature and transfer it to a sink with a higher temperature. This task is possible through the refrigeration cycle. The main components of a heat pump are: a source heat exchanger with a heat transfer fluid, a refrigerant-heat transfer fluid exchanger, an expansion valve, a sink heat exchanger, and a compressor (ASHRAE, 2008). The expansion valve and compressor with other components are part of a single heat pump unit which is commonly available. The same system can be used both for heating and cooling by changing the direction in which it works so that the source becomes the sink and vice-versa. During the heating season, the sink is the room that needs to be heated. There are many possible sources of heat such as air, water, ground, sewers and the sun. The design will be done using a horizontal ground source heat pump due to the characteristics of the site.

The source, through a closed loop, interacts with an indoor loop responsible for transferring thermal energy to the building. In the closed loop a heat transfer fluid circulates, while in the indoor loop a refrigerant is circulated. The interaction between the two loops is facilitated by the heat transfer fluid-refrigerant exchanger, which acts in the heating cycle as an evaporator. The heat transfer fluid enters the exchanger at a high temperature after absorbing heat from the ground and then exits at a lower temperature so it can re-circulate in the loop continuing to absorb energy. In the indoor loop, the refrigerant enters the heat exchanger as a liquid and as it absorbs heat from the heat transfer fluid it evaporates. The refrigerant then passes by a compressor which increases the refrigerant's pressure and temperature. At a high temperature, the refrigerant enters the indoor coil where the heat from the refrigerant is transferred to the air in the building. In this process the refrigerant looses heat and condenses. The liquid refrigerant passes through an expansion valve where its pressure and temperature are lowered. The cool refrigerant then re-enters the first heat exchanger so it can absorb heat from the heat transfer fluid and restart the cycle (Cengel and Boles, 2002).Figure 5 illustrates the process described.

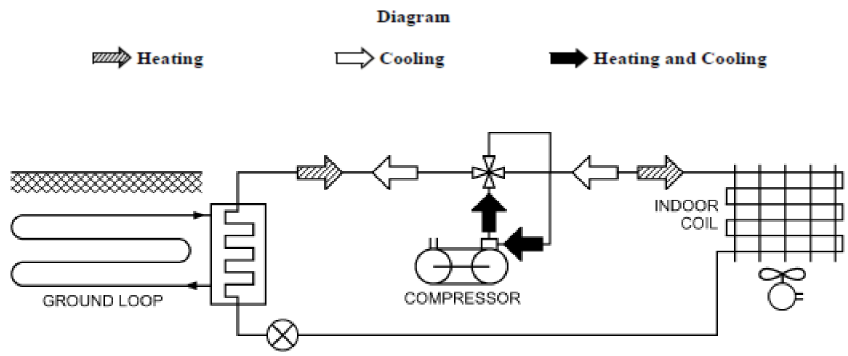

Figure 5. Heat pump system diagram (ASHRAE, 2008)

The performance of a heat pump system is measured by the coefficient of performance (COP). The COP is calculated using specific information on the components used in the actual system: amount of heat delivered (Q_L) and amount of energy required to operate the system ($W_{net,in}$), as in Equation 1 (Cengel and Boles, 2002).

$$COP_{hp} = \frac{Q_L}{W_{net,in}} \qquad \text{Eq. 1}$$

For ground source heat pump systems the COP usually ranges from 2.5 to 4 (Omer, 2006), and it is dictated by the heat pump unit selected.

Other parameters that significantly affect the efficiency of the system are: ground heat exchanger area, depth of ground heat exchanger below surface and horizontal pipe spacing of ground heat exchanger. These parameters must be determined in the design of the system (Healy and Ugursal, 1997).

The main environmental concern with ground source heat pumps is groundwater contamination due to antifreeze leaking from the ground loop present in the heat transfer fluid. The risk can be mitigated at each stage of the project: installation, operation, and decommissioning. In the installation phase it is recommended to ensure no sharp rocks come in contact with the pipes when filling the trenches. This practice will lower the risk of having cracks and subsequent leaks from the pipes. The greatest risk of exposure to antifreeze is during handling, thus appropriate practices must be used, such as wearing masks and protective clothing. The possibility of leaks from the pipes can also be minimized by following the manufacturer's procedure for installation and testing. Once this is completed and the system is operating the probability of a leak is slim. If a leak does occur, however, small amounts of antifreeze will actually be lost. A leak will cause a pressure drop and cavitation, and subsequent system shutdown, which will reduce the circulation of the fluid, thus resulting in a small loss of antifreeze. The biggest risk is rupture of the pipe which will lead to loss of high amounts of antifreeze. Pipe rupture should only occur if the pipe is mechanically damaged. This risk can be avoided by installing a tracer wire above the pipes at a depth of 6 inches (15.24 cm) below the surface. The tracer wire will allow for easy detection of the ground loop with a metal detector which will serve as a warning for future construction at the site to prevent accidental damage to the pipes. During the decommissioning phase, the antifreeze should be pumped out before shutting down the system (USEPA, 1997).

ii. Permeable Pavement

The majority of available land space for the ground source heat pump system is primarily located beneath the parking lot of public works building. Industry contacts were interviewed to determine important logistical problems with this type of installation. Ground source heat pump professional, Mr. Patrick Lambert, identified the primary issue as being the lack of soil moisture beneath civil works (see Appendix E). Literature findings underline the importance of soil moisture to maintain the efficiency of the ground source heat pump system. Leong et al. (1998) found that the performance of the ground heat pump increases significantly from complete dryness to 12.5%. Improved performance was found at even higher saturation levels such as 25%; however, little increase was found passed the half saturation level. Therefore, the design threshold value will be a moisture-content of 12.5% and an optimal value of 25%.

With the available land space on the building's lot, a few options were considered to provide the ground source heat pump with sufficient moisture. First, adjacent lots located south and west of the building have large grassed areas and are owned by the Town. The use of this land for the installation of a ground source heat pump system could inhibit future development of this land, which makes this option unattractive. Second, the industry contact, Mr. Lambert, had suggested using a French drain system to provide moisture through sub-irrigation methods. This method of using sub-irrigation was also proposed by Bloomquist (2003) as a solution for the moisture issues encountered with horizontally coiled ground source heat pump systems installed beneath parking lots. This method could be designed to control the amount of moisture found below ground, however this could increase maintenance costs and capital investment costs (due to deeper digging and more piping requirements), increase water use of the building, and could shift civil works and cause cracking. Though it could be feasible, an alternative solution was sought. Novel systems are currently under development, which integrate permeable pavement systems and ground source heat pump to minimize urban runoff and water treatment capacity requirements, maximize ground water recharge and water treatment through soil infiltration (Scholz and Grabowiecki, 2006). As such, the integration of permeable paving systems into the ground source heat pump design was a chosen solution.

A variety of permeable pavement systems exist such as porous concrete or asphalt, plastic or concrete grid pavers, and interlocking concrete block pavers (see Figure 6) (CVC and TRCA, 2012; Scholz and Grabowiecki, 2006). These types of systems, with the exception of the plastic grid pavers, would be suitable for light traffic and to support heavy vehicles (CVC and TRCA, 2012) as such plastic grid pavers have been excluded.

Porous concrete and asphalt are comparable in cost to traditional paving materials, and offer extremely high infiltration rates (see Fig 6 (a)). Furthermore, its similarity to traditional paving systems will allow it to be easily transitioned and accepted. Possible issues identified due to the lack of documentation for the building's infrastructure, is the possibility of future potholes being repaved with traditional pavement. This may be resolved through proper documentation and visual identification. However, another issue is that of clogging. It has been found that within three years these systems begin to clog and need to be subsequently removed and replaced due the size and amount of air voids (Scholz and Grabowiecki, 2006).

Interlocking concrete pavers include smaller concrete blocks with voids at open joints and corners to allow infiltration, as shown in Figure 6 (b). These open joints are typically filled with gravel or other coarse material. Concrete grid pavers are concrete blocks with large square voids in a grid pattern and smaller voids between segments, as shown in Fig 6(c). The voids are filled with sand, soil or other fine material, and can allow vegetation to grow within the voids. This vegetation would require additional maintenance, such as mowing and the small pore size leads to rapid clogging. Bean et al. (2004) found that the infiltration rate at various sites of interlocking concrete pavers was relatively high, compared to concrete grid pavers. Furthermore with small particle infiltration, such as sand, maintenance on the interlocking concrete pavers was shown to be effective at restoring high infiltration rates, whereas some grid pavers remained low. Smith (2006) also states that the concrete grid pavers are more suitable for low traffic areas, whereas permeable pavers have been used on low-traffic streets, parking lots and even industrial yards. Thus, interlocking concrete pavers was selected to provide moisture to the ground source heat pump.

In addition to infiltration rate benefits, interlocking concrete pavers have a high strength, high resistance to freeze-thaw cycles, heaving, de-icing salts, high abrasion resistance, and are not damaged by petroleum products or high temperatures. In comparison to porous concrete or asphalts, the paving units can be removed to access underground pipes, such as the ground source heat pump installation, in case of emergency, maintenance, or repair. Following this access, the paving units can be replaced, without the need of repurchasing surfacing material or large amounts of waste as would be the case with porous asphalt or concrete (Burak, 2002). Lastly, the Town of Baie-d'Urfé regulates against high impervious coverage for residents due to drainage constraints, which has restricted development. The use and promotion of sustainable drainage (such as interlocking concrete pavements – which qualify for LEED points), could better inform residents and limit restricted development (Smith, 2006).

Figure 6. (a) Permeable concrete; (b) Interlocking concrete paving; (c) Grid paving

5. COMBINATION OF SUGGESTED MODIFICATIONS

Three proposed modifications to the building are being made in order to improve the thermal efficiency of the building, addition of a ground source heat pump, replacement of the windows on the north façade, and increasing the air tightness by replacing the large windows with an insulated wall and smaller windows. These modifications would work optimally if combined all together but due to cost and time restraints of the Town, five scenarios have been developed and designed for.

- **Scenario 1**: Window replacement.
- **Scenario 2**: Modification to north façade by integration of an insulated wall and small operable windows.
- **Scenario 3**: Installation of a ground source heat pump.
- **Scenario 4**: Installation of a ground source heat pump and window replacement with double glazed windows of equal size.
- **Scenario 5**: Building an insulated wall in combination with a ground source heat pump.

6. DETAILED DESIGN

The proposed solutions were deisgned to meet the building's specefic requirements. The design process for these solutions is described here. For the purpose of consistency all heat loss calculations were made at the design temperature as specified by the building code of Canada for the Ste. Anne de Bellevue region. Baie-d'Urfé was not listed in the building code so the neighbouring town of Ste. Anne de Bellevue was chosen as a good representative of the region. The design temperatures were listed as +29°C in the summer and -26°C in the winter. The building energy audit showed that the main deficiency in the building is heating during the winter. For this reason, all calculations were performed at the winter design temperature of -26°C (NRCan, 2005).

a. Insulation

One proposed modification to the building façade to reduce the heat loss in the building includes removing the large windows from the north facing façade of the building and replacing them with a full, well insulated wall with smaller operable windows (scenario 2).

Hetlok Soya pray polyurethane foam was chosen to be the insulating layer in the wall because of its high U-value, and good thermal and environmental properties. The production plant is located in Boisbriand, Quebec, so the product is locally available and supports local business. It is made from recycled plastic and renewable vegetable oils and is the first Canadian made insulating material to adhere to the Montreal Protocol. It has an R-value of R6/inch (Isolation Girbec, 2007).

In order to calculate the heat loss through the designed wall, and later in the windows, the heat loss equation used was

$$q = UA\Delta T \qquad \text{Eq. 2}$$

The wall composition was designed to include the following components, with indicated thickness:

Table 2 - Wall Specifications

	RSI (m²°C/W)
Brick (12.7 mm)	0.0176
Plywood (12.7 mm)	0.11
Insulation (150 mm)	6.3
Drywall (12.7 mm)	0.079

$$q = \frac{1}{6.5066\,\frac{m^2{}^{\circ}C}{W}} \times 93.05m^2 \times \left(22 - (-26)\right)^{\circ}C = 686.45\ W$$

The north façade walls are not load bearing walls because these walls are already supported by structural I beams which do not need to be modified with the integration of the new walls. It was determined that a maximum heat loss of 7.38 W/m^2 would occur through the designed insulated walls at the minimum design temperature of -26°C. This value will be added to the window heat loss calculations in the coming section to determine the overall energy savings of this design scenario (Howell et. al., 2010).

b. Air Leakage

The air leakage is calculated based on the infiltration rate of air into the building. This is done using an effective area which is calculated by multiplying the exposed area of the building by a factor based on the construction of the building. For current air leakage the factor used was for a leaky building built before 1970. For scenario 1, the factor used was for average construction because no insulation was added to the existing walls however the windows were upgraded making the overall building more air tight. For scenario 2, the factor used was for good construction because a layer of good quality insulation is added following the current building code standards and guidelines for construction. Some infiltration will always be present and it is not a bad thing that it occurs to a small degree. It allows a small amount of natural ventilation and air circulation in the building to occur. The overall heat loss from infiltration not considering the infiltration through the holes in the building envelope was calculated to currently be 4.5 kW (See Appendix D). This along side of the heat losses from the holes and windows adds up to a significant heat loss (Howell et al., 2010). The air leakage was calculated only for the north façade because this is the area that is being modified and this is also the area that has the most heating related problems. It is proposed to fix the construction of only the three walls on the north façade and so the savings from the infiltration from these walls only is important.

There are four large holes in the building envelope, two of which are covered by a piece of plywood and two of which are connected to plastic air conditioning pipes. It was calculated that the heat loss through the four holes totals 3.6 kW. See Appendix D for a breakdown of the calculations (ASHERAE, 2009). For each of the proposed scenarios these holes should be properly covered with a layer of insulation.

c. Window Optimization

The U-value represents the amount of heat lost per square meter of window. Single glazed standard windows usually have a rather high U-value of around 5.6 W/m^{2}K, which means that for every square meter of window surface, the building is losing 5.6 W/K (WSC). In the winter when the temperature differential is significantly different, this number has the potential to become quite considerable. During the winter, the employees keep the indoor temperature of the building at 22°C. This results in a temperature difference of 48°C, or 48K.

$$heat\ loss = U * \Delta T * A_{window} \qquad \text{Eq.3}$$

$$current\ heat\ loss = 5.6 \frac{W}{m^2K} * 48K * 89.8569\text{m}^2 = 24.15\ \text{kW}$$

Currently, at -26°C, the building is losing 24.15 kW of heat energy through the windows. During the summer, the losses are fewer and insignificant because the temperature difference is only approximately 8-10°C.

Scenario 1 to replace the existing windows includes replacing them with fixed double glazed windows of the same size with a low E coating. Scenario 2 to replace the existing windows includes replacing the north façade with a solid wall and smaller operable double glazed, low E coated windows. In both scenarios, the windows would have the same characteristics found in figure 1 of Appendix F.

For scenario 1:

The window area and temperature difference will remain the same as in the above calculation. Only the U-value will change. Because this project is concerned more with the high heating requirements in the winter, the calculations will use the highest possible U-value based on the angle of the shading opening. The highest U-value, 1.22 W/m^2K occurs when the windows are fully closed.

$$Scenario\ 1\ heat\ loss = 1.22 \frac{W}{m^2K} * 48K * 89.8569\text{m}^2 = 5.26\ \text{kW}$$

For scenario 2:

The windows would be replaced with brick wall and smaller operable windows evenly spaced on the walls. The windows have the dimensions of 86cm x 96cm.

$$Scenario\ 2\ heat\ loss = 1.22 \frac{W}{m^2K} * 48K * 7.4304\text{m}^2 = 0.44\ \text{kW}$$

Results of building envelope modifications:

Current total heat loss totals:

$$infiltration + windows + holes$$

$$4.5\ kW + 24.15\ kW + 3.57\ kW = \mathbf{29.37\ kW}$$

Total heat loss from scenario 1:

$$infiltration + windows$$

$$2.23\ kW + 5.26\ kW = \mathbf{7.49\ kW}$$

Total heat loss from scenario 2:

$$infiltration + wall\ insulation + windows$$

$$1.1\ kW + 0.69\ kW + 0.44\ kW = \mathbf{2.23\ kW}$$

Replacing the windows for more energy efficient ones and replacing the north facing façade windows with an insulated wall and small operable windows results in a 74-92% reduction in heat loss respectively. This translates to a 12-15% total energy savings for the Town.

See Appendix G for further calculations showing the monthly average energy breakdown and yearly savings calculations.

d. Heat Pump

Description of simulation

The ground source heat pump must be designed to meet the energy requirements of the building. Based on the energy audit conducted the maximum peak that must be supplied is 45.6 kW. It is also important to consider the total energy that must be supplied to the building during the entire heating period. The heating load is determined based on the heat loss of the building and the number of degree days. Degree days were calculated using weather data for Montreal, and comparing for each day the difference between the desired building temperature of 22°C and the outside temperature (NCDIA, 2011). Degree days provide a total estimate of the total amount of degrees that the building needs to be heated in a one year period. The heat loss of the building was estimated taking into consideration heat loss through the walls, windows, ceiling, floor and holes found on the building, as well as including a safety factor increasing the calculated value by 20%. Calculations can be found in Appendix H.

The total heating load is smaller than the maximum peak; therefore the system will be designed so it can provide the peak energy need. However, the maximum peak occurs only during a few days of the year and usually at night when temperature is usually the lowest. Since the building is unoccupied at night, the maximum peak does not need to be strictly met. In these instances it is acceptable for the room temperature can be slightly below 22°C. Therefore, the system was designed to meet 90% of the extreme peak. Calculations can be found in Appendix I. In the rare case when the building is occupied and the energy demand becomes higher than the energy the ground source heat pump can supply, the system needs to be complemented with another form of heating. Since these events should not be frequent, the economic reductions in designing a smaller system will compensate for the eventual need to complement the system with another heating source.

The biggest component of the design of a ground source heat pump is the ground heat exchanger. Heat transfer principles were used to set up a MATLAB code that would determine the required dimensions of the system. Heat transfer from the soil to the heat transfer fluid is characterized by conductive heat transfer from the outside air through the soil, then by conductive heat transfer through the pipe, and finally by convective heat transfer from the pipe inner wall to the heat transfer fluid. This process is represented by equation 4, with the auxiliary equations 5 and 6 (Holman, 1997), and by calculating the soil temperature profile.

$$q = \frac{1}{\frac{1}{hA} + \frac{\ln\left(\frac{Do}{Di}\right)}{2\pi L K_{pipe}}} * \frac{(T_{soil} - T_{bo}) - (T_{soil} - T_{bi})}{\ln\left(\frac{T_{soil} - T_{bo}}{T_{soil} - T_{bi}}\right)} \qquad \text{Eq. 4}$$

$$h = \frac{0.023\, {Re_D}^{0.8} * Pr^{0.4} * K_f}{D_i} \qquad \text{Eq. 5}$$

$$Re_d = \frac{4m}{\pi D_i \mu} \qquad \text{Eq. 6}$$

The soil temperature profile was calculated using equation 7, which gives the temperature at any depth x at any time t (Williams and Gold, 2005).

$$T(x,t) = Tavg + A_t e^{-x\sqrt{\pi/\alpha to}} * \cos\left(\frac{2\pi t}{to} - x\sqrt{\frac{\pi}{\alpha to}}\right) \qquad \text{Eq. 7}$$

This equation was used to estimate the temperature profile of the soil between the frost line and the equilibrium soil temperature, where surface temperature no longer has an impact on soil temperature. In Montréal the frost line is at 1.2 m, in other words, in the winter the soil temperature is 0°C at a depth of 1.2m (Sharratt and McCool, 2005). The equilibrium soil temperature is around 8°C starting at depths of 12m (Williams and Gold, 2005). The soil temperature profile calculated is in Appendix J.

The parameters which are optimized in the simulation are the total pipe length, L, and the depth of pipe in soil, X. These parameters are varied to find the combinations which provide a heat transfer from the soil to the heat transfer fluid which is equal to or bigger than the required value for the system to operate by 0.5%. This required value is established using the COP of the heat pump unit selected according to equation 8.

$$q_{ground} = q_{building} - \frac{q_{building}}{COP} \qquad \text{Eq.8}$$

The COP of the system is determined by selecting a heat pump unit which is able to meet the capacity of the system. The unit chosen is the NLV 240 Water Source heat pump Envision Series which has a COP of 3.8 (WaterFurnace International, 2010). This unit also requires a mass flow rate of 4 kg/s of heat transfer fluid.

There are multiple combinations of pipe length and depth of pipe in soil which are able to supply the energy necessary. The decision of which combination to use is based on the space available in the parking lot. Only the western parking lot will be utilized since the eastern parking lot was recently repaved and the southern parking lot is frequently used by trucks with construction materials. The western parking lot covers an area of approximately 2000 m^2, which is the extreme maximum area the ground loop can cover. The design combination is the one with the shallowest depth which is able to cover an area smaller than the entire parking lot.

Some assumptions were made in order to simulate the actual heat transfer from the soil to the heat transfer fluid. These assumptions include:

1. System is at steady state
2. Properties of all materials, especially the heat transfer fluid, remain constant
3. Fully developed flow in the entire pipe
4. 100% efficiency of heat transfer from heat transfer fluid in heat pump unit
5. Conductive, convective and radiative heat transfer flows other than the ones in the simulation are negligible

The chosen heat transfer fluid to utilize in the system is a propylene glycol mixture. This is a common refrigerant used for HVAC purposes, and it is the least toxic antifreeze available (USEPA, 1997). The refrigerant properties were determined at 0°C for a solution with 0.3 glycol mass fraction according to the models developed by M. Conde Engineering (2011) (See table 3).

Table 3 – Properties of propylene glycol at 0°C with 0.3 mass fraction

Parameter	Unit	Value
Density, ρ	kg/m^3	1032
Specific heat capacity, C_p	J/kgK	3850
Heat conductivity, K_f	W/mK	0.428
Dynamic viscosity, μ	Pa/s	0.0075
Prandtl number, Pr	unitless	65

The pipe to be utilized in the ground loop is a thermally enhanced pipe, which has additives added to high-density polyethylene to increase its thermal conductivity (Raymond et Al., 2011). The thermal conductivity of the pipe, k_{pipe}, is 0.7 W/mK (Raymond et Al., 2011). A ¾'' pipe is typically used in ground loops (McQuay International, 2002), and thus it was utilized to perform the simulation.

Finally the soil will also influence the behavior of the system. Due to the requirement of the permeable pavement to be installed over the ground loop, sandy soil will be utilized. The soil properties utilized in the simulation are in table 4.

Table 4 – Properties of sand soil

Parameter	Unit	Value	Source
Heat diffusivity, α	m^2/s	1.0E-6	(Williams and Gold, 2005)

The programming code utilized to perform the simulation in MATLAB is available in Appendix K.

Results:

Utilizing the simulation described above the ground loop system for the ground source heat pump when installed alone should have a pipe length of 1998m and be installed at a depth of 2.3m. By installing this ground source heat pump system the energy consumption for heating purposes will be reduced to 10.84 kW, or 105 628 kWh/yr, which is the energy required to operate the system. The standard pipes spacing of 1m is utilized in this design. Therefore the total area covered by the pipes is slightly smaller than 1998m^2.

If the ground source heat pump is installed together with other modifications to the building, the dimensions of the ground loop will change since the heat that must be supplied to the building will decrease, and thus a different heat pump unit with different specifications must be used. When the ground source heat pump is installed in conjunction with replacing the windows, in the case of scenario 4, the heat pump unit that should be used is the NLV 160 which was a COP of 3.7 and requires a mass flow rate of 2.33kg/s (WaterFurnace International, 2010). When the ground source heat pump is installed in conjunction with constructing a wall with small operable windows, in case of scenario 5, the heat pump unit that should be used is the NLV 120 which was a COP of 3.6 and requires a mass flow rate of 1.87kg/s (WaterFurnace International, 2010).The possible ground loop dimensions, maintaining the same depth for all scenarios, for each case are in the table 5. Calculations for the energy consumption are available in Appendix L.

Table 5 – Ground Loop Dimensions for Different Scenarios

Scenario	Length (m)	Depth (m)	Energy consumption (kWh/yr)
3	1984	2.1	96056
4	1148	2.0	50972
5	1472	1.9	40861

The ground source heat pump system is designed to provide hot air to the building. The current ventilation system will then be used to provide heating as well. The heat pump unit installed must be able to convert thermal heat from the heat transfer fluid to thermal heat in the air of the ventilation system. The proposed unit to perform this task for scenario 3, for example, is the the NLV 240 Water Source heat pump Envision Series from WaterFurnace International which is connected directly to the ventilation system. The unit has dimensions of 0.864m by 2.238m, and a height of 1.675m, therefore it can easily be incorporated into the building. For detailed information on the installation requirements of the heat pump unit refer to the specification catalog.

e. Permeable Pavement

The design process for the permeable pavement system will be conducted in two parts: PART I will follow the Permeable Interlocking Concrete Pavement Design Manual published by the Interlocking Concrete Pavement Institute (ICPI) (Smith,2006) and Part II will consist of a hydrologic simulation. This simulation is conducted to verify that the moisture at the ground source heat pump will satisfy the minimum design threshold of 12.5% under conservative estimates. It is important to note design and modeling parameters based on soil compaction and soil properties needed to be estimated since the soil is presently under a parking lot, and will be excavated and subsequently modified for the ground source heat pump system.

<u>PART I: Permeable Interlocking Pavement Design</u>

Unless otherwise stated, the following information, design specifications and recommendations have been compiled and calculated based on the work of Smith (2006).

i) *Storm water management objectives:* Full, partial or no exfiltration (i.e. drain pipes diverting infiltrated water to storm sewer or stream) are possible options. The objective for the permeable pavement design is to provide moisture the ground source heat pump, as such full exfiltration has been selected, which is also the most common application (Smith, 2006), and includes overflows to manage possible runoff.

ii) *Site selection:* Parking lots are among the recommended applications for permeable pavement. However, it is not recommended for public works storage areas, due to the potential risk of clogging through fine construction and landscaping materials. Furthermore, a portion of the driveway has been recently repaved (in 2011), and should not be modified. Therefore, the site selected is in the northwest portion of the lot, as shown in Appendix A. This area is 1493 m^2 and will be designed to receive minimal additional runoff.

iii) *Design infiltration rate:* initial infiltration rates have been reported to be over 10^{-3} m/sec (by comparison, the infiltration rate of clay is 10^{-9} m/s). However, with time, it was found that this initial infiltration decreases, but reaches a plateau. Furthermore, it is possible to increase the infiltration rate through maintenance, but the recommended conservative design infiltration rate is 2.1×10^{-5} m/s (Smith, 2006). Furthermore, the recommended design infiltrate rate for full exfiltration in Canada (i.e. colder climates) is 2×10^{-6} m/sec for the subgrade soil. This requirement is met with sand as the subgrade soil with an infiltration rate between 5×10^{-6} to 4×10^{-4} m/s. Finer soil materials, such as clay, would not meet this requirement and would require subsurface drainage.

iv) *Design bearing ratio (California bearing ratio – CBR)*: it is recommended to have an R-value for 24, which can be obtained with an aggregate material such as gravel, which has a CBR value between 30 and 80. Furthermore, sandy soil has a CBR value between 10-40, which can be treated if bearing ratio does not exceed minimum required using cement treatments or a capping layer of crushed aggregate and a geotextile.

v) *Compaction*: compaction could greatly reduce the infiltration rate of the soil, and care should be taken to avoid the use of tracked construction equipment. However, for vehicle applications, the subgrade layer should be evaluated for the need for compaction to stabilize the soil, especially when wet. However, sandy soil should undergo minimal compaction.

vi) *Geotextiles*: To avoid the buildup of fine particles suspended in infiltration water, which can clog and reduce infiltration rates, a geotextile may be used. Geotextiles are also been shown to filter pollutants (such as BOD, metals and even promote microbial degradation of hydrocarbons) (Tota-Maharaj, 2009). Particle sizes, sieve analysis and void spaces of crushed aggregate are required for the design and selection of a geotextile. When such information is provided through the supplier, on-site or laboratory testing, information provided in Appendix M will allow the proper filter criteria to be met.

vii) Depth & Material selection:

a. Concrete pavers: a thickness of 80 mm was selected based on vehicle application requirements, while the spacing of 15 mm is suitable for pedestrian applications. For this small spacing, ASTM crushed aggregate No. 9 has been selected. Additionally, dark color pavers were selected to maximize snow melt (thus lower maintenance and salt requirements), infiltration, and solar heating in the winter season. Though this may hinder capabilities in summer season of ground source heat pump to reject heat, the air conditioning requirements are low in comparison to the heating requirements. Furthermore, this cooling requirement will be further lowered from building envelope design.

b. Bedding course: due to the uneven sublayers, a 50 mm compacted layer of ASTM No. 8 (also known as choke stone) crushed aggregate is recommended to smooth surface and provide filtration.

c. Open-graded base & sub-base: this section acts as an underground detention structure, which requires rapid infiltration and storage capacity. Its thickness is based on minimum requirements for traffic loads and maximum water detention time. The detention time cannot exceed 72 hours, since continual long term saturation can structurally weaken the subgrade soil. Using the most conservative estimates for the traffic load, along with soil type and a retention time of 1 day:

   - Open-graded base: No. 57 crushed aggregate (100 mm depth)
   - Sub-base: No. 2 ASTM crushed aggregate (450 mm depth)

PART II: Hydrologic conditions simulation at ground source heat pump depth using HYDRUS-1D

HYDRUS-1D is a one-dimensional soil and water modeling software. It has been demonstrated as a powerful tool for modeling water flow, heat, solute and CO_2 transport, as well as root water uptake and growth in unsaturated soil conditions (Simunek et al, 2008). Table 6 outlines the steps taken to model the site conditions.

The results of the HYDRUS-1D simulation demonstrate that the minimum design threshold of 12.5% moisture content at the ground source heat pump can be attained with a sand and gravel soil column, as shown in Figure 7. Furthermore, this simulation does not take into the following safety factor for added moisture: the contributing area runoff from adjacent impervious surfaces, snow melt, and inhibition of evaporation due to the paving units.

Table 6. Simulation parameters and information for HYDRUS-1D model

Step	Item selected / inputs
1. Main processes	Water flow
2. Geometry	2 soil materials, vertical, 3 m depth
3. Time information	Duration: 914 days (based on 2.5 years of data starting July 1st 2009) Maximum time step: 1 914 time variable boundary conditions - sinusoidal variations of precipitation generated by HYDRUS 914 meteorological records - Hargreaves formula
4. Hydraulic model	Dual-porosity (Durner, dual van Genutchten- Mualem) – selected due to preferential flow through aggregate in soil No hysteresis
5. Water flow parameters	Material 1: manually entered parameters obtained from Mace et al. (1998) Material 2: sand parameters
6. Boundary Conditions	Upper: atmospheric boundary conditions with surface runoff Lower: free drainage Initial condition: expressed in terms of pressure heard
7. Time Variable Conditions	Precipitation entered for t=1 – 914 days (NCDIA, 2012) Day 1-3: 12 cm of precipitation added to add initial moisture to system (watering of pavement should be done after installation to provide moisture to ground source heat pump)
8. Meteorological Parameters	Latitude: 45.47 ^{o} Crop data: no crop
9. Meteorological Conditions	T_{max} and T_{min} entered for t=1-9.14 days (NCDIA, 2012)
8. Graphical Editor	Initial pressure head: 1 (throughout entire profile) Material distribution: top 0.6m with Material 1 and remaining with Material 2. 3 observation nodes located at -1.9 m, -2.0 m and -2.3 m (coinciding with locations of ground source heat pumps for various scenarios)
9. Post-processing	Mass balance error = 0.001% From obs_node.out, values for water content at both depths graphed over 2.5 years of historical data.

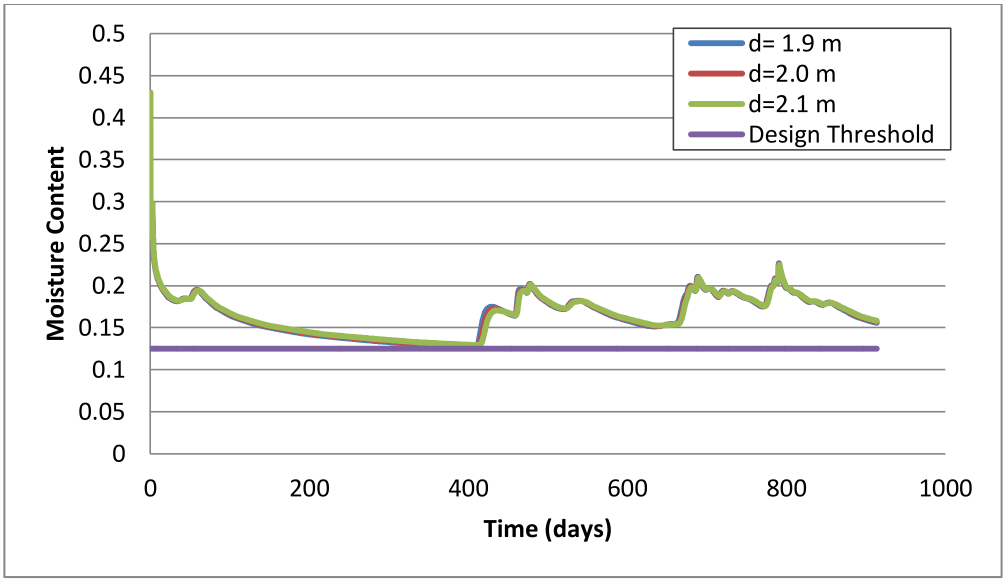

Figure 7. Modeling results of HYDRUS-1D simulation at ground source heat pump design depths

Figure 8. Isometric view of the new building layout

7. SUMMARY TABLE OF PROPOSED DESIGN SCENARIOS

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Windows	• Double glazed, low E-coating, U-value of 1.22W/m²°C. • Reduced infiltration by patching holes • Total heat loss of 7.49 kW	--	--	• Double glazed, low E-coating, U-value of 1.22W/m²°C. • Reduced infiltration by patching holes • Total heat loss of 7.49 kW	--
Insulated Wall and Operable Windows	--	• Insulated walls on the north façade and small operable windows. • Wall U-value 6.51 W/m2°C • Window U-value 1.22 W/m2°C • Reduced infiltration • Total heat loss of 2.23 kW	--	--	• Insulated walls on the north façade and small operable windows. • Wall U-value 6.51 W/m2°C • Window U-value 1.22 W/m2°C • Reduced infiltration • Total heat loss of 2.23 kW
Ground Source Heat Pump	--	--	• Pipe length of 1984m • Depth of 2.1m below the surface • NLV240 heat pump unit • Total thermal energy consumption of 96056kWh/yr	• Pipe length of 1148m • Depth of 2.0m below the surface • NLV160 heat pump unit • Total thermal energy consumption of 50972kWh/yr	• Pipe length of 1472m • Depth of 1.9m below the surface • NLV120 heat pump unit • Total thermal energy consumption of 40861kWh/yr

8. ECONOMIC ANALYSIS

Cost management is an important stage in the design process. It is utilized as a tool to balance a project's scope and deliver its expectation while respecting the allocated budget (Manfredonia, 2010). With an economic analysis, the Town of Baie-D'Urfé will be equipped with the information to determine whether the design is a feasible undertaking. It also forecasts expected costs to distribute to construction contractors and other project professionals that are within standard norms. Ultimately, the economic analysis will serve as a guide to determine the most effective choice among building alternatives (WBDG, 2011).

First, each of the three suggested alternative solution will be individually evaluated; these are listed as scenario 1, 2 and 3 in Section 9 Summary Table of Proposed Design Scenarios. Implementing any of these scenarios will reduce the building's energy consumption and furthermore profit from annual savings. The table 7 describes the capital cost, annual savings and payback period of each individual project (see Appendix N for calculations):

Table 7. Summary of Capital Cost and Annual Savings for scenarios 1-2-3

	Scenario 1	Scenario 2	Scenario 3
	Large Windows	Small Windows & Wall Insulation	Ground Source Heat Pump & Permeable Pavement
Capital Cost	$90,200	$24,000	$147,800
Annual Savings	$4,200	$5,100	$25,900
Payback Period	21.4 years	4.7 years	5.7 years

Scenario 1 has the highest payback period. This is due to the fact that 17 custom made windows would replace the existing large-scale windows. Because the windows would have to be designed specifically for the building, the 17 windows alone cost $75,200, an estimated cost calculated by Emma Sirois from Unicel Architectural. Scenario 1 also has a higher heat loss value compared to scenario 2. For these reasons, scenario 1 and scenario 4, which integrates replacing windows with the installation of GSHP, will be omitted from further analysis because they are not deemed as economically feasible due to their poor cost/benefits correlation.

Scenario 2 comprises of removing the large windows and building a wall with small operable windows for each room. Because the desired improvements are commonly performed construction renovations, the capital cost is relatively low. Contrary to scenario 3, installing a GSHP and permeable pavement, which is a more intricate specialized undertaking, requires a higher capital investment. However, scenario 3 provides the largest economic profit.

This leads to the recommendation of two scenarios. To receive the maximum benefits – minimizing heat loss and energy consumption – an integration of installing a wall with small windows as well as a GSHP system with a permeable pavement is selected (referred to as scenario 5). The second proposed recommendation is a more realistic affordable option that would only install the insulated wall with small windows (referred to as Scenario 2). In this situation, there is still potential to implementing a GSHP; once the project is paid off in 4.7 years, 6.2 years from then the Town will have accumulated from the annual savings 20% of the capital investment needed to implement a GSHP. Therefore, the second option can be potentially viewed as the first option but completed in two separate stages over a longer period of time. The table below summarizes the capital cost and savings of the suggested recommendations.

Table 8. Capital Cost and Savings Summary of the two Recommended Scenarios

	Scenario 2	Scenario 5
	Small Windows & Wall Insulation	Small Windows & Insulated Wall Ground Source Heat Pump & Permeable Pavement
Capital Cost	$24,000	$159,400
Annual Savings	$5,100	$35,800
Payback Period	4.7 years	4.5 years

9. CONCLUSION

From previous work it was determined that the thermal energy use of the public works building in Baie-d'Urfé must be minimized to reduce energy consumption. Following the analysis of possible solutions to address the problem modifications were designed for the building. These modifications include improvement of building insulation, minimization of air leakage, window optimization, and ground source heat pump combined with permeable pavement. These modifications can be implemented individually or in different combinations. Based on the costs and payback period two scenarios were finally recommended to the Town of Baie-d'Urfé. These are scenario 5 which includes all the proposed modifications, and scenario 2 which consists of the replacement of the windows in the front façade by an insulated wall with operable windows. Following the designs developed, The Town will be able to implement either of these scenarios according to their financial capabilities. With these modifications to the building the thermal energy use is significantly reduced, and the associated cost for energy will decrease as well.

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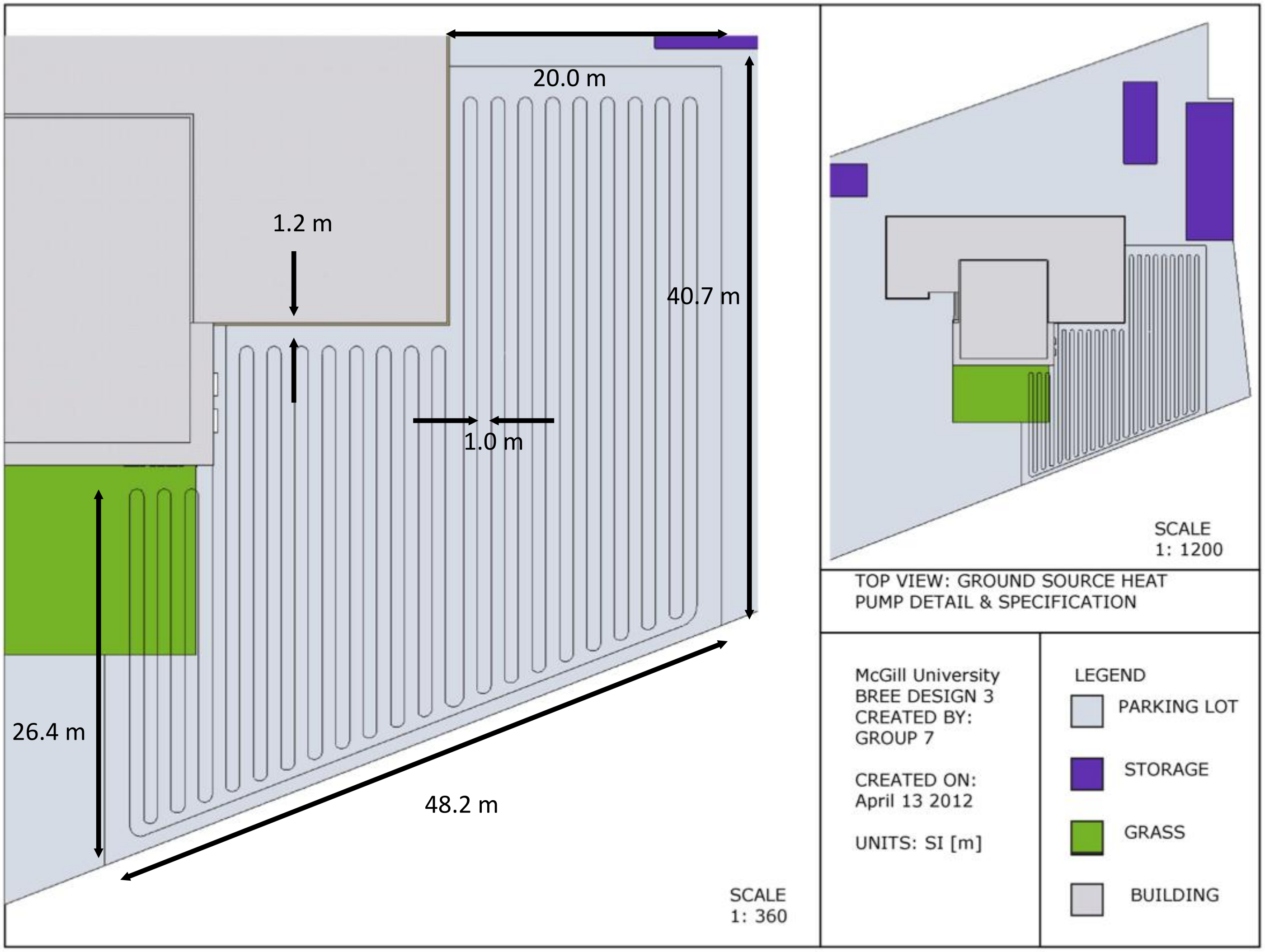
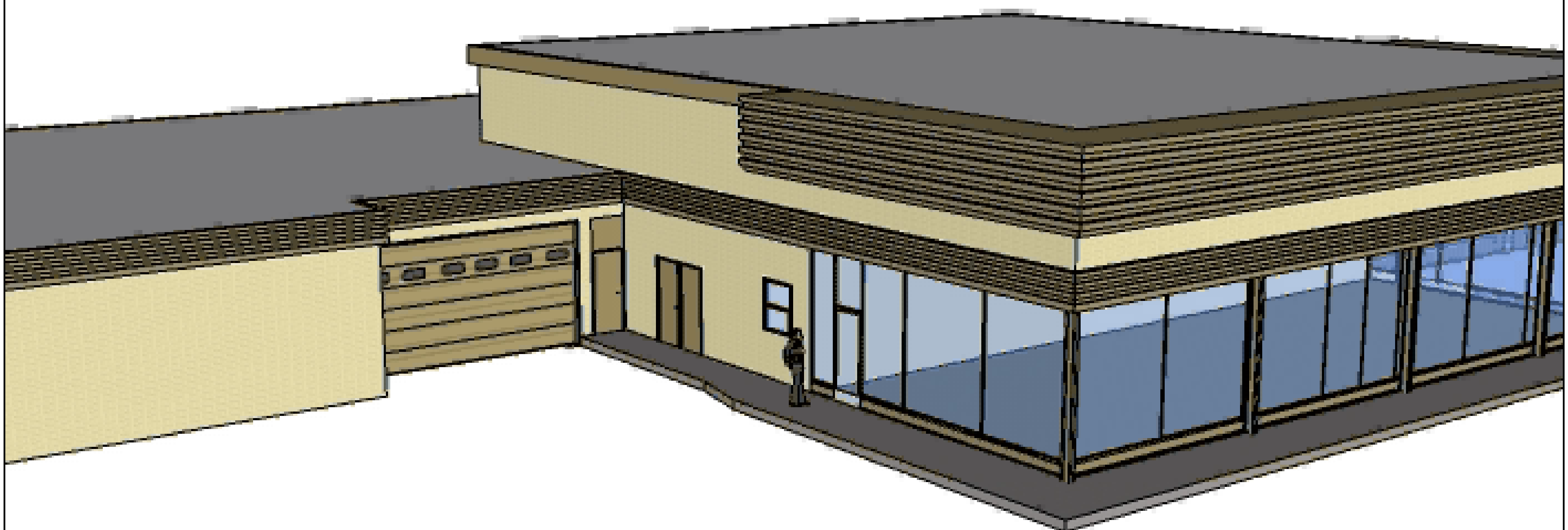
11. APPENDICES

APPENDIX A – FLOOR PLAN AND DESIGN SIMULATIONS

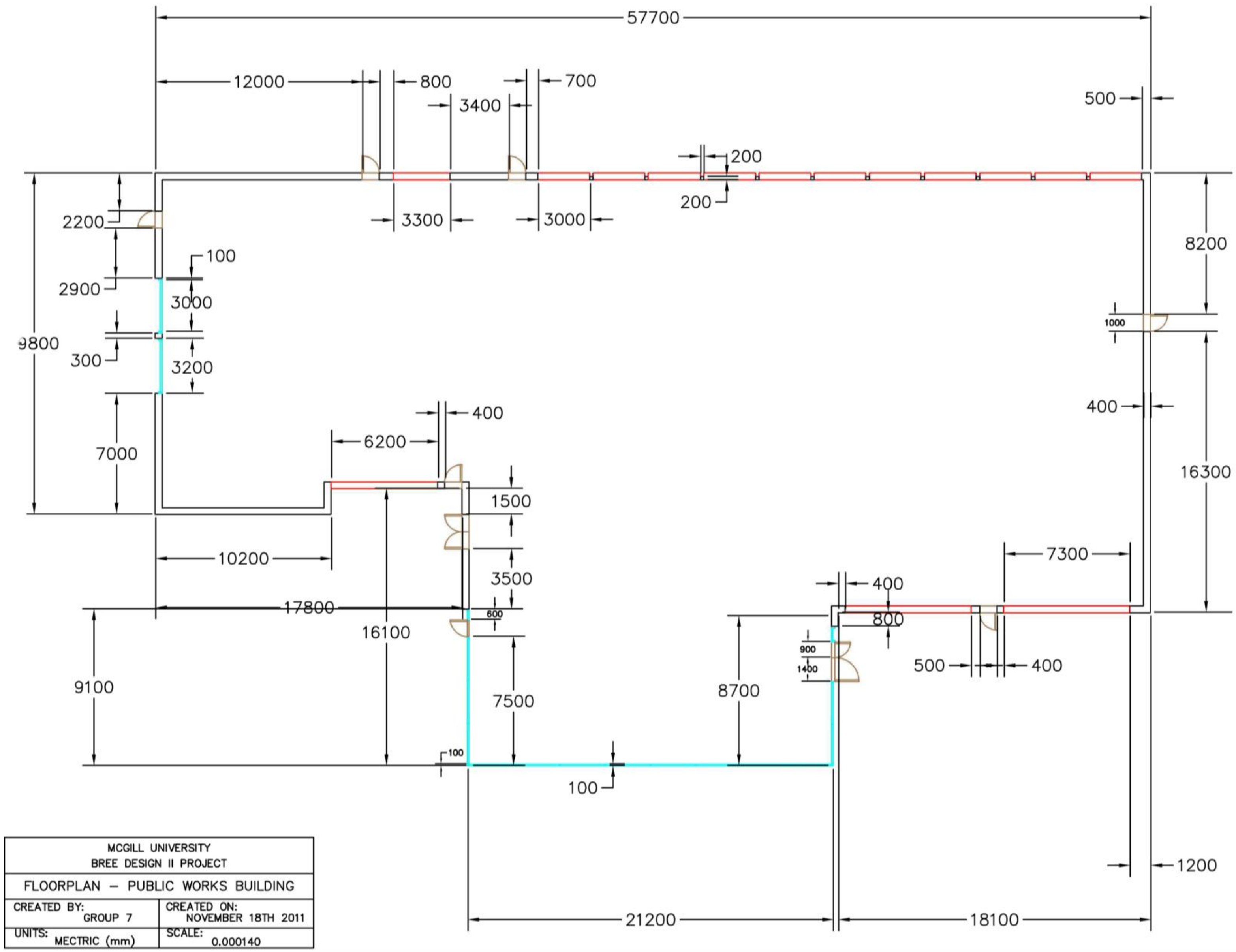




CURRENT BUILDING LAYOUT

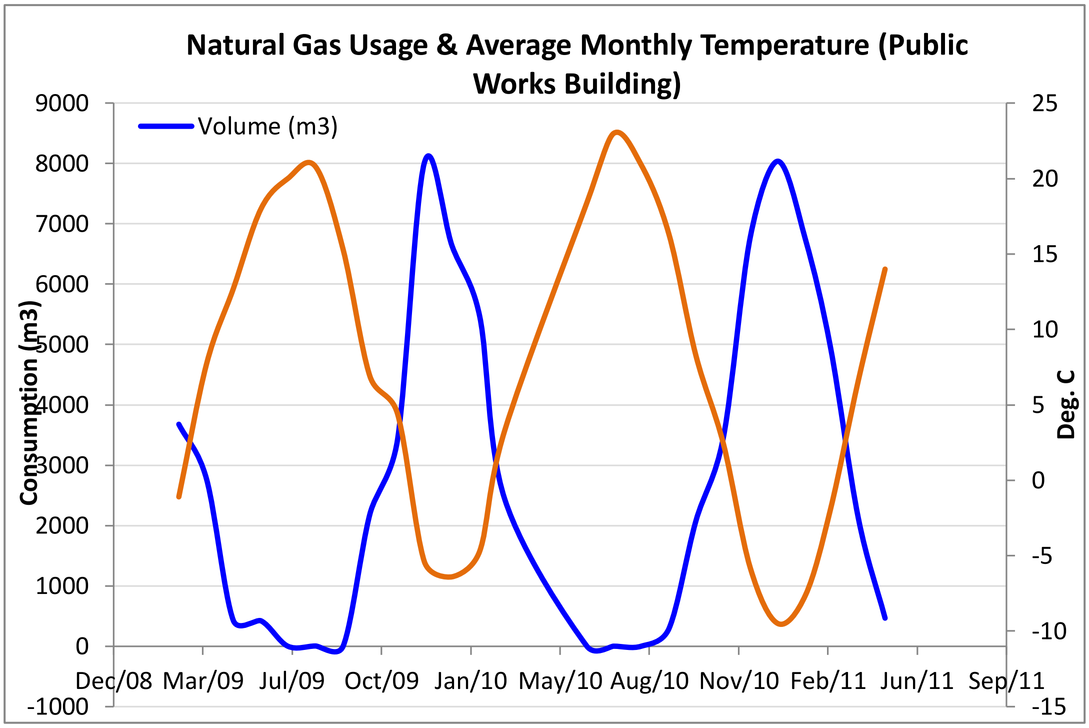
ISOMETRIC VIEW

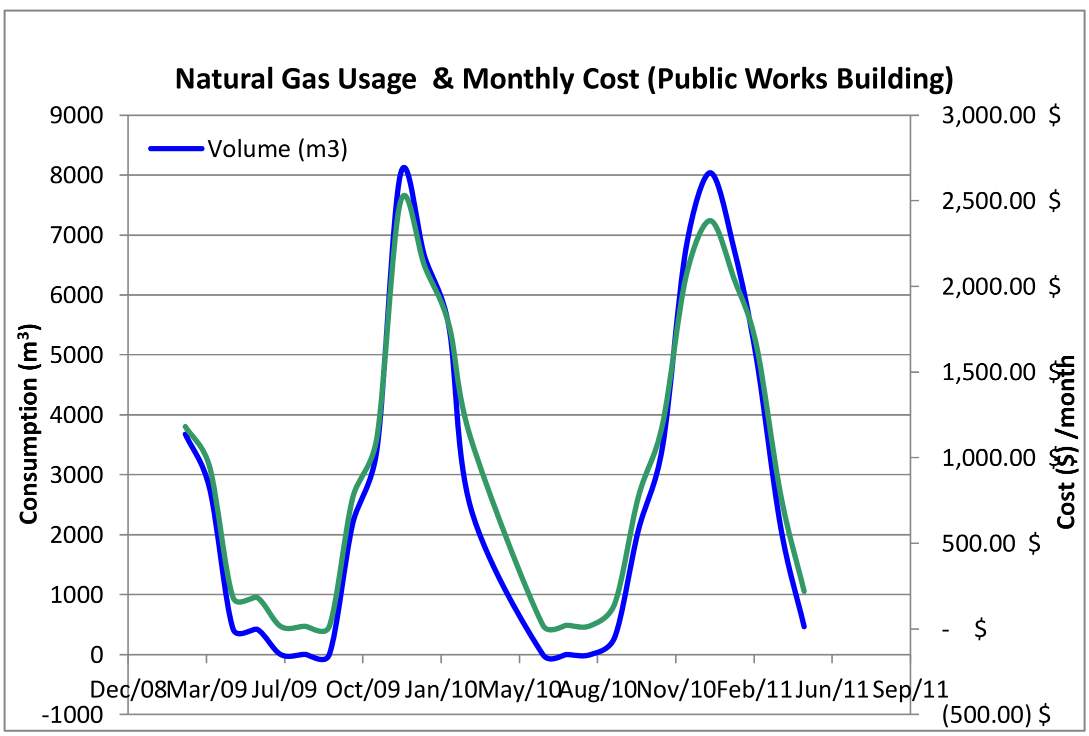
MARCH 12 2012 | GROUP 7

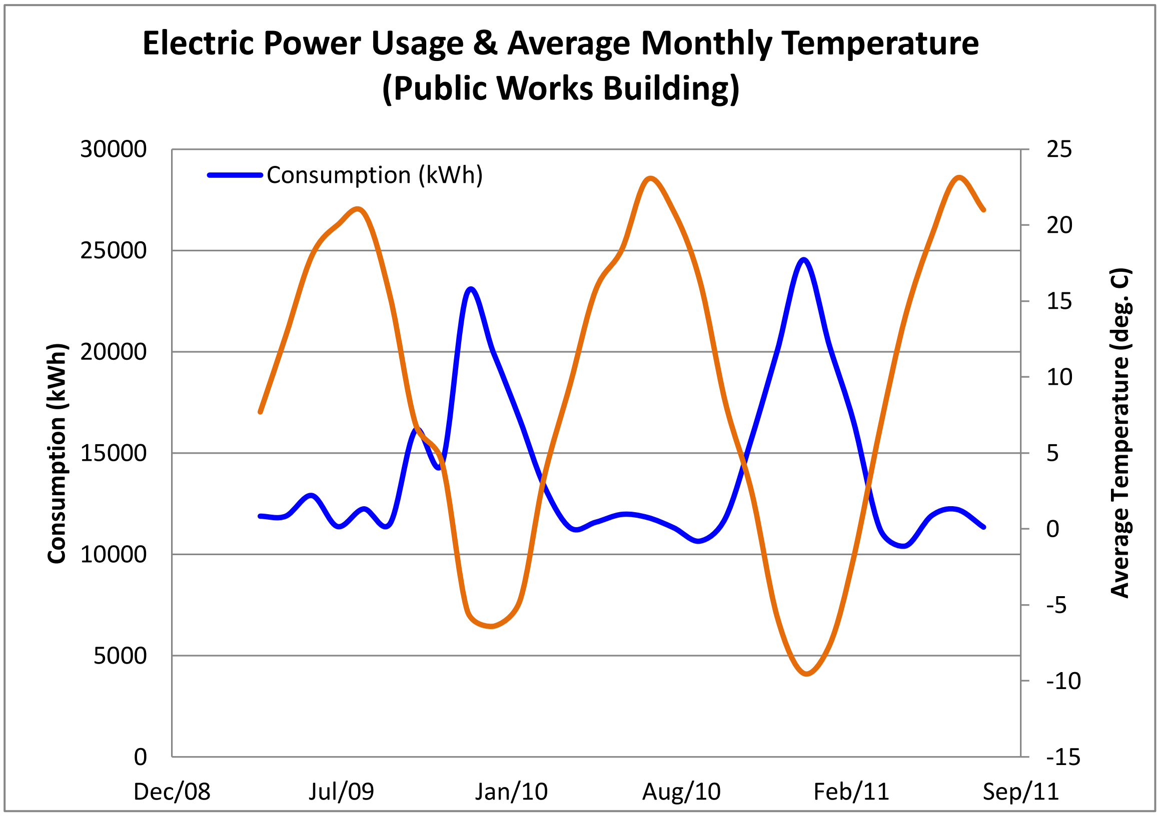

57700
12000
800
3400
700
500
200
200
3300
3000
2200
100
2900
3000
9800
300
3200
7000
8200
1000
400
16300
400
6200
1500
10200
3500
7300
400
800
17800
600
16100
900
1400
500
400
9100
7500
8700
100
100
1200
21200
18100
MCGILL UNIVERSITY
BREE DESIGN II PROJECT
FLOORPLAN – PUBLIC WORKS BUILDING
CREATED BY: GROUP 7
CREATED ON: NOVEMBER 18TH 2011
UNITS: MECTRIC (mm)
SCALE: 0.000140

APPENDIX B – ENERGY AUDITS DETAILS

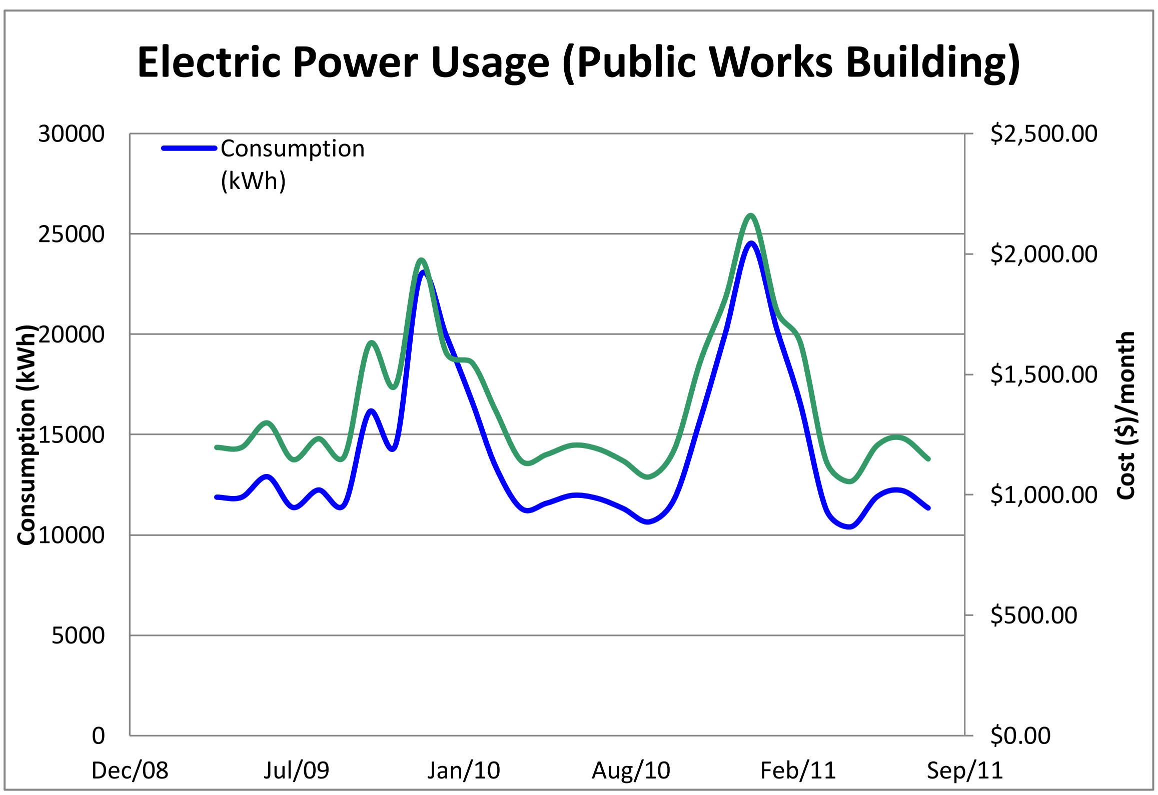
The following graphs were produced based on utility bills from December 2008 to September 2011. They were utilized in the energy audit.







Electric Power Usage & Average Monthly Temperature
(Public Works Building)
Consumption (kWh)
Consumption (kWh)
Average Temperature (deg. C)
30000
25000
20000
15000
10000
5000
0
25
20
15
10
5
0
-5
-10
-15
Dec/08
Jul/09
Jan/10
Aug/10
Feb/11
Sep/11



Electric Power Usage (Public Works Building)
Consumption (kWh)
Consumption (kWh)
Cost ($)/month
30000
25000
20000
15000
10000
5000
0
$2,500.00
$2,000.00
$1,500.00
$1,000.00
$500.00
$0.00
Dec/08
Jul/09
Jan/10
Aug/10
Feb/11
Sep/11

APPENDIX C– PUGH CHART

Design II ranking system based on results obtained by simulating each alternative.

criteria	weighting	heat pump	geothermal	green roof	air tightness	windows
heating energy	5	4	5	1	3	2
cooling energy	2	5	2	3	1	4
cost	5	3	1	2	5	4
Payback period	4	5	4	1	3	2
ease of integration	3	-1	-3	-1	1	3
environmental impact	1	0	0	3	0	0
total		62	41	25	57	55

APPENDIX D– INFILTRATION CALCULATIONS

Holes in Building	Description
	RECTANGLE – Mesh height 6.0cm width 18.0 cm Area: 0.0108 m^2 CIRCLE – Tube diameter 0.5cm Area: 0.0628 m^2 Located under the middle of the 6th window from the left (Katherine's office window).
	ELLIPSE – plywood vertical diameter 14.0 cm horizontal diameter 15.0 cm CIRCLE– plywood + spider webs diameter 3.0 cm Located under the bottom left corner of the 8th window from the left.
	CIRCLE – plywood diameter 14.0cm Located under the bottom left corner of the 1st window from the left on the eastern wall.

Heat loss through the holes:

$$A_L = A_{es} * A_{UL}$$

$$A_L = 108cm^2 + 0.785cm^2 = 108.785cm^2$$

$$Q_i = A_L * IDF$$

$$Q_i = 108.785 * 0.104 = 11.314\ l/s$$

$$q = C_S * Q_i * \Delta T$$

$$q = 1.23 * 11.314 * (22 - (-26)) = \mathbf{668\ W}$$

Heat loss due to infiltration on the north facing façade:

$$A_L = A_{es} * A_{UL}$$

$$A_L = 129.5947m^2 * 5.6\frac{cm^2}{m^2} = 725.73cm^2$$

$$Q_i = A_L * IDF$$

$$Q_i = 725.73 * 0.104 = 75.48\ l/s$$

$$q = C_S * Q_i * \Delta T$$

$$q = 1.23 * 75.48 * (22 - (-26)) = \mathbf{4.5\ kW}$$

Heat loss due to infiltration with scenario 1:

$$A_L = A_{es} * A_{UL}$$

$$A_L = 129.5947m^2 * 2.8\frac{cm^2}{m^2} = 362.87cm^2$$

$$Q_i = A_L * IDF$$

$$Q_i = 362.87 * 0.104 = 37.74\ l/s$$

$$q = C_S * Q_i * \Delta T$$

$$q = 1.23 * 37.74 * \left(22 - (-26)\right) = \mathbf{2.23\ kW}$$

Heat loss due to infiltration with scenario 2:

$$A_L = A_{es} * A_{UL}$$

$$A_L = 129.5947m^2 * 1.4\frac{cm^2}{m^2} = 181.4cm^2$$

$$Q_i = A_L * IDF$$

$$Q_i = 181.4 * 0.104 = 18.87\ l/s$$

$$q = C_S * Q_i * \Delta T$$

$$q = 1.23 * 18.87 * \left(22 - (-26)\right) = \mathbf{1.1\ kW}$$

Table 9 - Heat loss from each of the holes

	Area in m^2	Area in cm^2	Q (W)
RECTANGLE - Mesh		108	663.14
CIRCLE - Tube		0.785	4.82
ELLIPSE - plywood	0.06594		28.77
CIRCLE - Plywood	0.002826		1.23
CIRCLE - plywood	0.061544		26.86
TOTAL HEAT LOSS			**720**

APPENDIX E– CONFERENCE CALL WITH PATRICK LAMBERT

CONFERENCE CALL – FEBRUARY 10th, 2012 @ 2:30pm

Company name: Geo-energie

http://www.geo-energie.com/

Contact name: Patrick Lambert

Telephone: (450) 641 – 9128 (ext. 225)

Question 1: Have you done projects in the West Island or specifically in Baie-d'Urfé?

Yes, we've done projects or consulted with Hagen [in Baie-d'Urfé], Schluter [Ste-Anne's], Veteran's hospital [Ste-Anne's], John Abbott [Ste-Anne's]

Question 2: In order to complete various soil simulations, we need to obtain the soil properties in the area, such as thermal conductivity. Would you have any reference values?

The Baie-D'Urfe area has the highest soil thermal conductivity on the Island of Montreal. It does have issues with its soil texture (silty-clay/clay) in terms of drilling. However, this does not inhibit the installation of geothermal systems (vertical or horizontal) when compared to an area such as Ile-Perrot.

The soil conductivity for vertical loop system is approximately 2.6-3.2 btu/ft-^{o}F-h. For a horizontal system is approximately 0.7 btu… Conversion factor between imperial and metric is 1.71

Question 3: What kind of innovations are there in the field of geothermal presently?

Not much in terms of horizontal loops, except with higher heat transfer in pipes.

Type of pipe: IPL- quebec product (same high density polyethelene, combined with other minerals such as carbon). These pipes offer an increase of efficiency of 8-10% for vertical loop systems but little in terms horizontal loops. [possibly wrong – to research]

Improving overall heat exchanger

Configuration: "slinky" or coiled pipes

Question 4: Why are horizontal pipe systems uncommon?

In Quebec, it is very rare to design horizontal piping system (> 3% of total projects). Our company has done over 400 projects and has not installed any horizontal systems. The reason being it is monopolized by the drillers and construction unions (drillers have most of the market). Drillers make more money by drilling vertical systems, they do not want to lay down pipe.

In Ontario and other provinces, horizontal systems are more common.

There are 2 companies that currently install horizontal loop systems:

1) Geo-horizon
   Contact name: Janick Coulomb

2) Installation solutions – located in Gatineau

Contact name: Mr. Carriere

Question 5: What sort of environmental impact do geothermal systems have in terms of soil quality or microbial community?

Soil: 1 ft radius the pipe is anaerobic [is this the area that is affected only?]

No regional effects

Microbial community: Never heard this issue brought up or been asked this question

Question 6: Are there issues with under a paved area?

Main issue with paved area is with the air conditioning system since it becomes a solar panel unless it's deeper than 7-8 ft under pavement. It has been proven though not to be good for cooling, however shown to still be good in terms pipe life and for extracting heat (not rejecting heat).

This issue can be addressed by installing French drains underneath the civil work and geothermal system, to maintain moisture and prevent clay from cracking. Preferred area would be a gravel or grassy area

Heat exchanger won't work.

Question 7: When you first approach a client, how do you come arrive at your recommendations and designs?

Geo. Vs. non- geo systems:

First you consider the client's budget and available land space. If the land space is not there, there is no point in considering geothermal since land cannot just be extended or acquired easily. In terms of budget, geothermal is the most expensive HVAC system that can be installed: 10-12 K /ton for commercial/industrial compared to a standard rooftop system of $2500.

But clients choose geo for its ability to be used for both heating and cooling, more clients are aware of the technology and its benefits. A geothermal system is usually coupled with other systems (i.e. automated system controlled from cellphone) that provide clients a comfortable life, which draws more clients.

APPENDIX F– WINDOWS SPECIFICATIONS

HIGH PERFORMANCE CHARACTERISTICS

TYPE OF LOUVERS	OPENINGS	VISIBLE LIGHT		SOLAR HEAT GAIN	TOTAL HEAT GAIN	U-VALUE BTU / hr. / ft² / °F		*RELATIVE HEAT GAIN	SHADING COEFFICIENT
		% TRANS-MITTANCE	% OUTDOOR REFLECTANCE	BTU / hr. / ft²	BTU / hr. / ft²	WINTER NIGHT-TIME	SUMMER DAYTIME	BTU / hr. / ft² / °F	
WHITE BLADE	45°	18.4	21.8	56.3	70.1	0.51	0.49	66	0.30
	90°	40.8	14.8	99.7	112.9	0.49	0.47	112	0.53
	135°	15.8	18.1	52.2	66.0	0.51	0.49	62	0.28
	180°	0.1	40.8	16.9	31.2	0.53	0.41	24	0.09

Tests were performed in general accordance with ASHRAE Standard 74-73 using simulated sunlight equivalent to Air Mass 2 intensity (258 BTU/hr/ft²) a spectral distribution. A 15mph dynamic wind was applied to the exterior with natural convection on the interior of the specimen.
*Based on ASHRAE Solar Heat Gain Factor of 200 BTU/hr/ft² or 631 W/m² and an outdoor temperature of 15°F (9°C) higher than indoor, without outdoor shading.

Figure 1: High performance window characteristics from Vision Control (Unicel Architecture, 2012).

Table 10 - Window Measurements for Scenario 1 and 2

number of fixed windows	width (cm)	height (cm)
8 windows	233	306
4 windows	244	306
1 window	133	306
1 window	184	128.5
1 window	139	306
1 window	92	88
1 window	82.5	306
9 operable windows	86	96

APPENDIX G – MONTHLY BREAKDOWN OF NORTH FAÇADE HEAT LOSS

	mean temp (°C) 3 years	Q current (W)	Current (M_{onth}/yr)	Q insulation (W)	Q window 1: (W)	Scenario 1: windows (W_{month}/yr)	Q windows 2 (W)	scenario 2: Windows + Insulation (W)	Scenario 2 (W_{month}/yr)
January	-9.6	15902	1325	452	3464	289	286	738	62
February	-6.4	14291	1191	406	3113	259	257	664	55
March	0.1	11020	918	313	2401	200	199	512	43
April	7.9	7095	591	202	1546	129	128	329	27
May	14.1	3975	331	113	866	72	72	185	15
June	18.6	1711	143	49	373	31	31	79	7
July	22	0	0	0	0	0	0	0	0
August	20.9	554	46	16	121	10	10	26	2
September	16.4	2818	235	80	614	51	51	131	11
October	8.4	6844	570	194	1491	124	123	318	26
November	4	9058	755	257	1973	164	163	421	35
December	-4.6	13386	1115	380	2916	243	241	622	52
Total			**7221**			**1573**			**335**

APPENDIX H – LOAD CALCULATIONS

Degree days calculation with weather data from National Climate Data and Information Archive (2011).

Date	Mean Temp	Heat Degree Days
01/01/2010	-4.1	26.1
02/01/2010	-7.7	29.7
03/01/2010	-8.2	30.2
...	...	...
17/06/2010	20.9	1.1
18/06/2010	22.2	0
19/06/2010	23.2	0
...	...	...
24/11/2010	-2.3	24.3
25/11/2010	-5.7	27.7
26/11/2010	-1	23
...	...	...
03/08/2011	20.3	1.7
04/08/2011	21.8	0.2
05/08/2011	23	0
...	...	...
27/12/2011	0.1	21.9
28/12/2011	-6	28
29/12/2011	-16.5	38.5
Yearly total		**5114.7**

Calculated using: $Heating\ degree\ day = 22 - Mean\ temp$

Maximum heat loss calculation

	Scenario 3			Scenario 4			Scenario 5		
	Area (m^2)	U (W/m^2K)	q (kW)	Area (m^2)	U (W/m^2K)	q (kW)	Area (m^2)	U (W/m^2K)	q (kW)
infiltration	--	--	4.5	--	--	2.23	--	--	1.1
holes	--	--	0.72	--	--	0	--	--	0
windows	--	--	24.15	--	--	5.262	--	--	1.123
walls	368.1959	0.153689	2.716208	368.1959	0.154107	2.723595	368.1959	0.154107	2.723595
floor	1764.4	0.3	25.40736	1764.4	0.3	25.40736	1764.4	0.3	25.40736
ceiling	1764.4	0.2	16.93824	1764.4	0.2	16.93824	1764.4	0.2	16.93824
total			89.31817			63.07343			56.75063

Total heat loss includes 20% increase to compensate for losses which were not considered.

$$q = Area * U$$

Annual heating load based on minimum temperature of -26°C

Parameter	Units	Scenario 3	Scenario 4	Scenario 5
degree days	days	5114.7	5114.7	5114.7
max heat loss	w	89318.17	63073.43	56750.63
temp difference	K	48	48	48
annual heating load	kWh/yr	228417.8	161300.8	145131.2
annual heating load	kW	26.0578	18.40113	16.55651

Calculated using: $Annual\ heating\ load = Degree\ days * 24 * \frac{Max\ heat\ loss}{Temp\ difference}$ (Frazer, 2012)

The ratio $\frac{Max\ heat\ loss}{Temp\ difference}$ represents the specific heat loss coefficient of the building.

APPENDIX I – PEAK ENERGY DEMAND CALCULATIONS

From energy audit:

Peak building consumption	kWh/yr	401348
	kW	45.7856
	BTU/h	156226.9
	ton	13.01891
Design peak energy consumption	kW	41.20704
current total loss	kW	29.37

New energy peaks with implementation of windows and wall

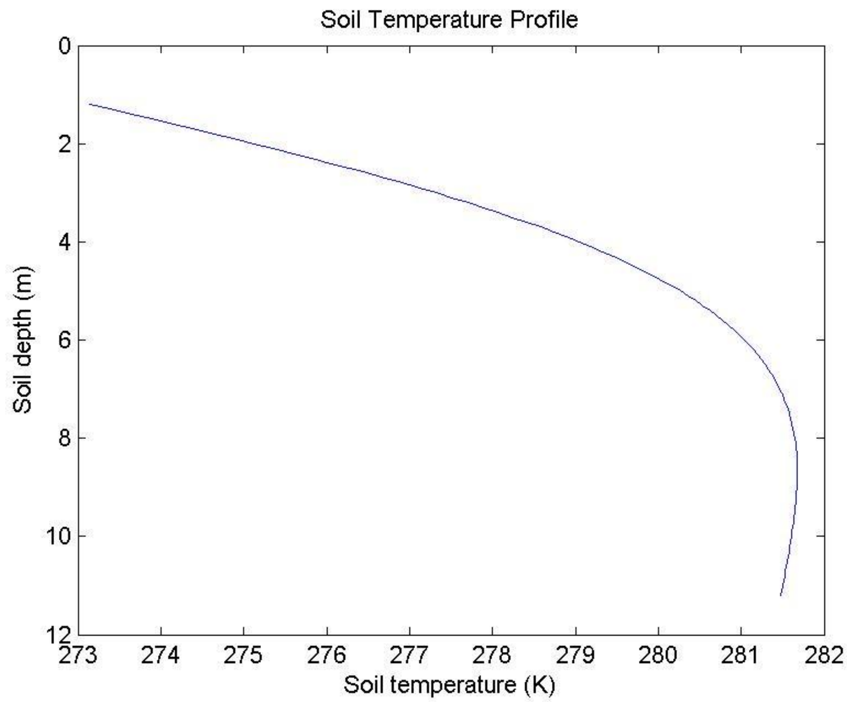
		Scenario 4	Scenario 5
modified window loss	kW	7.49	2.23
heat conserved	kW	21.88	27.14
new peak energy consumption	kW	23.9056	18.6456
	BTU/h	81569.283	63621.42
	ton	6.7974403	5.301785
Design peak energy consumption	kW	21.51504	16.78104

Calculated using:

$$heat\ conserved = current\ window\ loss - modified\ window\ loss$$

$$New\ peak\ energy\ consumption = peak\ building\ consumption - heat\ conserved$$

APPENDIX J – SOIL TEMPERATURE PROFILE



APPENDIX K – MATLAB SIMULATION CODE

For brevity, the MATLAB code for the simulation for scenario 3 only is presented. The code for scenarios 4 and 5 are virtually identical with exception of values discussed in the text.

Contents

- Master clear
- Parameters
- Soil Temperature Profile
- Variables
- Formulas
- Optimizing for (L) length and (X) depth
- Calculating design parameters

Master clear

```
clear all
close all
clc
```

Parameters

Pipe properties

```
Kpipe=0.7;  % W/mk thermal conductivity
Do = 0.027; % m outer diameter
Di= 0.021;  % m inner diameter

%Propylene glycol (refrigerant) properties at 0C and 0.3 mass fraction of glycol
in solution
Cp = 3850;     % J/kgK specific heat capacity
Kf = 0.428;     % W/mk thermal conductivity
mu = 0.0075;   % Pa/s dynamic viscosity
Pr = 65;       % Prandtl number

COP = 3.8; % COP of system chosen
qdot = 41207 - (41207/COP) ; % W heat to be extracted from soil
Tbi = 273.14;    % K refrigerant temperature in
Tsfc = 247.14;   % K surface temperature as -26C
```

Soil Temperature Profile

```
alpha = 1.0E-6; % m2/s for wet sand
to= 365.4*24*60*60; % s time in one cycle (1 year)
t = to/2; % studied time - winter condition
a= 8; % amplitude of temperature difference
Tavg = 8; % C temperature at infinity

x=0:0.1:10; %m soil depth
X= 1.2+x; %m depth corrected to start after frostline at 1.2m
tsoil = Tavg + 273.14 + (a*exp(-x.*sqrt(pi/(alpha*to))).*cos((2*pi*t/to)-
(x.*sqrt(pi/(alpha*to))))); % K soil temperature
plot(X,tsoil)
```

Variables

```
mdot=4;           % kg/s mass flow rate based on specifications from HP unit gpm=60
l = 800:2:7000;   % m length of pipe

[L,Tsoil] = meshgrid (l,tsoil); % meshgrid to use matrices in the formulas below
[L,X] = meshgrid (l,X); % meshgrid to use matrices in the formulas below
```

Formulas

```
REd=4*mdot/(pi*Di*mu);                   % Reynolds number
havg=0.023*(REd^0.8)*(Pr^0.4)*Kf/Di; % average convective heat transfer
coefficient W/m2K
A=pi*Di.*L;                              % Pipe cross sectional area m2

% main formula:
% qdot = mdot*Cp*(Tbo-Tbi) = UA*((Tsfc-Tbo)-(Tsfc-Tbi))/ln((Tsfc-Tbo)/(Tsfc-Tbi))

Tbo = Tbi + qdot/(mdot*Cp); % K refrigerant temperature out

UA = 1./((1./(havg.*A))+(log(Do/Di)./(2*pi.*L*Kpipe))); % W/k

Q = UA.*((Tsoil-Tbo)-(Tsoil-Tbi))./log((Tsoil-Tbo)./(Tsoil-Tbi)); % same as qdot
Qround = round (Q); % round numbers
```

Optimizing for (L) length and (X) depth

```
Q_index = find( qdot < Qround & Qround < qdot+(qdot*0.005) ); % finds the index
number of the Qs in-range

% Find corresponding values of length, depth & Q
length = L(Q_index);
depth = X(Q_index);
Qopt = Qround(Q_index);

table = [Qopt, length, depth]';% create a table of results
disp(' ')
disp('       Optimal Length and Depth of Pipe for q = 33737 W')%title of table
disp('    ---------------------------------------------------------- ')
fprintf('\tQ [W]\t\t Length [m]\t\t Depth [m]\n')% column headings
disp(' ')
fprintf('\t%4.0f\t\t %7.0f\t\t %7.2f\n',table) % table of results
```

```
        Optimal Length and Depth of Pipe for q = 33737 W
    ----------------------------------------------------------
      Q [W]        Length [m]        Depth [m]

      30434           804              2.60
      30510           806              2.60
      30398           898              2.50
      30465           900              2.50
      30401          1024              2.40
      30460          1026              2.40
      30382          1200              2.30
      30433          1202              2.30
      30483          1204              2.30
      30369          1472              2.20
      30411          1474              2.20
      30452          1476              2.20
      30493          1478              2.20
```

```
      30375           1984              2.10
      30405           1986              2.10
      30436           1988              2.10
      30467           1990              2.10
      30497           1992              2.10
      30374           4820              2.00
      30386           4822              2.00
      30399           4824              2.00
      30411           4826              2.00
      30424           4828              2.00
      30437           4830              2.00
      30449           4832              2.00
      30462           4834              2.00
      30474           4836              2.00
      30487           4838              2.00
      30500           4840              2.00
      30512           4842              2.00
      30364           6236              1.90
      30374           6238              1.90
      30383           6240              1.90
      30393           6242              1.90
      30403           6244              1.90
      30413           6246              1.90
      30422           6248              1.90
      30432           6250              1.90
      30442           6252              1.90
      30452           6254              1.90
      30461           6256              1.90
      30471           6258              1.90
      30481           6260              1.90
      30491           6262              1.90
      30500           6264              1.90
      30510           6266              1.90
```

Calculating design parameters

```
lengthopt_index=find(length<2100); %find possible lengths that fit in western
parking lot
depthopt = depth(lengthopt_index); %find corresponding depths
[depthopt_design, index_design] = min(depthopt); %select minimum depth
lengthopt_design=length(index_design); % find corresponding length

designtable = [lengthopt_design, depthopt_design]; % create a table of results

disp(' ')
disp('        Optimal Length and Depth Configuration')%title of table
disp('    ---------------------------------------------')
fprintf('\t Length [m]\t\t Depth [m]\n')% column headings
disp(' ')
fprintf('\t %7.0f\t\t %7.2f\n',designtable) % table of results
```

```
        Optimal Length and Depth Configuration
    ---------------------------------------------
       Length [m]         Depth [m]

          1984              2.10
```

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APPENDIX L – ENERGY CONSUMPTION OF EACH SCENARIO

Energy balance of Ground source heat pump with heat to the building as 90% of new peak energy consumption

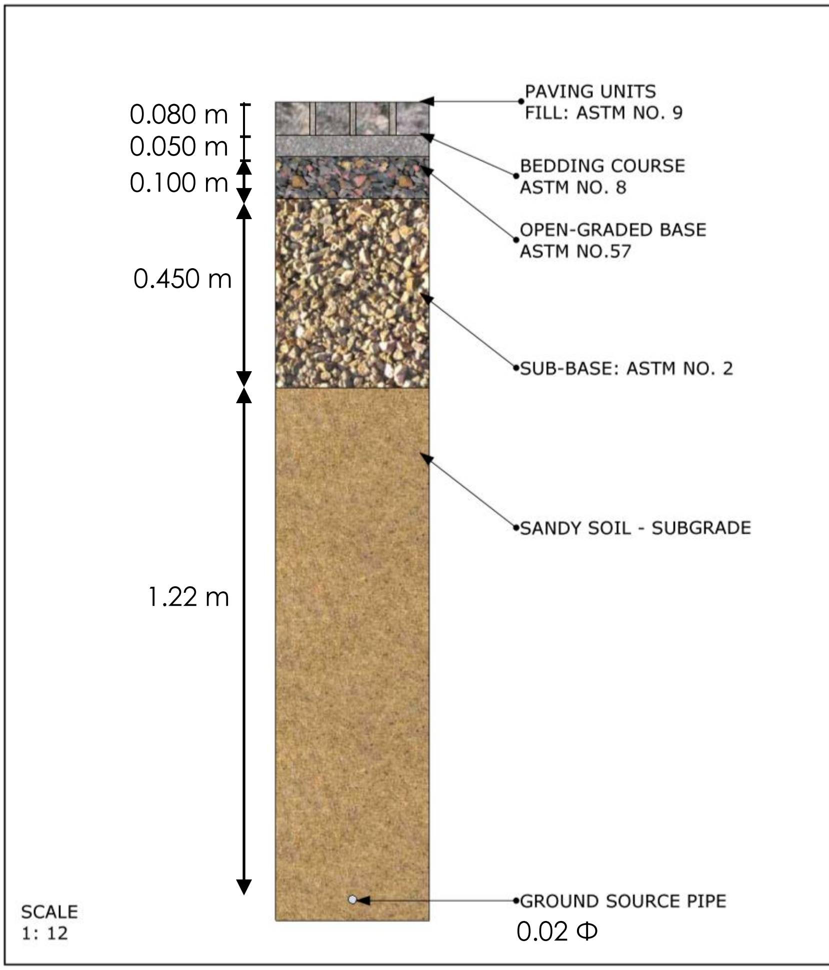
Parameter	Units	Scenario 3	Scenario 4	Scenario 5
$q_{building}$, heat to building	kW	41.20704	21.51504	16.78104
COP		3.8	3.7	3.6
$W_{net\ in}$, energy consumption	kW	10.84396	5.81488	4.6614
	kWh/yr	95056.1	50972.11	40860.96
q_{ground}, heat extracted from ground	kW	30.36308	15.70016	12.11964

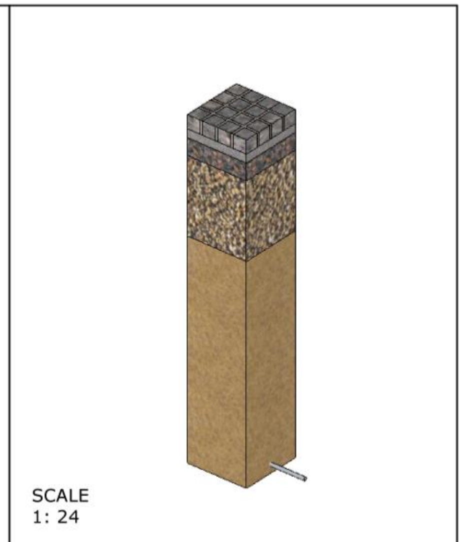
Calculated using:

$$q_{ground} = q_{building} - \frac{q_{building}}{COP}$$

$$Wnetin = \frac{q_{building}}{COP}$$

APPENDIX M – PERMEABLE PAVEMENT





SOIL CROSS-SECTION:
PERMEABLE PAVEMENT LAYERS & PIPE DEPTH

McGill University
BREE DESIGN 3
CREATED BY:
GROUP 7

CREATED ON:
April 13 2012

UNITS: SI [m]

APPENDIX N – ECONOMIC ANALYSIS CALCULATIONS

There are usually limitations to the economic analysis; factors that were not considered such as annual maintenance & operational costs, costs allocated to surveying and consulting, etc. The actual cost of theses projects may differ from what is presented. However the costs are relatively correct when comparing them to one another (i.e. In ascending order from least expensive to most expensive: installing a wall and operable windows → replacing large windows → installation of a GSHP and permeable pavement.)

The XE – Universal Currency Converter available at http://www.xe.com/ucc/ was used to exchange currency values to $CAN,

The US Inflation Calculator available at http://www.usinflationcalculator.com/ was used to calculate current quotes.

Scenario 1 - Large Windows

Calculating Capital Cost

TOTAL	**$90,215.00**	**REFERENCES**
17 custom windows	$75,200.00	Emma Sirois, Unicel Archetectual, Longueil, QC
installation	$15,015.00	Lindsay Fialkov, Freelance Interior Designer, Toronto, ON

Annual Savings	**$4,208.27**
total energy consumption (kWh/year)	351838.95
energy consumption (kW)	40.14
annual Savings Percentage	12.3%

Payback Period	**21.4**

Scenario 2 - Wall & Small Windows

Calculating Capital Cost

TOTAL	**$23,970.00**	**REFERENCES**
standard windows	$8,500.00	Emma Sirois, Unicel Archetectual, Longueil, QC
wall material (drywall, wood frame, plywood etc…)	$2,500.00	Rona, Montreal, QC
insulation	$2,960.00	Isolation Girbec, Boisbriand, QC
installation	$10,010.00	Lindsay Fialkov, Freelance Interior Designer, Toronto, ON

Annual Savings	**$5,130.61**
total energy consumption (kWh/year)	340987.8827
energy consumption (kW)	38.900
annual Savings Percentage	15.9%

Payback Period	**4.7**

Scenario 3 - GSHP & Permeable Pavement

Calculating Capital Cost

TOTAL	**$147,847.35**	**REFERENCES**
ground source heat pump unit	$21,466.67	NLV 240, Walter Furnace Envision, Fort Wayne, IN
installation	$32,840.00	Mark Bélanger, The Master Group L.P, Montreal, QC
pipes	$2,615.55	Tammy Kouri, Hudson Extrusions, Hudson, QC
construction: drilling, excavation, etc.	$76,800.00	G. Lafleur, Lafleur Constructions, Montreal, QC
grading	$1,611.40	Landphair, H. et al. 2000, Design Methods, Selection, and Cost Effectiveness of Stormwater Quality Structures, Texas Transportation Institute Research Report, College Station, TX.
paving	$5,373.13	
filter fabric	$1,073.82	
stone fill	$4,289.96	
sand	$933.76	
sight well	$800.37	
seeding	$42.69	

Annual Savings	**$25,949.82**
total energy consumption (kWh/year)	96056
annual Savings Percentage	76.1%

Payback Period	**5.7**

Scenario 4 - Large Windows, GSHP & Permeable Pavement

Calculating Capital Cost

TOTAL	$226,811.27	
Large windows	$90,215.00	see scenario 1 for calculations and references
GSHP & Permeable Pavement	$136,596.27	see scenario 3 for calculations and references, NLV 160 Unit used, pipe length changed

Annual Savings	$33,875.71
total energy consumption (kWh/year)	2810.24
annual Savings Percentage	99.3%

Payback Period	6.7

Scenario 5 - Wall & Small Windows, GSHP & Permeable Pavement

Calculating Capital Cost

TOTAL	$159,359.49	
wall & small windows	$23,970.00	see scenario 2 for calculations and references
GSHP & Permeable Pavement	$135,389.49	see scenario 3 for calculations and references, NLV 120 Unit used, pipe length changed

Annual Savings	$35,758.58
total energy consumption (kWh/year)	-19341.2
annual Savings Percentage	104.8%

Payback Period	4.5

APPENDIX O – DIVISION OF TASKS

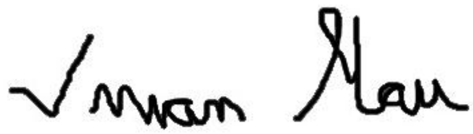
BREE 495 – DESIGN 3 – DIVISION OF TASKS & GROUP MEMBER PARTICIPATION		
Design Group Members:		**Project Description:**
(1) Allison Busgang	(3) Katherine Rispoli	Thermal Energy Use Optimization:
(2) Vivian Mau	(4) Wathsala Tennakoon	Baie-d'Urfe Public Works Building

Person	Activity Description
Alison Busgang	➢ Design of windows ➢ Design of insulation ➢ Design of air leakage ➢ Communication with companies for quotes ➢ Write up of sections of report corresponding to windows insulation and air leakage ➢ Final editing
Vivian Mau	➢ Design of ground loop for ground source heat pump wit MATLAB ➢ Selection of components of ground source heat pump ➢ Communication with companies for quotes ➢ Write up of sections of report corresponding to ground source heat pump ➢ Final editing
Katherine Rispoli	➢ Design of permeable pavement with HYDRUS 1D ➢ Drawing of building with proposed design on Google Sketch-up ➢ Write up of sections of report corresponding to permeable pavement ➢ Final editing
Wathsala Tennakoon	➢ Contribution to MATLAB simulation and Google Sketch-up ➢ Prepared PPT Presentation ➢ Economic analysis ➢ Write up of sections of report corresponding to economic analysis ➢ Final editing
Entire Group	➢ Interviews with Susan King, Patrick Lambert, Marc Belanger ➢ Site visit to obtain temperature, wind and window measurements ➢ Preparation of presentation ➢ Journal updates

The above distribution of tasks has been approved by all of the group members. Signatures below demonstrate agreement with this distribution, which has been additionally represented in percentage form:

1) Allison Busgang: 25%

2) Vivian Mau: 25%



3) Katherine Rispoli: 25%

4) Wathsala Tennakoon: 25%