UBC Social, Ecological Economic Development Studies (SEEDS) Student Reports

An Investigation of the Feasibility of A Ground Source Heat Pump for the New Student Union Building

Angeleen Ramey

Murray Helmer

Alex Pereira

University of British Columbia

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Carla Paterson

Abstract

In 2008 UBC students voted to replace the existing Student Union Building, with one which meets student needs while being as sustainable as possible. In order to meet the goal of a LEED platinum building, a highly sustainable heating source is necessary. Ground source heat pumps were investigated to determine if they would fulfill these criteria and were therefore examined using a triple bottom line assessment. The investigation was performed via assessing existing research on ground source heat pumps in addition to comparing the new SUB project to case studies of similarly sized buildings in locations with similar climates to that of Vancouver.

With regards to a triple bottom line assessment ground source heat pumps were shown to be viable based on all categories. Economically, despite a high capital cost a ground source heat pump will save money over its life time compared to traditional heating methods. While there are some environmental impacts associated with ground source heat pumps they are still more sustainable than any other heating methods. The major environmental problems posed by a ground source heat pump are carbon emissions associated with the electricity and materials used, as well as potential toxins released from the refrigerant. Socially a ground source heat pump would improve the quality of life for all parties involved with the construction, use and maintenance of the new SUB, in addition to demonstrating how sustainable buildings is possible in Vancouver.

Based on a triple bottom line assessment a ground source heat pump is the best heating methods for the new SUB. The required horizontal coil array should be installed under McInnes field as it is the most economical and socially sensible location. However due to the fact the exact design of the new SUB is not yet finalized, it was impossible to calculate the exact costs or carbon emissions for a ground source heat pump. As such some assumptions were made and more exact estimates should be calculated before proceeding with construction.

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Glossary

Aquifer	An underground water resource
Backfill	Material used to fill a drill hole or trench after an excavation
Heating Degree Days:	The sum of the difference between the average temperature for a day and 18°C over an entire year
High-Density Polyethylene	A type of plastic used commonly in construction
Ton	Units used in refrigeration and air conditioning; one commercial ton of refrigeration is the rate that will freeze one short ton of ice of specific latent heat 144 BtuIT per pound in 24 hours from water at the same temperature
Refrigerant	A fluid with a high thermal conductivity used in heat exchange systems
Thermal conductivity	A material property which regulates how easily heat flows to and from the material

List of Abbreviations

AMS: Alma Mater Society

CFC: Chlorofluorocarbons

GCHP: ground coupled heat pumps

GHG: Green house Gases

GSHP: ground source heat pump

HHD: Heating Degree Days

HVAC: Heating, Ventilation and Air Conditioning System

LEED: Leadership in Energy and Environmental Design

SWHP: surface water heat pumps

SUB: Student Union Building

1.0 Introduction

This report investigates the feasibility of installing a ground-source heat pump in the new Student Union Building, in order to achieve LEED platinum for the building. Ground-source heat pumps use the soil surrounding a building as either a heat sink to cool a building, or draw heat from the soil to heat the building. They can also use ground or surface water for a similar purpose.

Research was conducted to review the types of ground-source heat pumps available as well as their individual feasibilities for the new SUB. With reference to examples of similar systems that have been installed in Vancouver and Cedar City, Utah, ground-source technologies were evaluated for sustainability by a triple bottom line assessment. Reviews of potential environmental and social effects of such a system were conducted, as well as an assessment of the economic feasibility of installation.

2.0 Heat Pumps

A heat pump works on the same principles as a refrigerator, using electricity to move energy from one location to another. A compressor pumps refrigerant into a high-pressure pipe, which increases its temperature, which then sheds the excess heat in a heat exchanger coil. The refrigerant then passes through an expansion valve into a lower pressure pipe, which causes it to cool and absorb energy in a second coil. This process repeats itself in a closed cycle. (Natural Resources Canada, 2009)

2.1 Ground Source Heat Pumps

Ground source heat pumps (GSHP) transfer either warm or cold energy from the ground into a usable form such as: space heating, water heating or space cooling (Phetteplace, 2007). There are three different GSHP systems which could be installed in the new SUB. They are ground coupled heat pumps (GCHP), surface water heat pumps (SWHP) and hybrid systems composed of GSHP and a traditional heating method (Phetteplace, 2007).

A GCHP circulates a fluid, either an antifreeze water combination or a refrigerant, through loops of piping in the ground to a heat pump inside the building. The heat pump then exchanges energy with the fluid thus heating or cooling the building. (See Figure 1.) Because the main components of the systems are not exposed to the elements a GCHP has a life expectancy of at least 50 years (Rawling, 1999). However since the piping is underground it needs to be able to withstand corrosion in addition to having a high thermal conductivity. For these reasons high density polyethylene tubes are normally used. To increase the system’s efficiency turbulent flow in the piping is required so the piping is generally 20-40 mm in diameter (Rawlings, 1999). There are three ways a GCHP piping can be installed: vertical piping, horizontal piping or coiled piping.

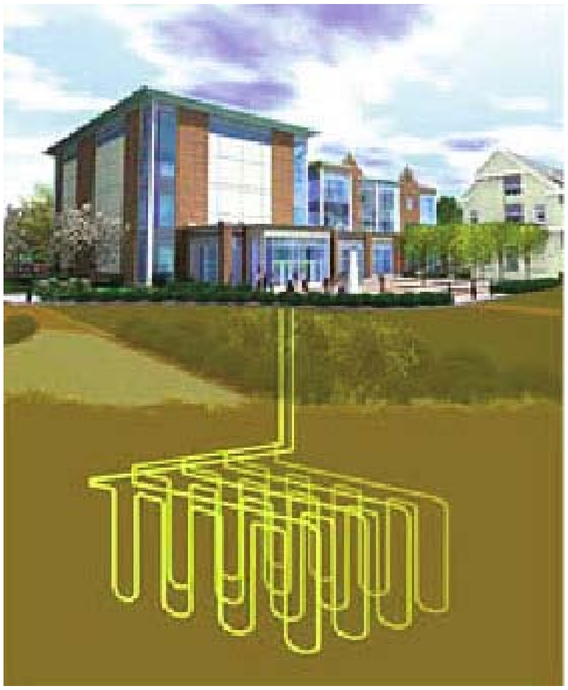

Figure 1: Ground Source Heat Pump

Source: http://www.climatecontrolse.co.uk/sustainable-products/ground-source-heat-pumps

A vertical GCHP consists of multiple drill holes 15 to 180 m deep, depending on the quantity of drill holes. Vertical GCHP experience more constant temperatures and are thus more efficient than horizontal installation. However they are far more expensive to install and need an experienced installation crew to be done properly. One other concern about vertical GCHP is the backfill material into the hole needs to have a high thermal conductivity otherwise the performance of the system can be compromised.

A horizontal GCHP consists of pipes laid in trenches 2 m beneath the surface. To save on costs multiple pipes can be placed in the same trench as long as they are at least 0.3 m apart (Rawlings, 1999). Since a horizontal GCHP can be installed at shallow depth they have relatively lower costs. Being close to the surface also has the advantage that the ground is generally more saturated thus increasing its thermal conductivity and the efficiency of the system. However horizontal GCHP require a large area and experience temperature swings which decreases their efficiency.

A coil GCHP is very similar to a horizontal GCHP except that instead of straight pipes coiled pipes are installed. Coiled GCHP have all the same benefits and disadvantages as a horizontal GCHP except that they need much shorter trench lengths since the coils drastically increase the surface area (Rawlings, 1999). This in turn reduces the costs. However coiled GCHP have the drawback that they are more difficult to install as backfilling can cause the spacing between coils to be disturbed, so they require an experienced technician. (See Figure 2 of the installation of a coiled GCHP.) This type of system would be more feasible than a horizontal GCHP for the new SUB as McInnes field (see Figure 3), adjacent to the SUB, is large enough for a coil system, but not a horizontal system. (See appendix A for calculations.)

Figure 2: Installation of coiled GCHP

Source: http://www.sustainservices.co.uk/heat_pumps.htm

2.2 Surface Water Heat Pumps

SWHPs use a very similar technology as GCHP the key difference is the piping goes into a body of water rather than underground. UBCs location close the ocean makes it a good candidate for SWHP. However, the distance to pipe a fluid to the ocean and back makes a SWHP less favourable for the new SUB because the energy consumed to pipe the water that distance. Although for buildings built closer to the cliffs SWHP should be considered as an option because it could potentially be viable.

2.3 Hybrid Heat Pump Systems

A hybrid GCHP system consists of a smaller GCHP with a different heating system, such as natural gas boilers, attached to cover the peak heating loads. This type of system could be an option for the new SUB. However, based on research of the area and the goal to make the new SUB LEED Platinum it does not make sense to use a hybrid system since it will consume more energy and release more GHG.

Figure 3: MacInnes Field, possible GCHP site.

Source: www.maps.google.ca

3.0 Economic Analysis

The main factor that lies in choosing the correct HVAC for the new SUB is price. As the new SUB organizers aim to reach LEED Platinum (UBC AMS, 2010) they will obviously aim to install the most efficient system, but with efficiency comes high cost. It's important that cost is evaluated over the lifetime of the building. This involves accounting for all possible costs of the building, mainly the installation costs, the operational costs and the maintenance costs.

3.1 Canyon View High School

In order to provide the stakeholders with economic data that best models the proposed new SUB we chose to borrow data from an existing ground-source geothermal application, Canyon View High School. Canyon View High School is located in Cedar City, Utah, where in the year 2000 a 550-ton geothermal HVAC system was installed. See Figure 4. The high school is a two story building with ~233,000 ft^2 of floor space (Geo-Heat Center, 2005). Cedar City has very similar weather to Vancouver with respect to seasonal temperature averages. Canyon View High School has 3390 Heating Degree Days (HDD) (Geo-Heat Center, 2005) while Vancouver has 2927 (National Resources Canada, 2009). This suggests that Vancouver is slightly milder compared to Cedar City.

The Canyon View installation is a good comparison to the new SUB project for a variety of reasons. First and most importantly the climate is very similar. Cedar City has a slightly higher HDD, which is expected due to the fact that Vancouver is slightly milder. Canyon View is also roughly the size of the proposed SUB; only slightly smaller then the proposed floor area of 255,000 ft^2 (UBC AMS, 2010). Also the usage characteristics or the two buildings are very similar; heavy traffic during the day, which tapers quickly in the afternoon. Finally, as with the new SUB, the geothermal HVAC system was installed during the building's construction and therefore was not a retrofit.

Figure 4: Canyon View High School, Cedar City, Utah
Source: http://www.cedarcitypictures.com

3.2 Cost Analysis

Like many emerging high-efficiency HVAC systems a ground-source geothermal system has a relatively high capital cost. This high capital cost is an investment because of the immense savings that will be experienced over the life of the building. The following is the breakdown of the capital costs of the Canyon View installation.

Capital Cost Analysis: (Geo-Heat Center, 2005)
Breakdown of the capital costs of the ground source system.

Mechanical/Plumbing:	\$2,457,000
Loop Field:	\$778,000
Total Ground Source:	\$3,235,000
Mechanical Cost/ ft^2:	\$13.87/ft^2

The *Mechanical/Plumbing* portion of the cost accounts for the installation and component costs of the interior plumbing along with the heat pumps themselves. The *Loop Field* accounts for the cost of drilling and installing the vertical ground loop field.

However it is important to note a coiled horizontal GCHP system would cost considerably less than a vertical ground loop field due to the fact that coiled fields are dug with an excavator and only a few feet deep while vertical fields require a drill and go to depths of hundreds of feet (ECONAR, 2009). (See Appendix A for Calculations.)

3.3 Savings Analysis

As previously noted, stakeholders should expect considerable savings over the life cycle of the building. This is due to low operational and maintenance costs of the ground-source geothermal system as opposed to conventional systems. Although the technology is still too new to know for sure, most geothermal applications have a warranty for 50 years and are predicted to last up to 200 years (ECONAR, 2009). Maintenance is rarely needed due to the fact that many of the components are housed inside or underground. The following is the annual utility costs of the Canyon View installation.

Operating Cost Analysis: (Geo-Heat Center, 2005)

Electricity:	$135,886.54
Natural Gas:	$5,446.87
Total:	$141,333.41
Cost/ft^2:	$0.61/ft^2

The stakeholders for the Canyon View installation are experiencing significant savings over a conventional HVAC system. First, the geothermal capital cost bid was more than the conventional system bid. In addition, they're currently enjoying savings of 29% over the annual energy cost of a comparable conventional system installed in other schools.

Savings Analysis: (Geo-Heat Center, 2005)

Total Conventional Capital Cost Bid:	$3,963,363 ($17.00/ ft^2)
Total Ground Source Capital Cost:	$3,235,000 ($13.87/ ft^2)
Cost Savings:	$3.13/ ft^2 ($729,000)

Ground Source Operating Cost:	$0.61/ ft^2
Conventional Operating Cost:	$0.86/ ft^2
Annual HVAC Energy Savings:	29%

Adjusted to the size of the proposed new SUB, the ground source system would save ~$800,000 in capital costs and ~$60,000/year in operating costs over the conventional system.

Financially a GSHP is a more economical heating system compared to traditional heating methods. Based on cost, a coiled GCHP would be the most appropriate system since in Vancouver it works as efficiently as the more expensive vertical GCHP and can be installed for a lower cost.

4.0 Environmental Impacts

Ground source heat pumps are considered one of the most environmentally conscious ways of heating a building. In terms of greenhouse gas emissions, there is no method of heating that has lower emissions. Also, GSHP systems are the most energy efficient option available, with efficiencies well over 100% possible. Although there are some potential components in a GSHP system which could pose environmental problems, these issues can be mitigated completely with proper choices of materials.

After installation, the only greenhouse gas emissions that result from a GSHP system are those emitted during the generation of the electricity used by the system. While most of the electricity produced in British Columbia comes from zero-emission sources, a significant amount is imported from elsewhere, such as coal-fired power plants in Alberta. As such, for every 10 MWh of electricity used in BC, approximately 1 tonne of CO_2 is released to the atmosphere (Bullfrog Power, 2010).

A figure of how much CO_2 would be released due to a GSHP system for the new SUB is almost impossible to find, as the heating load is based on numerous factors, such as: insulation, roof type, door and window size and type of foundation, most of which have yet to be determined. However, from the above, we can see that any large use of electricity will have significant greenhouse gas emissions. In spite of this, GSHP systems still have the lowest emissions of any heating system. Compared to electric heating, a GSHP will use 60-70% less electricity, which means an equal reduction in greenhouse emissions (Blum et al, 2009). Natural gas heating, the cleanest fossil fuel used in heating, will still have CO_2 emissions of 3-4 times that of GSHP. It is clear that in terms of greenhouse gas reduction, the clear option for heating is GSHP.

The largest source of carbon emissions during construction of a GSHP is from the large quantity of high-density polyethylene piping used in the heat sink underground. High-density polyethylene has an embodied greenhouse gas value of 2.4 kg CO_2 per kilogram of piping used, similar to that of PVC (Goldblum, 2007). It is difficult to estimate the quantity of greenhouse gas released from a GSHP system for the SUB, as piping length depends on a great number of factors such as building size, foundation type and exact GSHP system used (*HVAC for Beginners).*

Ground source heat pumps are also by far the most energy efficient means of heating. Because electricity is not used for heating, but instead used to draw energy from the soil, efficiencies of over 100% are both possible and easily found. Typical efficiencies, (also known as coefficients of performance) for GSHP systems are in the range of 300-400% (Blum et al, 2009). Compare this to 85% for natural gas heating and 90% for the best of electric heating. This shows that for the same heating load, GSHP systems use significantly less energy than their competitors.

One possible environmental issue arising from the use of a GSHP is the use of CFCs as a refrigerant in some models. However, this problem can be avoided entirely with the use of a mixture of water and antifreeze. Specifically, propylene glycol should be used because it is the safest and least environmentally damaging type of antifreeze. Propylene glycol does have a higher cost but this is worth it in terms of environmental concerns and safety (Heinonen et al, 1997). There is some risk of environmental damage to underground aquifers from leakage of this antifreeze; however, this risk is low if care is taken in the installation of the system.

In terms of other environmental impacts, a GSHP will not have any significant impacts beyond those outlined above. Because the entire system is contained underground and within the building, there is no need for more space than the building footprint. Considering this and the above, it is safe to say that ground source heat pump systems are the most environmentally friendly heating option for the new student union building.

5.0 Social Impacts of a Ground Source Heat Pump

Installing a GSHP or hybrid system has many social benefits. It will affect the student population, maintenance staff and the general population in many positive ways.

To start, a GSHP would benefit the maintenance staff of the SUB for many reasons. First it is a very reliable system requiring little maintenance with an expected lifespan of 50 years. Next, since it will be housed entirely inside the building there is little threat of vandalism which might cause the system to be unusable. Unlike other types of sustainable power generation GSHP creates little noise so there is no threat of hearing damage from it (Rawling, 1999). However not all of a GSHP's impacts are beneficial. There will be some extra work for the maintenance staff at the start of installation because they will have to be trained on how a GSHP is different than a normal furnace/air condition/heating system. This is because a GSHP is different from traditional heating systems in that fact that it is more efficient if it is left on the same temperature for day and night rather then changing the temperature at night when a building is not occupied.

A GSHP will affect student life in the SUB in many ways. Since the majority of the system is housed underground it does not diminish the aesthetics or functionality of the building in any way. Another benefit for the students is safety, since there is no combustion there is little fire or combustion risk. Finally it will increase air quality on campus because it does not emit any local pollutants (Rawling, 1999).

If our recommendations of installing a horizontal GCHP under Macinnes Field are taken it could temporarily cause a negative affect on student life. This would be because of a lack of a field. However the installation would take less than a year and the field would be returned to normal after this, with no future detriments from the process.

However if planned correctly the construction phase could also have many benefits for students. Many types of engineers monitor construction for quality control as one of there job requirements. By inviting engineering classes to observe the construction/drilling this could be beneficial to them by giving them real world experience for when they try to look for a job. This would be an easy way to get student involved in the project and allow them to learn from it.

By installing a GSHP it will also affect the general population. First it provides a case study for new local commercial buildings to model themselves after. By showing a

GSHP can be installed in Vancouver and making the knowledge public it will encourage local companies to make the switch to a GSHP in their own buildings. BC Hydro would also be able to use the New SUB as a case study. They would be able to show how a commercial sized building is able to shift its electrical load away from peak hours. Second by raising the demand for sustainable heating systems it shows there is a market for them and thus lowers the cost. It also provides jobs for workers who are skilled in sustainable design.

The positive social impacts far out weigh the negative impacts for a GSHP, thus making it a better heating and cooling system compared to traditional methods.

6.0 Local Case Study

As of 2005 18 GCHP have been installed in commercial buildings around the lower mainland, thus proving they can be used in Vancouver's climate. An example is the Bob McMath School in Richmond which is roughly half the size of the new SUB. It had a hybrid gas and coil GSHP system installed which reduces their purchased energy consumption by 50% (McNeil, 1999). This resulted in a cost saving of $11, 000 per year. The reason a hybrid system was used instead of just a coiled GCHP was because they only had a budget of $2.4 million for the entire building construction costs. The success of this project makes the possibility of GCHP very feasible for UBC.

7.0 Conclusion and Recommendations

The economic, environmental and social impacts show that a ground source heat pump would be beneficial for UBC to install. Financially although there is a high capital cost, it is completely offset by the savings over the life time of the new SUB. This is due to the low maintenance and operations costs, making it economically beneficial in the long-term. Although the lifecycle of a GSHP does produce GHG emissions it is significantly lower then any other HVAC alternatives. The safety, health and demonstration potential makes a GSHP a positive influence on the surrounding community. Taking the economic, environmental and social aspects of a GSHP into account shows that it is the best type of HVAC system to install.

Based on the analysis of different types of GSHP, a GCHP would be the best type of system to use in the New SUB. The type of GCHP system chosen should be based on ground conditions, budget and building heating load. The buildings block load will depend on the New SUB's: foundation, type of roof, insulation, number of windows and doors, desired temperature and size. Unfortunately most of this information is not yet available. The location and size of the McInnes field, adjacent to the current SUB, are optimal for a coil GCHP, based on the estimated block load of the new building. As such, this report recommends that a coil GCHP is by far the most economical and sustainable heating and cooling system for the new SUB.

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Appendix A
Calculations for Required Field Size

Loop Field Feasibility Analysis
by: Alex Pereira
550-ton system

Geometric Derivation:

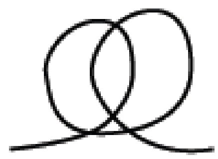
One loop:

$r = 0.4m$

$C = 2\pi r = 2.51m$

$A = \pi r^2 = 0.50m^2$

Two Loop:



$r = 0.4m$

$C_2 = 5.02m$

$A_2 = 2A - 0.5A = 1.5A = 0.75m^2$

$$\boxed{A_{total} = n(0.5m^2) - 0.25(n-1)}$$

where n is the number of coils.

Between 31-90 m is needed per ton of heating/cooling capacity of the system. The exact amount is largely dependent of the thermal conductivity of the soil.[1]

$$550ton \times \frac{31m}{ton} \times \frac{1coil}{2.51m} \doteq 6793coils$$

$$550ton \times \frac{90m}{ton} \times \frac{1coil}{2.51m} \doteq 19721coils$$

Area: using the A_{total} formula above

Using Google Earth the field had been determined to be roughly 95m long and 70m wide ($A_{field} = 6650m^2$).

$$A_{\min} = 1699m^2$$

In conclusion MacInnes field is a feasibly large enough for the needed horizontal coil array.

$$A_{\max} = 4930m^2$$

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[1] Chiasson, A.D. (1999), "ADVANCES IN MODELING OF GROUND-SOURCE HEAT PUMP SYSTEMS", Oklahoma State University, retrieved 2009-04-23