Climate Change Central

Feasibility of Ground Source Heat Pumps in Alberta

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Executive Summary

Ground source heat pumps (GSHPs) are a technology available as a green alternative to conventional heating and cooling of residential, industrial and commercial buildings. This discussion paper examines the use of GSHPs and looks at their economics and greenhouse gas emissions.

GSHPs provide heat and cooling energy, and can provide an economical alternative for space heating, cooling and domestic hot water systems. Because air conditioning is not common in Alberta’s residential market, GSHPs are not a viable, economical replacement for only space and hot water heating.

Ground Source Heat Pumps

Introduction

Conventional space heating in Alberta relies on burning natural gas to heat air which is distributed throughout a building. This process has become more efficient in recent years due to improvements in heating equipment such as condensing gas furnaces. However the process still relies on the burning of fossil fuels which produces greenhouse gases (GHGs). An alternative that has been gaining popularity due to improving economics over the past few years relies on the natural heat in the earth to heat our buildings. Ground source heat pumps are sometimes considered a viable alternative for space heating.

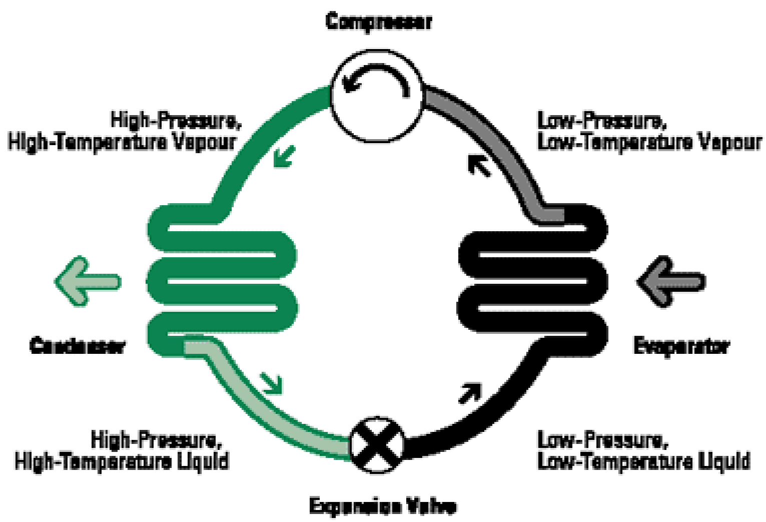
The Technology

The heat pump has been used in various regions of Canada and Europe for many years. A ground source heat pump (GSHP) is a device that extracts heat from the earth beneath the frost line or from a body of water and transfers it to a building for heating in winter, and reverses the process to cool buildings in summer.

Heat pumps transfer heat by circulating a refrigerant through a cycle of evaporation and condensation, similar to the operation of a refrigerator. A compressor pumps the refrigerant between two heat exchanger coils. In one coil, the refrigerant is evaporated at low pressure and absorbs heat from its surroundings. The refrigerant is then compressed as it transfers to the other coil, where it condenses at high pressure and releases heat. (See Figure 1)[1] The major advantage of the GSHP is that it does not burn fossil fuels on site. Electricity is used to operate the system, however the inherent energy in the heat extracted from the earth is much higher than the electricity required to drive the system components.

[1] Heating and Cooling with a Heat Pump/NRCan/Cat.No.M144-51/2004E

Figure 1



GSHPs have three main components: the heat pump unit itself, the liquid heat exchange medium (open system or closed loop), and the ductwork to deliver heated air to the building.

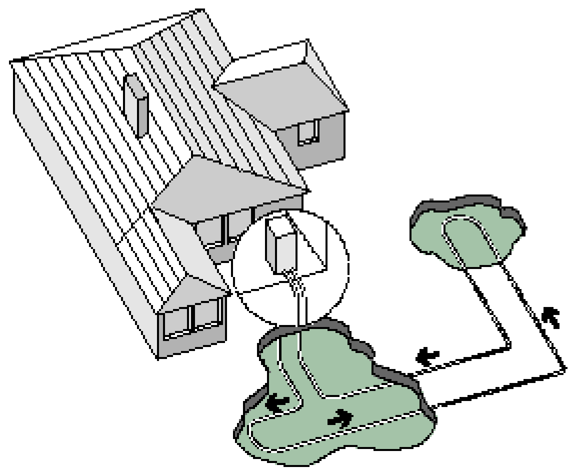
The use of heat pumps allows energy to be extracted from below the frost line where ground temperatures remain relatively constant throughout the year. A ground source heat pump uses the ground as the source of heat in the winter, and as the "sink" for heat removed from the home in the summer. The liquid's temperature is raised by the heat pump, and the heat is transferred to indoor air. During summer months, the process is reversed as heat is taken from the indoor air and transferred to the ground by the ground water or antifreeze solution.

The underground piping system used to transfer heat can be either an open system or closed loop. An open system takes advantage of the heat retained in an underground or open body of water. The water is drawn up through a well directly or from an open body of water to the heat exchanger, where heat is extracted, then discharged either to an above-ground body of water, such as a stream or pond, or back to the same underground water body through a separate well.

More common in most regions is the closed-loop system, shown in Figure 2, which collects heat from below ground by means of a continuous loop of piping buried underground below the frost line. An antifreeze solution, chilled by the heat pump's heat exchange system to several degrees colder than the outside soil, circulates through the piping and absorbs heat from the surrounding soil, returning to the heat pump located inside the building.

Ground source heat pumps can be configured as either horizontal or vertical. The configuration is dependent on a number of factors including what configuration is most suitable for your property, soil types, excavation equipment and cost. As the name implies, in a horizontal loop the underground piping system is buried horizontally whereas in a vertical loop they are buried vertically.

Figure 2: Typical Horizontal GSHP Closed Loop System



The ductwork involved in a typical GSHP should be matched to the capacity of the heat pump. Failure to do so can result in some portions of a building being too hot or too cool. As with a traditional forced air furnace, it is necessary to ensure that there is adequate fresh air intake in the building. This is especially important in new buildings, which are often more airtight than older buildings.

As with air-source heat pumps, GSHPs are available with varying efficiency ratings. Heat pump efficiency is defined as the ratio of the heat energy output to the electrical energy input, called the coefficient of performance (CoP), the higher the CoP, the more efficient the heating cycle of a heat pump. The energy efficiency ratio (EER) measures the cooling efficiency of a heat pump. It is defined as the ratio of cooling capacity in BTU/h to the electrical energy input in watts. In Canada the minimum requirement CoP for heat pumps ranges from 2.8 to 3.2, depending on the type of system used.

Open loop systems have heating coefficient of performance (CoP) ratings ranging from 3.6 to 5.2, and cooling EER ratings between 16.2 and 31.1. Those intended for closed-loop applications have heating CoP ratings between 3.1 and 4.9, while EER ratings range from 13.4 to 25.8. CoP ratings will be ultimately dependent on the temperature of the collecting medium, the earth or ground water source, and the quality of the design and installation. It should be noted that specifications are governed by Canadian Standard Association (CSA) regulations.

Ground source systems now can be qualified under Canada's ENERGY STAR® High Efficiency Initiative.[2] In Canada, ENERGY STAR currently includes the following product specifications for ground source systems:

Table 1:
Key ENERGY STAR Criteria for Ground-Source Heat Pumps (2004)

Product Type	Minimum EER	Minimum CoP
Closed-loop	14.1	3.3
Open-loop	16.2	3.6
Direct Expansion	15.0	3.5

In Canada, where air temperatures can go below –30°C, and where winter ground temperatures are generally in the range of 2°C to 6°C, earth-energy systems have a CoP of between 2.8 and 3.8.

In Alberta, a GSHP will yield energy savings that are 25 – 40 per cent over conventional heating and cooling systems.[3] The energy and cost savings will depend on the efficiency of your current system, geographic location in the province, cost of gas for your current system and cost of electricity for a heat pump system.

The Market

Ground source heat pumps can be utilized in any size of building, ranging from residential and small commercial/institutional (SCI) to large high rises. In the Alberta mass market, there exists just over 1 million residential energy customers in Alberta, and over 104,000 farm residences, plus approximately 161,000 SCI customers.

A 1999 study indicated over 63 per cent of Canadian heat pump sales were in B.C., Ontario and Nova Scotia, however GSHP installations represented less than 1 per cent of the total non-residential heating and cooling market. The higher uptake in B.C. and Ontario is largely due to the fact that heat pump economics are most attractive when there are both heating and air conditioning requirements, lower electricity prices compared to competing space heating alternatives, plus some provincial government financial assistance. Southern B.C. and Ontario climates have the highest air conditioning loads in the country as well as high population densities. Heating and cooling requirements of buildings are determined by seasonal ambient temperatures

[2] The international ENERGY STAR symbol is a simple way for consumers to identify products that are among the most energy-efficient on the market.
[3] Heating and Cooling With a Heat Pump, NRCan/OEE

and a building's insulation conditions, and these requirements are best calculated using the degree-day method.[4]

Broadly speaking, the market for GSHPs falls into two categories, new installations and replacements. Other provinces have seen market penetration in retrofits, however GSHPs are still largely considered an unconventional heating and cooling option. Air conditioning is not common in most of Alberta's existing residential dwellings, however it is more common in the SCI market, thus the heat pump market would have the greatest potential for small commercial or institutional buildings in southern Alberta.

The slow uptake of GSHPs in Alberta can be partially attributed to two factors. The first factor is the current pricing structure of natural gas and electricity in Alberta. Virtually all conventional space heating in Alberta is with natural gas, which continues to be relatively inexpensive as consumers are protected by the provincial government's natural gas cap. It is also important to note that GSHPs use electricity to drive the pump, and Alberta's electricity market and tariffs continue to change. Presently, residential consumers are paying approximately $0.10/kWh. The majority of consumers, residential and SCI, pay for electricity on the Regulated Rate Option (RRO). Currently, the RRO protects the consumer from rising power pool prices however this protection is on a declining scale as consumers are exposed to fluctuating power pool prices by an increasing 20 per cent per year. The RRO ends in 2010 when consumers will have full exposure to pool price, or the option of entering into a contract with an energy retailer. The net effect is that the uncertainty in electricity and natural gas prices makes it difficult to estimate the economics of heat pump installations.

Secondly, the GSHP, as with any new competing technology for space heating, has to go head-to-head with the current technology, natural gas furnaces. At the residential level, there is a significant gap between the capital cost of a conventional gas furnace, whether mid-efficiency or high efficiency, and a GSHP system. Air conditioning has very low saturation levels in the Alberta residential market, and GSHPs provide both heating and air conditioning. Higher natural gas costs complemented by lower electricity costs would enhance heat pump economics. Some other non-financial barriers to market penetration have also been identified such as[5]:

- divisibility: the ability to try on a limited basis before full adoption;
- communicability: how well does the technology communicate benefits;
- compatibility: how closely does a GSHP system compare to conventional HVAC systems
- complexity: how easy is it to understand both the benefits and features of the technology.

[4] Degree day is a calculation for a specific geographic location that measures the average daily temperature above or below 18 degrees C.
[5] GSHP Market Development Strategy, Marbek Resource Consultants, March 1999

With heating and cooling systems, proper maintenance will ensure the heat pump operates at optimum efficiency. And as with conventional systems, some of the maintenance can be done by the building owner, and some will need to be done by a qualified service person. Some items you can do yourself are cleaning and replacing filters, vacuuming and cleaning coils and cleaning the fan as suggested by manufacturer's instructions. Some fan motors require lubrication semi-annually. Keep ductwork clean and free from obstructions as well as vents and registers. Qualified service contractors should be called to do more technical inspections and maintenance on refrigerants, mechanical and electrical components on a periodic basis.

Economics

The life cycle cost (LCC) is defined as the total initial cost plus operating cost over the life of the equipment. For a building's heating requirements, Table 2 illustrates the LCC of a residential application over a 20-year life of a heat pump compared to conventional mid-efficiency and high-efficiency furnaces, for three scenarios of energy prices. At a 20-year life the LCC is higher for the GSHP, however increasing the life span of the system closes the gap on the LCC. Including air conditioning and a boiler system in larger facilities would have a positive impact on the LCC for heat pumps.

The base case electricity cost is based on a retail price of $.08/kWh, plus $0.02/kWh, which is an average residential commodity cost in all electricity tariffs for unbundled distribution and transmissions charges. The base case natural gas cost is based on the Alberta natural gas capped price of $8.75/GJ.

Assumptions for this calculation were the following:

- 0.64 Discount factor
- 3 per cent inflation
- maintenance costs not included
- mid-efficiency residential furnace, natural gas consumption of 130 GJ//yr and fan motor of 920 kWh/yr
- high-efficiency furnace natural gas consumption of 111 GJ/yr and fan motor of 650 kWh/yr
- GSHP motor consumption of 9000 kWh/yr.
- capital and installation costs:
    - mid-efficiency furnace - $4000
    - high-efficiency furnace - $5500
    - GSHP - $25,000

Table 2 – Life Cycle Cost – 20 years

	LCC sensitivity to increasing energy costs	GSHP	Mid-E NG Furnace	HE NG Furnace
Base Case	LCC (NG=$8.75/GJ; El=$.10/kWh)	$39,720	$19,738	$18,723
Sc. 1	LCC (NG=$15/GJ; El=$.10/kWh)	$39,720	$30,138	$27,574
Sc 2	LCC (NG=$15/GJ; El=$.15/kWh)	$47,080	$30,727	$27,990

Greenhouse Gas Emissions from GSHPs versus Conventional Furnaces

In Alberta, switching from a conventional furnace to a GSHP involves switching from natural gas, a relatively low GHG intensive fuel, to electricity which is a high-emitting fuel in Alberta. This is because a large majority of Alberta's power is produced from the burning of coal.

Using RETScreen Energy Model – Ground Source Heat Pump Project a number of calculations were performed to determine the GHG emissions from conventional forced air furnaces and GSHPs. Calculations were based on the following assumptions, generally considered to be consistent with the average residence in Alberta:

- residence is heated by natural gas by a furnace using 24 000 kWh_e per year (160 m2 multiplied by 150 KWh/m2 for an average home)[6]
- residence doesn't have air conditioning
- weather conditions equivalent to Edmonton
- 160 m^2 house
- two stories
- medium insulation level with a full basement

Details of the GSHP used for calculations include:

- vertical closed loop system
- standard heat exchanger layout

[6] Natural resources Canada, 2002

A number of calculations were performed to examine the effects of different efficiencies of furnaces (65 per cent, 85 per cent and 92 per cent) as well as different efficiencies of heat pumps (standard, medium and high) and insulation levels (low, medium and high). Upon completing calculations in RETScreen, calculations showed that a building with low insulation was not feasible.[7] The savings realized from switching from various conventional forced air furnaces to various GSHP technologies in a house with medium insulation are summarized in Table 3 while changes in GHG emissions on a highly insulated house are summarized in Table 4.

Table 3: Change in GHG Emissions Observed when Switching from Conventional Forced Air Furnaces to Various GSHP Efficiencies for Medium Insulated Houses

Furnace Efficiency (AFUE)	Standard Efficiency Heat Pump			Medium Efficiency Heat Pump			High Efficiency Heat Pump		
	Emissions Associated with Heating Using a GSHP	Emissions Associated with Cooling Using a GSHP	Total Emissions from Heating and Cooling	Emissions Associated with Heating Using a GSHP	Emissions Associated with Cooling Using a GSHP	Total Emissions from Heating and Cooling	Emissions Associated with Heating Using a GSHP	Emissions Associated with Cooling Using a GSHP	Total Emissions from Heating and Cooling
65%	-0.94	-2.45	-3.39	0.08	-1.97	-1.89	1.34	-1.67	-0.32
85%	-0.28	-2.45	-5.25	-1.71	-1.97	-3.68	-0.35	-1.67	-2.02
92%	-3.26	-2.45	-5.71	-2.15	-1.97	-4.12	-0.77	-1.67	-2.44

Table 4: Change in GHG Emissions Observed when Switching from Conventional Forced Air Furnaces to Various GSHP Efficiencies for Highly Insulated Houses

Furnace Efficiency (AFUE)	Standard Efficiency Heat Pump			Medium Efficiency Heat Pump			High Efficiency Heat Pump		
	Emissions Associated with Heating Using a GSHP	Emissions Associated with Cooling Using a GSHP	Total Emissions from Heating and Cooling	Emissions Associated with Heating Using a GSHP	Emissions Associated with Cooling Using a GSHP	Total Emissions from Heating and Cooling	Emissions Associated with Heating Using a GSHP	Emissions Associated with Cooling Using a GSHP	Total Emissions from Heating and Cooling
65%	-0.93	-3.07	-4.00	-0.27	-2.48	-2.75	0.61	-2.10	-1.49
85%	-2.03	-3.07	-5.10	-1.37	-2.48	-3.85	-0.47	-2.10	-2.57
92%	-2.30	-3.07	-5.37	-1.64	-2.48	-4.12	-0.74	-2.10	-2.84

In all cases, calculations using numbers representative of an Alberta energy mix showed that switching from conventional forced air furnaces to GSHPs resulted in an increase in GHG emissions. The main reason for this was the assumption that air conditioning was not part of the base case. However when calculations are repeated with the assumption that air conditioning is included in the base case, small GHG savings are realized in a few cases. Changes in GHG emissions from switching from conventional furnaces to GSHPs when air conditioning is considered part of the base case are summarized in Tables 5 and 6. Small GHG savings are realized when switching from a low- and medium-efficiency furnace to a high-efficiency heat pump when a house has medium insulation. Small GHG savings are also realized when

[7] When low insulation was chosen, the model returned an error of "insufficient GHX size"

switching from a low-efficiency furnace to a high-efficiency heat pump in a highly insulated house.

Table 5: Change in GHG Emissions Observed when Switching from Conventional Forced Air Furnaces to Various GSHP Efficiencies for Medium Insulated Houses When Air Conditioning is Considered in the Base Case

Furnace Efficiency (AFUE)	Standard Efficiency Heat Pump			Medium Efficiency Heat Pump			High Efficiency Heat Pump		
	Emissions Associated with Heating Using a GSHP	Emissions Associated with Cooling Using a GSHP	Total Emissions from Heating and Cooling	Emissions Associated with Heating Using a GSHP	Emissions Associated with Cooling Using a GSHP	Total Emissions from Heating and Cooling	Emissions Associated with Heating Using a GSHP	Emissions Associated with Cooling Using a GSHP	Total Emissions from Heating and Cooling
65%	-0.94	-0.14	-1.08	0.08	0.34	0.41	1.34	0.64	1.98
85%	-2.80	-0.14	-2.94	-1.71	0.34	-1.37	-0.35	0.64	0.29
92%	-3.26	-0.14	-3.40	-2.15	0.34	-1.81	-0.77	0.64	-0.13

Table 6: Change in GHG Emissions Observed when Switching from Conventional Forced Air Furnaces to Various GSHP Efficiencies for Highly Insulated Houses When Air Conditioning is Considered in the Base Case

Furnace Efficiency (AFUE)	Standard Efficiency Heat Pump			Medium Efficiency Heat Pump			High Efficiency Heat Pump		
	Emissions Associated with Heating Using a GSHP	Emissions Associated with Cooling Using a GSHP	Total Emissions from Heating and Cooling	Emissions Associated with Heating Using a GSHP	Emissions Associated with Cooling Using a GSHP	Total Emissions from Heating and Cooling	Emissions Associated with Heating Using a GSHP	Emissions Associated with Cooling Using a GSHP	Total Emissions from Heating and Cooling
65%	-0.93	-0.53	-1.46	-0.27	0.06	-0.20	0.61	0.44	1.05
85%	-2.03	-0.53	-2.56	-1.37	0.06	-1.30	-0.47	0.44	-0.03
92%	-2.30	-0.53	-2.83	-1.64	0.06	-1.57	-0.74	0.44	-0.30

Given the Alberta energy mix, it can largely be generalized that switching from conventional forced air furnaces to GSHPs in typical residential applications does not result in any GHG benefits. However, it is important to note that when electricity is purchased from renewable sources (i.e. wind power) there are significant GHG savings from switching from conventional forced air furnaces to GSHPs.

Limitations

It is important to note that this analysis is for residential applications as commercial applications may have substantially different economics and GHG balance. It is also important to note that this analysis does not account for supplementary heating and cooling that may occur such as the use of portable AC units and fans during warm periods which have the potential to substantially increase electricity consumption and GHG emissions.

Conclusions

GSHPs are increasingly becoming more economic for both residential and SCI applications, however under current energy pricing conditions in Alberta, they are not as economical as conventional forced air gas furnaces and have higher associated GHG emissions in residential applications. However, when green power is purchased, the GHG emissions of GSHPs are lower than emissions associated with traditional residential heating.

Frequently Asked Questions

What are the benefits of installing a GSHP to the homeowner or business owner?

A ground source heat pump generally offers lower maintenance and greater comfort year-round. GHG reductions from GSHP are somewhat controversial in Alberta. If the electricity used to run the heat pump is produced from renewable sources, it provides an opportunity to have a GHG neutral residence. However, since power in Alberta is largely generated by coal and natural gas, powering a GSHP will often result in an increase in GHG emissions.

What is the payback period?

Payback periods are site specific based on many factors identified above. While the installation costs of a GSHP are higher than a conventional heating system, they do offer the benefit of providing cooling as well.

What are the costs associated with having a GSHP?

It is important to remember that when one installs a GSHP in Alberta they are generally changing their source of heating from natural gas to electricity. Therefore there will be a decrease in natural gas charges and an increase in electricity charges as the operation of a heat pump requires electricity.

What is involved with installing a GSHP?

Installation differs based on the type of GSHP installed and the location of installation. Generally, installation involves the drilling of bore holes or excavating a horizontal trench which is used to house the piping anatomy that holds an anti-freeze liquid that is used to transfer the heat to and from the earth.

How long does an installation take?

A typical residential installation can be done in as little as two days whereas commercial systems vary greatly depending on geography and system size.

References

1. The Canadian Geo-Exchange Coalition is the association representing heat pump industry in Canada. Details are available on their website: http://www.geo-exchange.ca/en/home.html

2. Office of Energy Efficiency, Natural Resources Canada, provides energy efficiency information on heat pumps and conventional heating and cooling systems, http://www.oee.nrcan.gc.ca/english/index.cfm

3. GHG Impacts of Geoexchange, J. Hanova/Dec 2007

Appendix A: GHG Calculation Methodology

In order to calculate the GHG emissions of conventional forced air furnaces and GSHPs the following methodologies were used.

A summary document prepared by SaskEnergy entitled “Natural Gas High-Efficiency Furnaces… More Heat for your Heating Dollar” provided some of the basic information needed to complete GHG calculations for various types of conventional forced air furnaces.[8] The document summarized the cost of operating various furnaces as follows:

Annual Cost of Operating:	Standard Furnace with Belt Drive	Mid Efficiency Furnace with Belt Drive	High Efficiency Furnace with Belt Drive	High Efficiency Furnace with High Efficiency Motor
Electrical Motor	310.00	258.00	258.00	69.00
Natural Gas Consumption of Furnace	1,063.00	797.00	693.00	705.00
Total Cost	1,373.00	1,055.00	951.00	774.00

These costs were determined using fuel rates from November 1, 2006 (Natural Gas $0.3393 /m3 and Electricity $0.0899 kWh). By dividing the dollar amounts by these unit costs, the Energy use per unit was determined as follows:

Annual Energy Use	Standard Furnace with Belt Drive	Mid Efficiency Furnace with Belt Drive	High Efficiency Furnace with Belt Drive	High Efficiency Furnace with High Efficiency Motor
Electrical Motor (kWh)	3,448	2,870	2,870	768
Natural Gas (GJ)	177	88	76	78

GHG emissions were calculated by taking the annual energy use and multiplying it by the following emissions factors:

- Electricity: 0.935 T CO_2e/kWh
- Natural Gas from residential use 49.9 Kg CO2e/GJ.[9]

[8] Available at: http://www.saskenergy.com/residential/appliances/HighEfficiencyFurnace.pdf
[9] From Pembina Institutes “Sources and Calculations for the Pembina Institute’s “One Less Tonne” Tool, Version 6.