Ground Source Heat Pumps versus High Efficiency Natural Gas Furnaces in Alberta

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Ground Source Heat Pumps (GSHPs) have been used for heating and cooling buildings in northern Europe for a couple of decades and at least a decade in eastern Canada and the USA. There are far fewer GSHP installations in the Canadian prairies than in eastern Canada. Natural gas furnaces (80% efficient or less) dominate prairie homes because High Efficiency Natural Gas furnaces (HENGs:>90% efficient) are more expensive. Major builders of new homes in the Edmonton area still install 80% efficient furnaces most of the time.

GSHPs exchange heat with the ground under a building. In the winter the heat is collected in a plastic pipe that either runs horizontally under the frost line in the soil or vertically in a series of drilled holes. The pipe is filled with a thermal fluid that has its temperature maintained lower than that of the surrounding soil. Heat flows from higher temperatures to lower temperatures. Inside the building there is a machine (water furnace, etc) which collects the heat from the ground pipe and relays it into the building heat distribution system. In hot summers the GSHP system operates in reverse by taking unwanted heat from the building and relaying it into the ground. GSHPs currently have efficiencies (Coefficient of Performance=COP) up to about 500%, depending on whether they are cooling or heating. No fossil fuel is used except in the production of the electricity that operates the GSHP system. Efficiency is generally taken as the amount of heat produced by a heating system expressed as a percent of the energy input required to operate the system.

At present GSHP systems are somewhat more expensive to install than other heating/cooling systems. However, because they use no fossil fuel, GSHPs may be favored over fully electrical or natural gas systems by those who can amortize initial costs, pay up front or get a subsidy. Subsidies are given in Connecticutt for such installations and they may reduce the payback periods to 1-3 years (RETScreen website, e-textbook). In time the initial cost of GSHPs will decrease as is the case for most new technological devices. The cost of operating any heating system depends on several factors. These costs will be examined below for GSHPs versus HENGs.

The total cost of heating a building by any heating system depends on the building's air-tighness and insulation, the coldness of the climate and the inside controlled temperature setting. An adequately sized furnace in a 40+ year- old Edmonton house with little insulation comes on more frequently than in an R-2000 house. The latter has 15.2 cm thick outer walls full of insulation (R20-30) and an even thicker ceiling (insulation=R40). These houses also have tight vapour barriers and air/heat exchangers. In an even better insulated house (R40 walls, R 60 ceiling) of the R-2000+ variety (Shaw J 2002) the frequency of active heating or cooling is even lower. Building better insulated houses or retrofitting them is usually the best way to save energy and money.

Cane and Garnet (2000) in their paper on global warming impacts of GSHPs and other heating/cooling systems simulated the heating operation of a 230 m^2 house in each of 4 major cities from eastern to western Canada. Electric (100% efficient), oil (78%), natural gas(90%), and both air- and ground-sourced heat pump (GSHP=330%) heating systems were simulated. The authors calculated the Total Equivalent Warming Impact (TEWI) on the global climate for the carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions from combustion of the fossil fuels, including that used to produce electricity (indirect impact) in each city. The authors found that in all cities except Halifax the GSHP had a lower TEWI value than did the other methods of heating the simulated house. They said that Halifax used considerably more coal to produce electricity than the cities of other provinces. Greene and Ugursal (2000) also found that CO2 equivalent emissions associated with GSHP operation were lower than those of electric, oil-fired and propane-fired heating systems.

Cost of Operating a GSHP versus a Natural Gas Furnace

Heating, ventilating and air-conditioning (HVAC) professionals who install GSHPs compare the costs of using different fuels in heating systems with different operating efficiencies by expressing the energy content of the fuels using the same measurement scale. British thermal units (BTUs) are used here to make the cost comparison (Table 1) for a HENG, electric heating and a GSHP. The last column shows the relative costs of input energy regardless of other factors. Natural gas is sold by the gigajoule (GJ) whereas electricity is sold by the Kilowatt-hour (KWh) in Alberta. Prices per GJ and KWh are current.

The arithmetic shown in Table 1 was rearranged in Table 2 to show the price of electricity/KWh below which a GSHP operates cheaper than a HENG operating at 90% efficiency. The tabular values for operating costs of a HENG were computed first and they show that as the amount of heat required is reduced the cost of operating the HENG furnace is reduced. Reduction of operating cost was correlated with reduction in gas price as expected.

The last 3 columns of Table 2 show that the price of electricity/KWh, below which a GSHP is cheaper to operate than a HENG furnace, increases with GSHP efficiency and decreases with the price of gas. In addition, it is clear that as the price of natural gas goes above it's past range, the money saved by higher GSHP efficiencies will be even greater.

The above calculations do not consider the various and different service charges that fuel suppliers may have or the cost of the electricity to run the natural gas furnace.

Table 3 shows the electrical energy and natural gas used (in italics) by the 230 m^2 house simulated by Cane and Garnet (2000) in four Canadian cities. Although it may be the practice in eastern Canada to install GSHP capacity up to 75% of the building heating need (Minea 2000; RETScreen 2000) and to use a supplemental heating supply (usually electrical), Cane and Garnet did not mention this issue. Let us assume that all the electricity was used to provide 100% of the heating by the GSHP.

As in the previous tables the cost of electricity and gas can be manipulated. The cost of gas/m^3 was calculated as 37.2*0.001*$5.50= $0.2046 (Table 3). In RETScreen 2000 one m^3 of natural gas is 37.2 MJ (fuel types-table 2).

Here again we see that the GSHP provides cheaper heating than a HENG furnace when gas is more than 2.7 times (($5.50/277.8)/0.07) the price of electricity (on a KWh basis).

TEWI Effect of GSHPs and HENG Furnaces

In Table 4 the total direct and indirect kg equivalents of CO_2 (italicized columns) have been transcribed from Cane and Garnet (2000) for the simulated house in each of the four cities. Because I could not be sure of their calculations or find their references, I show similar calculated values in the adjacent column to the right. My calculations use the CO_2 emission factor of 1880g/m^3 for burning natural gas and CO_2 equivalents of 0.043g/m^3 for methane and 0.02g/m^3 for nitrous oxide emissions (VCR Inc. Registration Guide, 1999. – p. 32). Methane and nitrous oxide are 21 and 310 times more potent than CO_2 in their potential climate warming effects (Alberta Agriculture, Food and Rural Development 2002). The VCR document also gives indirect emissions resulting from electrical energy consumption by province (p. 34). I used the values found there of 0.02, 0.18, 0.0014, 0.78 and 0.991 kg CO_2 equivalents/KWh for the simulated house data in Vancouver, Toronto, Montreal, Halifax and Alberta, respectively. Low values are associated with more dependence on hydroelectric or natural gas generation of power. Higher values (Halifax) are associated with the use of much coal in the generation of electricity.

Example calculations for the values of “79” and ‘2550” (Table 4) are given there. The value of “0.02” in the calculation for BC is changed to be that of each province as given above. These same calculations were done in the last column of this table assuming the kg CO_2 equivalent/KWh of 0.991 for Alberta.

Although the values (Table 4) are different than those of Cane and Garnet (2000) the same lower TEWI value for the GSHP compared to that of the HENG furnace was found for all cities except Halifax. Hence, coal-fired production of electricity may result in GSHPs polluting more than HENG furnaces.

Discussion

It is clear that the relative costs of heating a house by GSHP or a HENG furnace in Alberta depend on the amount of insulation and air-tightness of the house, the efficiency of the GSHP and the relative prices of natural gas and electricity (Table 2). With additional improvements in the efficiency of GSHPs and R-2000, or better house construction, the total cost of heating by GSHP will be less than by HENG because less electricity will be needed annually. No cost from natural gas use will occur because it is not needed by a GSHP. In addition, the capital cost of a GSHP includes summer air-conditioning capability. With a HENG you must buy a separate air-conditioning system for summer use, if required.

Coal-fired electricity as used for heating will probably be around much longer than natural gas because the latter is predicted to last 40-65 years whereas there is a 300-400 year supply of coal. This can be confirmed on reputable Internet websites. Electricity from coal probably will not rise in price (disregarding the current deregulation problems) as fast as the smaller amount of natural gas which is left, at least until we can see the successful development of under-sea hydrated methane reserves.

Meanwhile GSHPs have a great potential to contribute to a “greener” Alberta. However, this will not occur until the coal-fired electricity production industry begins using better green house gas emission (GHG) reduction technology. Reductions of the indirect emissions from 0.991 kg CO_2 equivalent/KWh of electricity produced to below the 0.65 to 0.70 kg range are needed to bring GHG emissions of GSHPs below those of HENGs (Table 4).

There are several houses with GSHPs already in Alberta. GSHP houses need to be monitored and have their results reported publically because of the difference between theory and practice. Such monitoring data would be a better indicator of how dollar efficent and "green" domestic housing installations of GSHPs would be.

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TABLE 1

Fuel Cost Comparisons

Btu's Required Fuel	1,000,000 Units	Btu's / unit	Cost / unit	Efficiency	Useable Btu's / Unit	Units Needed	Operating Cost
HENG	Gigajoule	947817	$ 7.00	95%	900,426 [1]	1.11 [2]	7.77 [3]
Electric	Kilowatt hour	3412	$ 0.06	100%	3,412	293.08	17.58
GSHP	Kilowatt hour	3412	$ 0.06	350%	11,942	83.74	5.02

1= 95%*947.817   2= 1,000,000/900426   3= 1.11*$7.00

1 GJ=947817 BTU, 1 KWh=3412 BTU : Handbook of Physics and Chemistry 71[st] Edition pages 1-24, 25

TABLE 2

Price of Electricity/Kwh below which a GSHP operates cheaper than a HENG furnace at 90% efficiency

Gas $/GJ	BTUs* Needed	HENG Operating Cost $	GSHP Efficiency (COP) 250%	350%	450%
	160000	**1.69**			
9.00	100000	1.06	0.09	0.13	0.16
	60000	0.63			
	160000	1.13			
6.00	100000	0.70	0.06	**0.084**	0.107
	60000	0.42			
	160000	0.56			
3.00	100000	0.35	0.03	0.042	0.054
	60000	0.21			

1.69=9*160000/(HENG efficiency)*947817

0.084=0.70*3.5{GSHP eff}*3412/100000

* Could be taken as the size of furnace needed for the building.

TABLE 3

Annual fuel use[1] and cost of heating by GSHP[2] and HENG[2] for a simulated House in 4 cities.

City	System	Electrical Energy [kWh/yr]	Electrical Cost $0.07	Gas Energy [m3/yr]	Gas Cost $0.2046	Annual Total Cost
Vancouver	GSHP[2]	*3926*	274.82			274.82
	HENG[2]	*686*	48.02	*1344*	274.98	323.00
Toronto	GSHP	*6724*	470.68			470.68
	HENG	*766*	53.62	*2211*	452.37	505.99
Montreal	GSHP	*7829*	548.03			548.03
	HENG	*809*	56.63	*2435*	498.20	554.83
Halifax	GSHP	*6701*	469.07			469.07
	HENG	*835*	58.45	*2222*	454.62	513.07

[1] Cane and Garnet (2000)

[2] GSHP= Ground Source Heat Pump

[2] HENG= High Efficiency Natural Gas furnace

TABLE 4

Total Equivalent Warming Impact (TEWI) of the simulated house in 4 Canadian cities.

City	System	Electrical Energy [kWh/yr][1]	Gas Energy [m3/yr][1]	Indirect + Direct kg e of CO2/yr[1]	Indirect + Direct kg e of CO2/yr[2]	Total kg CO2/yr as if in Alberta electric coef.=.991
Vancouver	GSHP[3]	*3926*		*6314*	**79**	3891
	HENG[3]	*686*	*1344*	*54467*	**2550**	3216
Toronto	GSHP	*6724*		*23333*	1210	6663
	HENG	*766*	*2211*	*90811*	4310	4931
Montreal	GSHP	*7829*		*4330*	11	7759
	HENG	*809*	*2435*	*97577*	4596	5397
Halifax	GSHP	*6701*		*131811*	5227	6641
	HENG	*835*	*2222*	*104994*	4844	5021

[1] Table 4 in Cane and Garnet : 2000

[2] 79 =3926*0.02[BC electric factor] : 2550=686*0.02+(1880+0.043*21+0.02*310)*0.001*1344

[3] GSHP=Ground Source Heat Pump

[3] HENG= High Efficiency Natural Gas Furnace