Heat Pumps: A snapshot of the technology in cold climates

Desktop Study

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Energy Solutions Centre
Yukon Government

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Technology Overview

The following section contains a quick review of heat pump technology taken from the Natural Resources Canada publication, "Heating and Cooling With a Heat Pump". This publication has much more detail than this overview and is recommended reading for anyone who is seriously considering installing a heat pump. It is available on line at http://oee.nrcan.gc.ca/publications/infosource/pub/home/heating-heat-pump/booklet.pdf.

A heat pump is an electrical device that extracts heat from one place and transfers it to another. A refrigerator is an example of a heat pump working only in cooling mode. An air-source heat pump absorbs heat from the outdoor air in winter and rejects heat into the home, thereby warming it. In summer it can also work in reverse as an air conditioner, by absorbing heat from the house and rejecting it to the outdoor air. It is the most common type of space heating heat pump found in Canadian homes. However, ground-source heat pumps, which draw heat from the ground or ground water, are becoming more widely used.

Heat pumps transfer heat by circulating a refrigerant through a cycle of evaporation and condensation. 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 enroute to the other coil, where it condenses at high pressure. At this point, it releases the heat it absorbed earlier in the cycle.

The energy costs of a heat pump can be lower than those of other heating systems, particularly electric or oil heating systems. However, the relative savings will depend on whether a homeowner is currently using electricity, oil, propane, or wood and the costs of each of these energy sources. By running a heat pump, a homeowner will use less oil, propane or wood, but more electricity. Depending on the costs of the heating alternatives, the payback period for investment in an air-source heat pump could be anywhere from two to more than seven years, or greater than ten years for a ground-source heat pump. The Energy Solutions Centre will be undertaking field trials and other research to more accurately ascertain the particular factors that have significant impacts on the effectiveness and pay back periods of these technologies in Yukon. [1]

Heat pumps transfer heat from the energy contained in the air or the ground to the interior of the home. Although they use electricity to do this, they are usually more efficient than electric resistance heating because for each kilowatt hour of electricity that is used to transfer heat, up to four kilowatt hours of heat energy may be delivered. This ratio of heat energy output to electrical energy input is called the coefficient of performance, or COP.

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[1] Doug Cane of Caneta, the creator of the brochure, "Heating and Cooling with a Heat Pump" is to be retained to do this work in the winter of 2010.

Air-source Heat Pumps

For air-source heat pumps, the COP varies with the outside air temperature. For example at 10°C the COP for a conventional air-source heat pump is typically about 3.3. At -8.3°C, the COP is typically 2.3 and at -15°C, the COP is typically 1. In other words, at that temperature there is no advantage in using a heat pump compared to electric resistance heating. The COP decreases with temperature because the heat pump's capacity to extract heat from cooler air decreases as the temperature drops. Due to the Yukon's long winters with temperatures often well below -15°C, a home with a typical air-source heat pump would need to have a second heating system for the coldest parts of the winter. (There are cold climate heat pumps that are rated to have a COP of 1.95 at -34°C[2], but these were not included in the NRCan publication, "Heating and Cooling With a Heat Pump" being summarized here.)

Ground-source Heat Pumps

The temperature of the earth remains much more constant than the temperature of the air, therefore the COP for ground-source heat pumps remains much more constant during the winter than the COP for air-source heat pumps. Where air temperatures go below -30°C, winter ground temperatures are generally in the range of -2°C to 4°C and ground-source heat pump systems have a COP of between 2.5 and 3.8.

There are two types of ground-source heat pump systems: open loop and closed loop. The terms "open" or "closed loop" refer to the circuit of underground piping outside of the house, used to bring the ground's heat into the heat pump inside the house.

Open Loop Systems

Open loop systems take advantage of the heat retained in an underground body of water. The water is drawn up through a well directly to the heat exchanger, where its heat is extracted. The water is 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.

Closed Loop Systems

Closed loop systems collect heat from the ground by means of a continuous loop of piping buried either horizontally or vertically underground. An antifreeze solution circulates through the piping and absorbs heat from the surrounding soil. The underground piping accounts for the extra capital cost and longer pay back period of a ground-source heat pump system compared to an air-source heat pump system.

Ground-source heat pump systems have a life expectancy of 20 to 25 years. This is higher than for air-source heat pumps because the compressor has less thermal and mechanical stress, and is protected from the environment. Most air-source heat pumps have their compressor outside, perhaps because the industry has been manufacturing units largely for warmer climates.

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[2] Hallowell International Acadia Heat Pump Performance Chart

Yukon Context

Oil heating is the most prevalent form of home heating in the Yukon. As concerns over climate change, rising oil prices and air quality increase, many Yukon residents are seeking ‘cleaner’ heating options with more stable prices. One such option that is gaining increasing attention is the use of heat pumps to capture the heat energy of the air or the ground right outside our homes, thus providing a local, renewable supply of clean energy.

However, it is important to remember that heat pumps are not the source of this energy, but merely a transferring agent. As such, heat pumps need electrical energy to move the heat from outside to inside our homes. That means that if the electricity required by the heat pump is generated by a renewable resource, such as wind or hydro, then the whole heating system is renewable. This is often the case in the Yukon, except in the winter when we most need the heat.

Currently, the vast majority of our electricity is generated by hydro plants that rely on seasonably variable water supplies. Our electrical demand is at its highest during the coldest days of the winter when our hydro reserves are at their lowest and diesel generators are often required to meet the electrical demand. This means that while heat pumps are more efficient than direct resistance heating, if they become widely employed in the Yukon, they could increase our electrical demand to the point that we have to switch to generating electricity with diesel generators far more often. Obviously this prospect would lessen the overall potential benefits that would come from using heat pumps powered by hydro only. This problem is further exacerbated when one considers the relatively low efficiency of a modern diesel generator (30-40%) to convert diesel fuel to electricity as compared to the relatively high efficiency of an oil burning heating appliance (80-95%) to convert oil to heat. It is clear that if a community is using diesel generators to produce electricity, even very efficient forms of electric heating such as heat pumps cannot be considered to be environmentally benign.

To illustrate just how much extra electricity heat pumps could use, consider that between 1998 and 2008 Yukoners used approximately 30,000 cubic metres of stove oil and light fuel oil per annum for heating. This is equivalent to 260 GWh of heat per annum. If it were supplied by heat pumps with a COP of 3, then an additional 32 MW of capacity would be required within the Yukon’s electricity grids.[3] Considering that the current Yukon hydro capacity in winter is approximately 60 MW, that 32 MW represents a 50% increase in capacity.

On the other hand, there is the possibility that if enough Yukoners used heat pump systems in synchronicity with the demand cycle of the grid then we could make better use of our existing hydro resources. This could work by homeowners using their heat pumps during the milder parts of the winter, the shoulder seasons and the summer and then switching to their back up heating systems during the coldest parts of the winter. This would have the dual benefits of better optimizing the use of our hydro resources and

[3] See Appendix A for the supporting calculations.

reducing the Yukon's total fossil fuel consumption. Of course, matching individual homeowners' heat pump usage to hydro supply could be a complex task for the electrical utilities and would involve specific demand side management policies and technologies.

Notwithstanding the potential impacts on the Yukon's electrical system, an increasing number of Energy Solution Centre clients are asking for more information on heat pumps. Many of them have already become familiar with the general information covered earlier in this report and now have specific questions pertaining to local conditions. The questions are usually in regard to:

1. How well heat pumps work in a cold climate such as that found in the Yukon;
2. How closely manufacturers' efficiency and performance claims match actual efficiencies and performances in Yukon conditions;
3. How much the systems cost to install and maintain;
4. Who is qualified to install and maintain heat pump systems; and
5. What issues there may be that could cause problems in the future for homeowners installing heat pump systems.

The interest in heat pumps lead to the Energy Solutions Centre's undertaking research to answer our clients' questions. The Energy Solutions Centre initiated a field study of one ground-source heat pump system and one air-source heat pump system in the Whitehorse area to better understand how well these systems perform in our climate. The ground-source heat pump study was completed on the Duncan house in March 2006. For this study, the Energy Solutions Centre retained an engineering firm to monitor the performance of a hybrid ground-source heat pump and solar heating system over a one year period. This study showed that the ground-source heat pump provided approximately 75% of the average heating load during the winter. The authors of the study recommended that more work would be needed to determine the impact that the heating system is having on the surrounding ground temperature. The complete study is available on the Energy Solutions Centre web site at http://www.esc.gov.yk.ca/pdf/duncan_residential_hybrid_system.pdf.

The Energy Solutions Centre is planning to monitor an air-source heat pump system at the office of a local non-profit society, housed in a former residential building. Their air-source heat pump is a "cold climate" heat pump which is rated to operate at temperatures as low as -34°C.

As well as these two empirical studies, during the summer and fall of 2009 the Energy Solutions Centre undertook a desktop study to learn about the heat pump experiences of other agencies[4] across North America in regard to the five questions listed earlier. Their responses follow in the next section.

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[4] The Energy Solutions Centre contacted the following agencies:

1. Cold Climate Housing Research Centre of Alaska
2. Canmet Energy (NRCan)
3. Canada Mortgage and Housing Corporation
4. Canadian Association for Renewable Energies (C.A.R.E.)
5. Heating, Refrigeration and Air Conditioning Institute of Canada (HRAI)
6. The Canadian GeoExchange Coalition (Geo Connection magazine, *Performance of Ground Source Heat Pumps in Manitoba, June 2009*)

7. The Government of Manitoba's Technology and Energy Branch (they offer an incentive for geothermal systems)
8. The Manitoba Geothermal Energy Alliance
9. Manitoba Hydro
10. The Arctic Energy Alliance
11. Government of NWT Public Works
12. Efficiency New Brunswick
13. BC Hydro
14. FortisBC Inc. (A gas and electrical utility in BC)
15. Interview with Richard Corbett that appeared in the Yukon News in November 2000, commissioned by YDC
16. Geo-Xergy Systems Inc. (Manitoba geothermal heating company)
17. EnergyIdeas Clearinghouse (Washington State University Extension Energy Program, *Product and Technology Review of the Acadia Heat Pump*, December 2007)
18. Office of Energy Efficiency (NRCan)
19. Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (Caddet Analyses Series No. 27, *Learning from experiences with Commercial/Institutional Heat Pump Systems in Cold Climate*, *August 2000*)
20. Hallowell International web site, http://www.gotohallowell.com/default.aspx
21. Presenters Skip Hayden and Bert Phillips at the "Efficient Heat Pumps for Cold Climates" lecture given during the October 28-29, 2009 Energy Retrofits for Houses Conference in Toronto, Ontario.

The effectiveness of heat pumps in cold climates - a snapshot of North American experiences

How well do heat pumps work in a cold climate such as that found in the Yukon?

While there are dissenters, the majority of the agencies queried, many of whom have experience with multiple heat pump installations, agree that well-designed ground source heat pumps should work well in the Yukon, but that air source heat pumps are not as appropriate a technology for our climate as ground source heat pumps are. These agencies tend to view air source heat pumps less favourably due to their diminishing Coefficients of Performance (COP) as the outdoor air temperature decreases, the inefficiency of having to defrost the outside coils frequently, and the negative effect the cold has on moving parts, chiefly the compressors.

Air-source compared to ground-source heat pumps

Bill Eggertson, Executive Director of c.a.r.e. states:

> *Air-source stops working when ambient outside air temperatures drop below 0℃. GSHP works in ANY climate, and [their performance] depends on the heat loss of your building and the conductivity of your soil. The same F280 heat loss in a house in Toronto with the same soil (ideally, wet soil; avoid dry sand) would need the same size heat pump. For the far north, you need to trench deeper (below the frost line) and watch out for permafrost. Beyond those concerns, you can size to obtain 100% heating and 100% DHW, as well as 100% cooling if you need it.*
>
> Sara Mudge, Residential Energy Advisor for Efficiency New Brunswick advices: *Heat pump technologies have improved a bit in the last few years, however not drastically. So unfortunately you'll likely find that air source heat pumps are not a viable technology for your region [i.e., the Yukon]. But there may be some potential for high efficiency geothermal systems.*

Air-source heat pumps

> Keith Veerman, Manager of PowerSense Programs for Fortis BC Inc. offers his experience:
> *Although we haven't done any detailed field tests, ASHPs work best (most efficiently) in the range of -5℃ and above, which is the typical outside winter temperature in the south-central BC where FortisBC provides electrical service. ASHPs will work at lower temperatures, and installers set the switch-over temperature somewhere between -8 to -12℃, albeit the auxiliary heat will likely cycle in order to augment the ASHP's diminishing output. Below that setting the heat pump is switched off and the back-up or auxiliary heat (electric or gas furnace) takes over. They also have the unfortunate necessity of defrosting the outside coils several times a day, which puts the ASHP in reverse i.e. cooling mode, so the hot refrigerant can quickly melt the frost build-up. In short I doubt that ASHPs are suitable to the Yukon climate.*

Other views are provided by Richard Corbet, a Yukon engineer with air source heat pump installation and maintenance experience in Whitehorse, Steve Duncan of Duncan's

Ltd., in Whitehorse and Duane Hallowell, President and CEO of Hallowell International, a manufacturer of the Acadia Heat Pump. In a Yukon Development Corporation sponsored column that appeared in the Yukon News in November 2000, Richard Corbet points out that,

> *Whitehorse does not offer the perfect winter operating conditions for an air source heat pump, but* [his heat pump] *comfortably heats his 216- square-metre house even when it is as cold as minus 20°C outside.*

Another Yukon News article from December 2005 states that the Duncan's Ltd. shop has had heat pumps installed at the shop for more than a decade plus they have four more in a different building. Steve Duncan is quoted in the article saying that, "*These devices hit their limits in the Yukon as they can only draw enough heat from the outside air down to a temperature of -15 or -20°C. Then another source of heating needs to kick in."*

Hallowell claims that even at -30°C, the Acadia provides enough heat that a back up heat source is not needed. Experience in Fort Smith in the Northwest Territories may be proving Hallowell's claims correct. The Government of the Northwest Territories is currently monitoring the performance of an Acadia heat pump in a government building in Fort Smith. Preliminary results from 85 days of monitoring (which represents 32% of an average year based on heating degree days) are showing a COP of 2.6. Hallowell gives COP's of 1.93 at -34°C to 4.59 at 16.7°C for the Acadia.

The Frostbite Society installed a Hallowell cold climate air source heat pump at their society's building. There is also a small number of other air source heat pumps (perhaps around five) installed in the Yukon. Several manufactured by Mitsubishi have been installed by Midnight Sun Sheet Metal and Heating and more are planned to be installed. The performance of these heat pumps has not been monitored by an independent third party.

<u>Ground-source heat pumps</u>

In contrast to air source heat pumps, there appears to be more agreement on ground-source heat pump technology being suitable to the Yukon's climate. The Manitoba Government clearly supports ground-source heat pumps and offers incentives to Manitobans to install these systems. Robert Walger, Project Manager, Energy, Climate Change and Green Initiatives, with the Government of Manitoba says,

> *Geothermal heat pump technologies are a proven technology. Manitoba has one of the coldest climates on the continent and there are over 6000 geothermal heat pumps installed and operating in Manitoba.*

Jeff Zimmerman, Technical Coordinator of HRAI also supports ground-source heat pumps because their COP is not nearly as affected by winter temperatures as air-source heat pumps. He says,

> *Even at -20℃ the GSHP continues to operate with little or no impairment to its rated output. We did a field study of a number of GSHP installations, back in the mid-90s when our GSHP program was new, and it verified both the COPs and energy savings. Even GSHPs that were sized to the CSA minimum of 60% of the*

DHL (Design Heat Load) were producing ≥90% of the dwelling's seasonal heat load. The CSA standard was subsequently revised to increase the minimum sizing to 70% of the DHL so the GSHP is expected to provide ~95% of the winter heating load.

How closely do manufacturers' efficiency and performance claims match actual efficiencies and performances?

Again, there are a few dissenting opinions on this issue, but actual third party tests show that the manufacturer's stated COP is likely not going to be matched in the field.

Air-source heat pumps

In reference to air source heat pumps, Sara Mudge, of Efficiency New Brunswick says,

> *The COP of a heat pump will vary based on the climate region. Since most heat pumps are manufactured and tested in the U.S. their efficiency is measured at a temperature of 8℃; not that cold! This means the performance indicated on the technical specifications are likely to be much better than what you will experience in your climate.*
>
> *For example, a typical ENERGY STAR-rated Air Source Heat Pump has a Heating Season Performance Factor (HSPF) of 8.3, but in New Brunswick we expect the performance to be about 6.7 (average winter temperature is -4℃). Most air source heat pumps don't work at temperatures below -15℃. So for months where you are consistently below that temperature you will require some other form of heat. The lower the average outdoor temperature, the lower the efficiency. And the lower the efficiency, the less economically viable the system. Although there is some temperature fluctuation below ground, it is not as severe as air temperature fluctuations. For this reason geothermal heat pumps have a significantly higher efficiency rating. In NB, a COP of 3.5 is quite common for geothermal (as compared to a COP of 2.0 for Air Source).*

The Washington State University summarized a number of independent reviews of Hallowell's Acadia air-source heat pump. Their summary shows that, while the heat pumps were providing useful heat with minimal maintenance, actual COP's were not as good as the manufacturers' stated COP's. For example:

> *In 2006 the Bonneville Power Administration completed a two-year performance study of five Cold Climate Heat Pumps manufactured by Nyle. This earlier version of the technologically similar Acadia manufactured by Hallowell was shown to meet the heating requirements at three of the five sites without the use of any backup resistance heating. These sites ranged from 3,500 to 4,444 heating degree days [Celsius]*. (For comparison, Whitehorse had 7,066 heating degree days (Celsius) in 2008). *On-site monitoring found operational COPs similar to other typical air source systems ranging from 1.2 to 2.1 across all temperature ranges and averaging about 1.7. This is less than the manufacturer's specifications.* (Washington State University, EnergyIdeas Clearinghouse, PTR #19 December 2007)

In the conclusion to their summary, the writers for EnergyIdeas Clearhouse state:

> *The Acadia heat pump shows promise to fill a market niche for a heat pump for colder climates. Initial field testing suggest that the heating COP of the Acadia is not as high as what is advertised, as high as laboratory testing indicates, or indeed may not be as high as other high performance heat pumps in the moderate temperature ranges. It does, however, seem to have superior performance at lower temperatures without having to resort to backup resistance heating required by other air source systems (except in extreme conditions)….The additional complexity of multiple hermetic compressors may reduce their service life and increase the frequency of replacement (since repairs of hermetic compressors are impractical).* (EnergyIdeas Clearinghouse, PTR #19 December 2007).

Skip Hayden of CanmetENERGY told an audience at the October, 2009 Energy Retrofits for Houses conference that Canmet is currently testing the Hallowell two-stage heat pump and two other cold climate heat pumps. The results of these tests should be available in May of 2010.

<u>Ground-source heat pumps</u>

In reference to ground source heat pumps, John Carr from the Arctic Energy Alliances says,

> *COP is determined by a static laboratory temperature, which never exists in nature. If you were in a glacial aquifer, your COP would vary considerably from the stated level. I've seen analyses of +/- (usually -) 20%*. John goes on to say, *as you probably know, the manufacturers' COPs are very optimistic as they are based on higher ground temperatures than we have due to our long cold winters.*

In June, 2009, Manitoba Hydro released the results of a comprehensive study of ground source heat pumps conducted over a three year period. Their findings show that, just as with air source heat pumps, the actual COP's of ground source heat pumps are less than the manufacturers' rated COP's:

> *Manufacturers of geothermal heat pumps have traditionally reported coefficients of performance (COP) of 3.1 to 4.0. These efficiency levels are based on instantaneous tests conducted under controlled conditions and do not consider all of the losses that may occur in an installed system operating in varying conditions. Test data for ten Manitoba homes shows that the Seasonal Coefficient of Performance (SCOP) of the monitored ground source heat pump systems range from 1.8 to 3.5 with an average of 2.8 for a one year period. SCOP is defined as the total energy (kWh) delivered by the system divided by the total energy input (kWh) to the system over the heating season.* (Rob Andrushuk and Phil Merkel, Manitoba Hydro)

Similar to other industries and equipment manufacturers, there are equipment efficiency standards available to rate the equipment.[5] While the "field" COP often varies from the

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[5] In the case of geothermal heat pumps, COP performance is rated in accordance to the International Standards Organization (ISO) Standard 13256-1 & 13256-2. The AHRI, as a third party, certifies equipment to ISO/AHRI Standard

rated COP, Ed Lohrenz, the Vice President of Geo-Xergy and an internationally recognized trainer, designer and educator believes that,

> *The test results are pretty fair for comparison purposes. The actual COP of a system depends on the temperature of the fluid from the ground heat exchanger. IF the system has been designed properly the heat pump should perform reasonably close to the manufacturer's specifications. If the system is not designed properly the actual performance could drop significantly. Determining the building loads and understanding the geology and designing the system appropriately are key*.

How much do the systems cost to install and maintain?

The short answer to this question is, more than a conventional heating system -- in some cases much more. In the Yukon, both air source and ground source heat pump systems range from about $6,000 (this was the equipment cost only for Richard Corbet's air source heat pump in Granger) to over $50,000 (this was the approximate cost for the equipment and labour for Steve Duncan's ground source heat pump in Porter Creek).

<u>Ground-source heat pumps</u>

The Yukon costs are similar to costs in other areas of North America. For example, while referring to ground source heat pumps, Bill Eggertson, of c.a.r.e. says,

> *This question is impossible to answer without a heat loss and soil conductivity rating. We guesstimate $25-30k for a retrofit in Toronto, assuming good land access, average heat loss, sufficient CFM in ductwork, etc. For new construction, this can be lower (if integrated into construction from the design stage). Maintenance is easy; keep the filters clean and re-pressure the loop every 2 years.*

A more northerly perspective is given by John Carr, Technical Specialist of the Arctic Energy Alliance:

> *We occasionally get people interested in heat pump systems, until they find out that our expensive electricity (~$0.25 per kWh in Yellowknife) and high cost of installation means the paybacks are quite long, if ever. I've heard installed costs for residential GSHP systems in Yellowknife (vertical loops in rock) are in the $60-$70K range. I've also talked to a company in Hay River that thought they could install a horizontal array GSHP system down there for around $60K.*

<u>Air-source and Ground-source heat pump comparisons</u>

In areas where heat pumps are fairly common, the paybacks are still long. Here are a couple of examples from New Brunswick and BC:

Sara Mudge of Efficiency New Brunswick claims that,

> *A typical air source installation costs $6-12k. However, a geothermal system costs $15-30K depending on the size and soil conditions. So you may find that the cost greatly outweighs the potential savings.*

13256-1. An AHRI "Certificate of Product Ratings" confirms the geothermal heat pump equipment has been rated by the AHRI to ISO 13256-1. This certificate can be found in the AHRI Directory of Certified Product Performance at the following AHRI web site: http://www.ahridirectory.org/ahridirectory/pages/wbahp/defaultSearch.aspx.

BC Hydro recommends that,

Customers look at heat pumps only where natural gas is not available and/or where there is a significant cooling load (few places in B.C.). The pay-back on a heat pump system, at today's electricity prices, is at least a couple of decades. So instead of a heat pump system, our energy engineer would recommend the extra money be spent to ensure the house uses as little energy as possible. In existing housing, that includes draft proofing, upgrading the building envelope and installing a high efficiency heating system that is designed specific to the house.

There are, however others that look on the high up-front costs of these systems more favourably. Robert Wagner of the Government of Manitoba is one such person. He says,

A geothermal heat pump system requires an upfront incremental investment over a conventional fossil fuel heating system. In return a geothermal heat pump provides annual operational savings. These long term savings justify the upfront investment. If fossil fuel heat{cost] rise faster than the electricity to run the heat pump, then the savings over time could become larger. Furthermore, there may be less energy price volatility with a geothermal heat pump system compared to conventional fossil fuel heating systems (i.e. heating oil, propane).

Ed Lohrenz, of Geo-Xergy agrees with Wagner, stating,

Geothermal systems are generally more costly to install than a comparable conventional system, but I have seen situations where a poorly designed conventional system is more expensive than a well designed geothermal system. Usually the cost of the ground heat exchanger is the difference and this can vary significantly depending on the land area available and the geology.

Richard Corbet also agrees with Wagner. As written in the Yukon News Column referenced earlier,

Richard Corbet considered oil heat and figures it would have cost him about $8,000 to install an oil furnace. The problem was he would always be stuck with the potentially high cost of fuel oil. Enter the heat pump. It cost him about $6,000 to install his unit, and he figures he will have saved that much money by this time next year. 'I expect it to take a year and a half for the payback. I can prove it as I have the propane records from the previous owners. It would cost $5,000 to $7,000 per year to heat this house with propane.'[6]

Keith Veerman shows how economies of scale affect these prices. In BC, where many more air source heat pumps are being installed than elsewhere in Canada, he says,

The installed cost of an ASHP runs from $4-6k in our area, based on a volume of about 900 units/year and a typical size of 2.5-3 tons, as they can be fairly easily

[6] Note that in March, 2009 Yukon Housing Corp. published statistics describing the annual cost to heat an efficient home (100 MBTU or 29,308 kWh). For electric resistance heating it was approximately $4,300 per year, using the most efficient oil furnace it was approximately $2,500 and using the most efficient propane furnace it was approximately $4,200.

> *retrofitted into most houses with forced air furnaces. GSHPs are 4 or 5 times more expensive because of our limited market (≤100/yr), larger size (5-6 tons), and they tend to go into more expensive custom new homes*.

In an interview published at www.gotohallowell.com, Duane Hallowell says that installation costs for his Acadia air source heat pump have been from $10,000 to $14, 000 (USD). In another interview the manufacturer and distributor said installation costs have been $8,000 to $12,000 (USD), including ducting and claims that this is about $3,000 to $4,000 more than a standard heat pump. (EnergyIdeas Clearinghouse, PTR #19 December 2007).

Who is qualified to install and maintain heat pump systems?
Qualified heat pump installers should be accredited by regional associations such as the Manitoba Geothermal Energy Alliance and the B.C. GeoExchange Coalition, or national and international organizations such as the International Ground Source Heat Pump Association (IGSHPA) and the Canadian GeoExchange Coaltion (CGC). However, Ed Lohrenz of Geo-Xergy cautions that,

> *There are training courses for installers provided by the Canadian GeoExchange Coalition (CGC) and by the International Ground Source Heat Pump Association (IGSHPA) [but] these are only a few days in length and do not really qualify a person taking the course to design and install a system. It is always good to check references. If you are looking at larger commercial systems there are not many really well qualified people.*

The New Brunswick government requires that any heating system that contains refrigerant (such as a heat pump) be installed by a licensed HVAC contractor with their Ozone Depleting Substances Handling Certification.

Perhaps the best advice comes from Bill Eggertson of c.a.r.e. who says that, "*Anyone trained by a heat pump manufacturer is qualified and would receive support from the manufacturer."*

Are there any home owner issues that may cause problems in the future for people installing heat pump systems?
It appears that the biggest problems that occur with heat pump systems are caused by poorly designed systems that have been installed by unqualified installers. This is of course also true for many conventional heating systems. In the case of heat pump systems, this issue results in various problems such as those described below:

<u>Ground-source heat pumps</u>
John Carr, of the Arctic Energy Alliance advised that, *"One system here in Yellowknife uses groundwater from bore-holes in the rock and is supposed to have had problems with cold intake water temperatures meaning that less heat could be extracted than anticipated, at higher cost."*

In relation to ground source heat pumps, Bill Eggertson of c.a.r.e. says that,

> *the biggest problem is dealer under sizing of heat loss or misrating of soil conductivity, often done to keep the install price low. C448 demands minimum 70% sizing (optimal IF you design properly) but utilities prefer 100% to avoid peak demand* [because in many areas of North America, backup heat is provided by an electric furnace] *(but it raises the price by 50%).* [The price increase is due to the ground loop having to be larger which involves using a greater land area for the ground loop, more trenching, backfilling and piping.]

Robert Walger, of the Government of Manitoba, believes that ground source heat pumps should have few problems as long as they are properly designed and "*account for the building heating/cooling load, the design of an appropriate ground loop system for the specific site application, etc. as per the Canadian Standards Association Standard C-448.02 - Design and Installation of Earth Energy Systems.*"

In geographic regions that have a significant cooling load, sufficient heat can be taken from the house and rejected to the ground to balance the heat taken from the ground in the heating season. However, in Canada and the northern U.S., where significantly more heat is taken from the ground than is returned to it by ground-source heat pumps, there is the potential to cool the ground enough that the COP of the heat pump is reduced over time. As Colin Craven, of the Cold Climate Housing Research Center says,

> *There are anecdotal tales of heat pumps in the northern U.S. that exceed the heat balance around the ground loop, and … [end up] having declining COP's over a few years. This is obviously an important consideration for homeowners, especially considering the high capital costs for such a heating system.*

A study conducted for Manitoba Hydro showed that of the ground source heat pump systems studied,

> *The systems operated for an average of 2041 equivalent full load hours in heating mode and only 218 hours in cooling mode. This causes an imbalance to the ground of approximately 5 to 1 for heat being extracted from the ground versus heat that is being rejected to the ground. This thermal imbalance could cause significant issues with a heat pump's long term sustainable performance if it is not properly considered at the design phase.*

This issue has also come up in BC's Fraser Valley,

> *where there is little/no A/C load to thermally recharge the ground, thus the loop temperatures were depressed over a number of years. Ultimately the heat pump(s) will trip out on low temperatures* (Keith Veerman of Fortis BC).

Veerman goes on to say that,

> *even in areas of British Columbia with more of a balance in terms of an air conditioning load to partially recharge the thermal capacity of the ground loop, there is still a 3 or 4 to 1 ratio between winter and summer load. So to a large extent the ground loop depends on heat transfer from adjacent soil and ultimately solar flux on the surface for recharging.*

To help mitigate the effects of the thermal imbalance caused by taking more heat from the ground than is returned to it, some systems are designed to include solar panels to capture solar heat in the summer and transfer it back into the ground via the ground loop. Whether this has the desired effect of maintaining the design ground temperature over the life of the heat pump has yet to be verified.

The Manitoba Hydro study of ground source heat pumps pointed to a few other issues worth noting:

> *Domestic water heating savings from the desuperheater[7] in a heating dominated climate may not justify the capital cost and maintenance costs connected to the desuperheater.*
>
> *The significant in-rush currents and the high numbers of starts associated with the compressors have the potential to cause a momentary dimming of lights (flicker) or other power quality issues. Ensuring that the electrical system supplying power to the heat pump is robust and utilizing lights that are less susceptible to flicker could help reduce the effects of flicker.*

<u>Air-source heat pumps</u>
Other problems that arise for homeowners installing heat pumps relate to the noise of air-source heat pumps and the performance effects of irregular or absent maintenance on heat pump systems (including ground-source heat pump systems).

Conclusion

From the agencies queried for this desk top study, we can conclude that heat pumps, whether air source or ground source, are similar to other heating systems in that they will only work well if they are designed well and sized specifically for the building they are meant to heat.

The way in which heat pump systems differ from other heating systems is that they are often significantly more expensive. Given the greater upfront cost and longer payback periods, people who are interested in installing these systems usually do so because they want to avoid the rising costs (financial, environmental, social and political) of conventional fuels. Bill Semple, Senior Researcher with CMHC says that these prudent people are willing to make a significant investment in energy conservation but questions whether this is the most effective way to spend their money. He notes that one consultant he knows has looked at this and done some calculations in terms of payback and he feels that conservation efforts on buildings (i.e., very high insulation levels, air tightness etc.) are more cost effective than this technology. This opinion was echoed by Bert Phillips, an engineer with the Manitoba engineering firm called UNIES, in his presentation on heat pumps at the October 2009 Energy Retrofit for Houses conference.

While energy efficiency home retrofits probably have a better payback than heat pumps for most existing housing in Canada, the leading edge of housing in Canada may produce

[7] A desuperheater is a heat exchanger that takes some of the ground-source heat pump system's heat to heat domestic hot water.

an increasing number of very well-sealed, highly-insulated and efficiently ventilated homes. It is likely that in the Yukon and in most of Canada, these homes will still need a heat source. In these cases, a heat pump heating system may prove to be the most cost-effective heating system over the long term.

Recommendations for future consideration

- This desktop study has relied on the input of energy specialists from across North America. Many of them have presented opinions on how heat pumps would work in northern climates such as the Yukon's based on their research in milder climates. While their opinions are well-informed extrapolations, they are not based on actual experience in the Yukon's climate. In order for the Energy Solutions Centre to give its clients better advice on heat pump performance in the Yukon, we will need to continue our research in this area. Monitoring the performance of known heat pump installations in the Yukon and documenting the results should continue. The design of our monitoring studies would benefit from input from designers of the Canmet studies of both ground-source and air-source heat pumps. Skip Hayden, Senior Researcher with the Integrated Energy Systems Lab at CanmetENERGY has undertaken a ground source heat pump study where he monitored the power consumption of all the inputs to the heat pump system (including the auxiliary electric heat), the loop temperatures and flows and the run times. Over the winter of 09-10 he will be monitoring the performance of three different types of air-source cold-climate heat pumps.

- This study has also largely relied on other jurisdictions for evaluations of the financial costs and benefits of heat pump systems. The Energy Solutions Centre should initiate a Yukon-based analysis of the economics of heat pump systems using Yukon climate data and Yukon energy, material and labour costs. The analysis should include a practical approach to using heat pumps in a climate where we know a back-up heat source will likely be needed in most cases. The analysis should help to determine temperature thresholds at which the economics of switching to a back-up heating system are most favourable.

Appendix A – Impact of Heat Pumps on Yukon's Electrical System

Between 1998 and 2008 the Yukon used approximately	30,000m^3
of stove oil and light fuel oil per annum.	
Assuming	39 GJ/m^3
and an overall combustion efficiency of	80%
this represents	(30,000m^3*39GJ*80%)= 936,000GJ
or 936,000GJ*1000kWh/3.6GJ=	260,000,000kWh
of heat per annum from that heating source.	
If it were supplied by heat pumps with a COP of	3
It would represent	260,000,000kWh/3= 86,666,667kWh
of electricity generation that would be needed.	

Since approximately	30%
of heating must be done during the coldest winter months, an electricity capacity of approximately (86,666,667kWh*30%)/(62days*24h/day)/1000kW/MW=	17MW
of winter average capacity would need to be added to the electricity grid to provide for this winter peak.	

The annual average capacity requirement would be 86,666,667kWh/yr/8760h/yr/1000kW/MW=	10MW
The peak requirement would be about	10MW/31%= 32MW
assuming a heating load factor of about	31%

(The heating load factor is the ratio of average heating degree hours to peak heating degree hours (i.e., the average is 31% of the peak))[8]

[8] Source: Yukon Government Files