An Evaluation of Air Source Heat Pump Technology in Yukon

May 31, 2013

Photo courtesy of Derek Yap
Whitehorse, May 2013

energy solutions centre

Yukon
Energy, Mines and Resources

Executive Summary

Cold-climate air-source heat pumps (ASHP) are increasingly being installed in Yukon. These systems provide heat using electricity at a better efficiency than an electrical heater or conventional oil furnace. There are concerns that the efficiencies of ASHP will decrease with outside temperatures. Additional concerns have arisen over whether widespread ASHP use may increase energy consumption in Yukon either through inefficient use of heat pumps in the winter and/or use of heat pumps in summer as air conditioners. Either situation could lead to increased diesel consumption if the increased electrical demand due to ASHP use exceeds available hydro capacity. This project was therefore undertaken to evaluate the economic and technical feasibility of operating ASHPs in Yukon to determine whether or not this product is appropriate for Yukon government to promote and support.

Based on this assessment ASHP performance in Yukon appears to align with performance specifications set out by manufacturers of this technology and are a cost effective heating alternative for Yukon residents. With this in mind, and subject to additional research, the recommendation of this report is that cold-climate air-source heat pumps should be included in the Government of Yukon's suite of energy efficient product promotion initiatives.

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1.0 Introduction

An air-source heat pump (ASHP) is an electrically powered mechanical device that transfers heat energy from the outside air into a building in an efficient manner to provide primary and secondary heating. Cold-climate ASHPs are an emerging option for providing heat in Yukon buildings. There are concerns that the efficiencies of ASHPs will decrease with outside temperatures, which average annually between -0.7°C to -3.9°C and reach daily minimum temperatures of -22°C to -32.8°C in January[1]. Concerns also exist that widespread ASHP use may increase energy consumption in Yukon either through inefficient use of heat pumps in the winter and/or use of heat pumps in summer as air conditioners. Either situation could lead to increased diesel consumption if the increased electrical demand due to ASHP use exceeds available hydro capacity. Such concerns are related to the ongoing strain placed on the generating capacity of Yukon's power grid, particularly during the heating season, as reported by Yukon Energy Corporation (2012).The goal of this project is therefore to evaluate the economic and technical feasibility of operating ASHPs in the North and determine whether or not this product is appropriate for Yukon government to promote and support.

1.1 Geographic Scope: Defining a Cold Climate

For the purposes of this study, a cold climate is defined by Zones C and D of the broad Canadian Climate Zones established for Energy Star® qualification purposes (Figure 1). As is evident from Figure 1, Zones C and D constitute the climate zones of Yukon. A cold climate is therefore defined as one having more than 5,500 heating degree days (HDD) in a given year (Canada, 2011). The higher the average HDD value, the colder the location is and the larger the heating demand will be (Canada, 2011)[2].

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HAUTE EFFICACITÉ

Figure 1: Canadian Climate Zones (NRCan, 2011)

[1] Based on the 1971-2000 climate normal for five weather stations in Yukon (Burwash, Mayo A, Pelly Ranch, Watson Lake A, Whitehorse A), http://www.climate.weatheroffice.gc.ca.

[2] A heating degree day (HDD) is the annual sum of the degrees of the average daily temperature for all days below 18°C in a given year. This accumulated sum is averaged over a 30-year period to provide a good indication of the average heating demand in a given location.

1.2 Scoping and Methodology

Initial scoping for this project determined three key uncertainties influencing Yukon government Energy Solutions Centre's decision to promote the use of this technology in Yukon (i.e., can ASHPs be considered an efficient "best in class" technology in a cold climate?):

1. Will ASHPs perform under real world conditions in Yukon as indicated by the manufacturers of these systems?
2. Will consumers use ASHP systems in the manner necessary to ensure the use of diesel generated electricity does not increase over time? That is, will the benefits of improved efficiency of these appliances at moderately cold temperatures outweigh the costs of increased electrical consumption during severely cold periods?
3. Do the necessary conditions, such as electricity and heating prices, exist and are they projected to continue, in order to make ASHPs economically viable for use in Yukon?

Several steps were taken to manage the scope of research, given information and resource constraints. A preliminary literature review was undertaken to establish a common understanding of the benefits and constraints of ASHP systems in a cold climate such as Yukon's climate and to provide an overview of the cold climate heat pump technology and its components. The literature review is summarized in Section 2 and provided in full in Appendix A.

This literature review provided a basis for qualitative directed interviews with ASHP appliance owners using a "snowball" technique. Research questions #1 and #2 were then addressed through a combination of qualitative interviews with heat pump owners in Whitehorse and Fairbanks and through modelling by the Yukon government's Energy Solutions Centre (ESC) to further the performance evaluation completed by Caneta (2010). The interview guide developed to support the interviews is provided in Appendix B. Research question #3 was addressed through an analysis of interview and modelling results to provide the conclusions of this report.

2.0 Air-source heat pumps: The Basics

Heat pump technology has been available in its current form more or less since the 1930s, although not reliable or economically feasible until the 1960s, nor tested in cold climates until the late 1970s/1980s. The components of an ASHP include the ducts, compressors and working fluid. Heat is extracted from the air by the ASHP refrigerant in a cycle that pulls heat from the outside air as it vaporizes and releases heat when it is condensed. The vaporization and condensation of the refrigerant is facilitated by the use of a pump (hence "heat pump") that forces the air through an evaporator and then into a condenser. Electricity is required by the system to drive the pump. The working fluid releases heat as it is forced to condense into a high pressure liquid. In turn, heat is absorbed by the system as the liquid evaporates, a cycle illustrated in Figure 2.

While models of ASHPs seem to vary widely, the United States Department of Energy has broadly grouped them into three basic types: split systems, packaged systems and ductless room heat pumps.

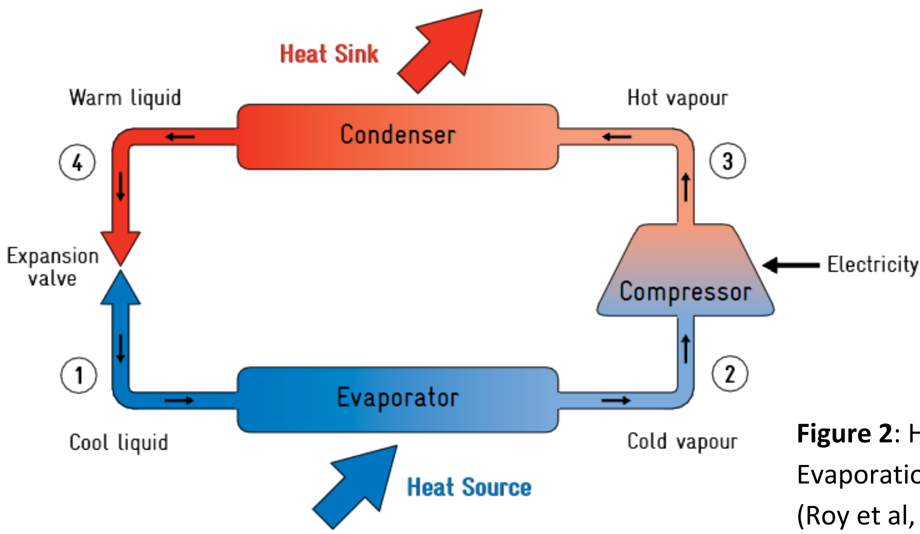

Figure 2: Heat Pump Evaporation/Condensation Cycle (Roy et al, 2010)

Split system ASHPs are the most common type of ASHP in the continental United States. These systems have one coil indoors and one coil outdoors. The compressor, located outdoors, compresses the refrigerant and then forces it indoors where it releases heat into the supply ducts. Once in the duct system, heat is moved through the house by a fan (air handler). The working fluid then moves through the expansion valve outdoors where it evaporates into a gas, absorbing heat, before being returned indoors. Cool air indoors is circulated back to the fan via return ducts.

Packaged systems house both the coils and the fan outdoors. Heated air is then delivered indoors through a duct system.

Ductless room heat pumps are essentially another form of packaged system that does not use ductwork. A common form of ductless heat pump is the *mini-split heat pump*. As with split systems, mini-split systems have two loops, one located indoors and one located outdoors. Heated air is delivered directly into the room or space where it is located.

A fourth broad type of ASHP, referred to as *hybrid systems*[3] was evident in the literature review. These systems are essentially one of the above ASHP types that are permanently coupled with variable electric heating.

The components used to make up the ASHP, and the trade-offs with each, such as the size of the system versus the type of compressor it uses, determines the efficiency of the heat pump in a cold climate. Therefore, the relative performance of ASHP systems, especially in cold climates, is very dependent on what components are being used.

[3] As defined by Franklin Energy.

3.0 Simulation of Potential Performance of Cold Climate Air Source Heat Pumps in Yukon

The Yukon government's Energy Solutions Centre evaluated the anticipated cost/energy savings of ASHP in Yukon climate through the use of the following simulation. The simulation builds on the work completed by Caneta (2010) and is the product of a number of tools and data collection sources including: HOT2000, Environment Canada Weather Database for Yukon and simulation tools developed by Energy Solutions Centre for the purpose of this evaluation.

The modelling began with a confirmation of the correlation between outdoor air temperature and coefficient of performance (COP). As demonstrated in Figure 3.1, and in keeping with the findings of the literature review in Section 2, COP declines with temperature as more energy is required to extract heat from the air. This relationship is also demonstrated to be true between heating capacity and outside temperature in Figure 3.2.

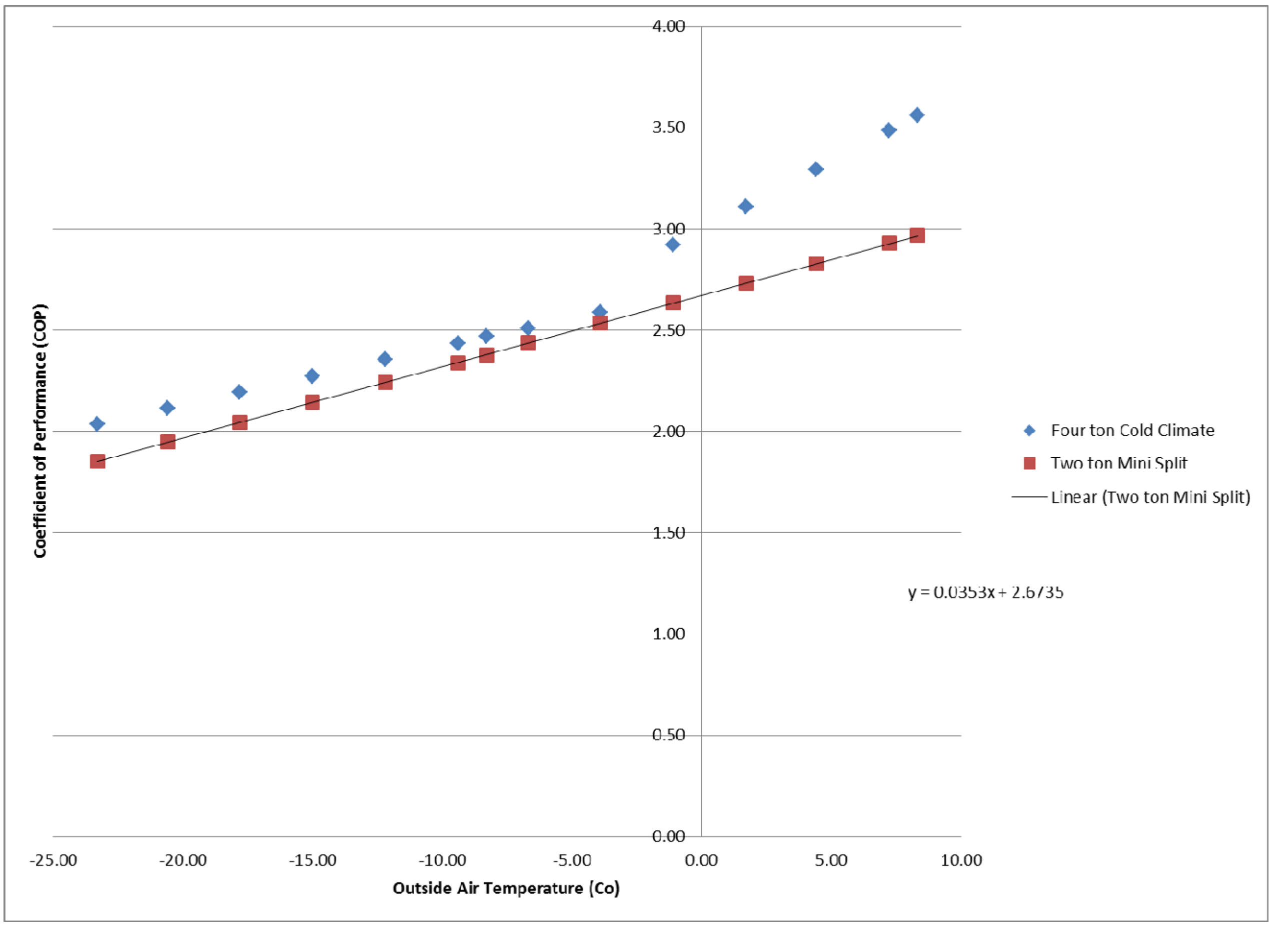

Figure 3.1: COP vs. Outside Air Temperature for a Split System ASHP and a Mini Split (Caneta, 2010)

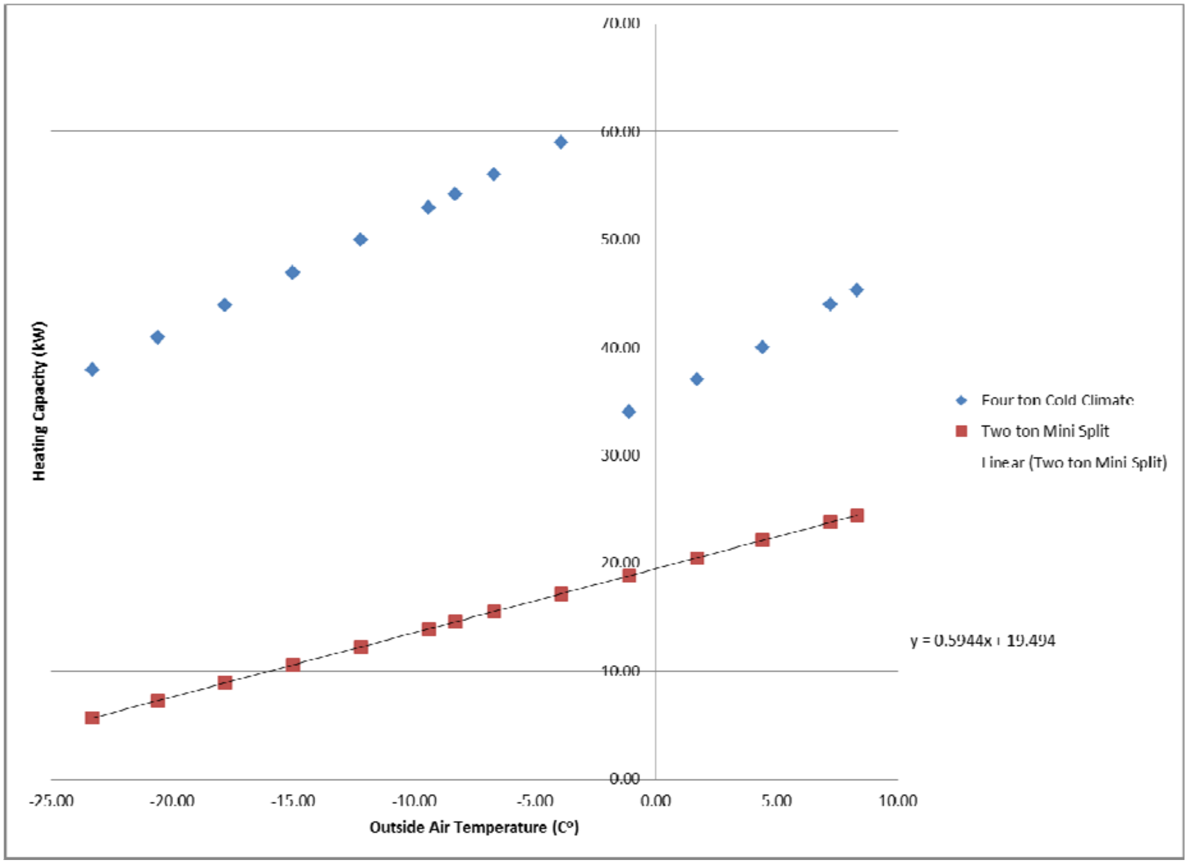

Figure 3.2: ASHP Capacity vs. Outside Air Temperature for a Split System and a Mini Split

The effect of temperature on heat pump performance (i.e., the decline in heating capacity and COP with temperature) is strong enough to suggest that variability in seasonal temperature will also affect the performance of these systems. The effects of variable temperature was then investigated by first extrapolating a linear relationship between outside temperatures and both COP and heating capacity[4]. The linear relationship was then combined with the 5-year average weather data for the City of Whitehorse.

As expected, the relationship between ASHP capacity and temperature variability illustrated in Figure 3.3 shows that COP declines through the fall, reaches a nadir during December, and rises through the winter and spring to a peak capacity in August.

[4] This relationship was developed using the data collected by Caneta for a four ton Cold Climate ASHP.

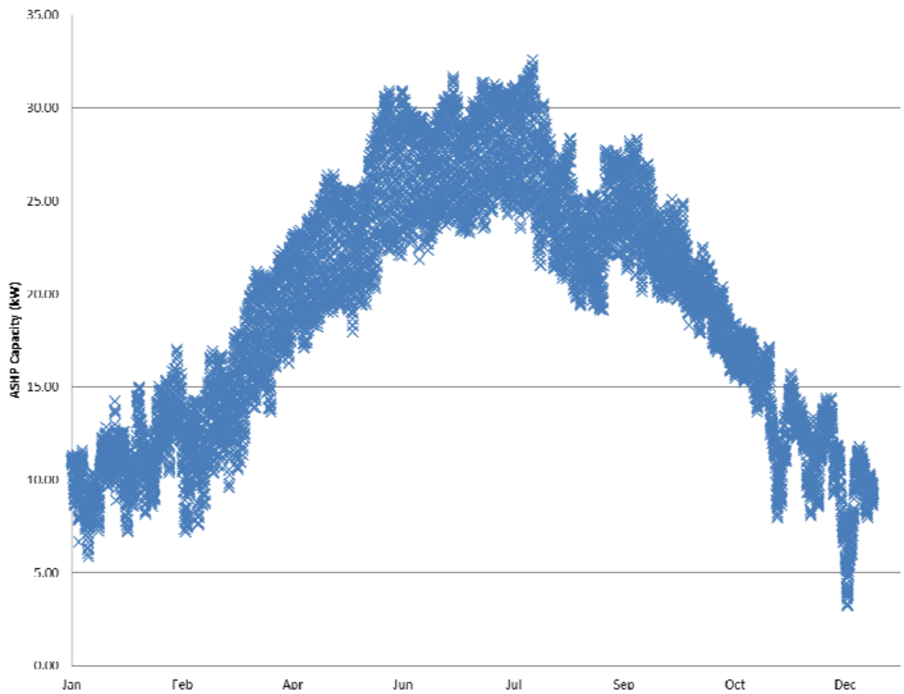

Figure 3.3: Two-ton Cold Climate ASHP Capacity Over the Course of a Year (using 5-year average weather data 2005-2010)

The inverse of this relationship (i.e., between COP and hourly heating demand), plotted in Figure 3.4, demonstrates that the ASHP capacity (ability to produce heat), as well as its COP (efficiency), decrease during the coldest winter months when a home's heating load is at its peak. This is an important relationship to understand because the likely effect of this relationship is to increase the cost of using an ASHP during the coldest winter months.

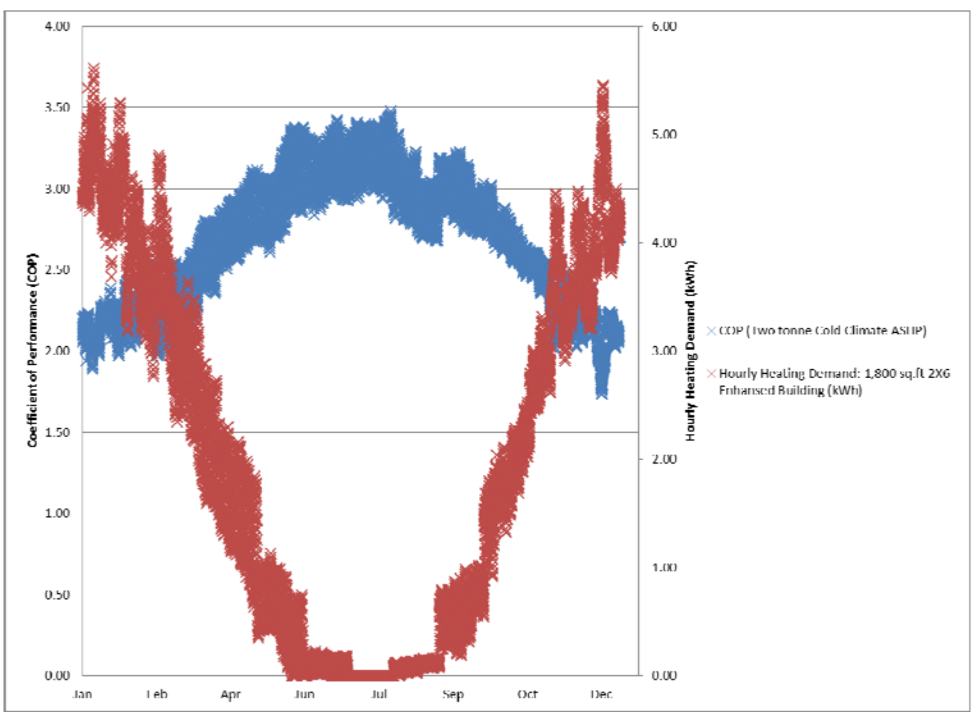

Figure 3.4: Two-ton Cold Climate ASHP COP Over the Course of a Year and Estimated Heating Demand for an Average New Yukon Home* (using 5-year average weather data 2005-2010)

The financial effect of the correlation demonstrated in Figure 3.4 was subsequently tested through the calculation of real world annual energy savings for a customer who installed an ASHP. The savings were determined through HOT2000 simulations for two separate high efficiency ASHPs: one with an NRCan rated HSPF of 9.4 and one with an HSPF of 8.2. The estimated performance of these two (Energy Star® rated) appliances is given in the tables below.

Table 3.1: Annual Energy Savings Provided by HSPF 9.4 and HSPF 8.2 air-source heat pump						
HSPF 9.4 ASHP	**Space Heating Load (kWh)**	**Heat Pump Input (kWh)**	**ASHP Output (kWh)**	**ASHP COP**	**Supplemental Heat (kWh)**	**Energy Savings (kWh)**
January	3,425.06	537.47	1,358.78	2.53	2,066.28	821.31
February	2,541.06	634.14	1,623.69	2.56	917.36	989.56
March	2,042.58	670.44	1,808.19	2.70	234.39	1,137.75
April	1,162.67	365.97	1,131.06	3.09	31.61	765.08
May	405.81	119.72	395.67	3.30	10.14	275.94
June	64.42	25.39	62.78	2.47	1.64	37.39
July	0.00	0.00	0.00	0.00	0.00	0.00
August	68.58	26.75	66.83	2.50	1.75	40.08
September	443.69	130.25	432.72	3.32	10.97	302.47
October	1,356.83	430.47	1,319.50	3.07	37.33	889.03
November	2,312.89	716.36	1,887.19	2.63	425.69	1,170.83
December	3,025.39	665.64	1,701.53	2.56	1,323.86	1,035.89
Total	**16,848.97**	**4,322.61**	**11,787.94**	**2.73**	**5,061.03**	**7,465.33**
Annual Percent Energy Savings						**44 percent**
HSPF 8.2 ASHP	**Space Heating Load (kWh)**	**Heat Pump Input (kWh)**	**ASHP Output (kWh)**	**ASHP COP**	**Supplemental Heat (kWh)**	**Energy Savings (kWh)**
January	3,425.06	602.00	1,358.78	2.26	2,066.28	756.78
February	2,541.06	710.28	1,623.69	2.29	917.36	913.42
March	2,042.58	750.94	1,808.19	2.41	234.39	1,057.25
April	1,162.67	409.92	1,131.06	2.76	31.61	721.14
May	405.81	133.92	395.67	2.95	10.14	261.75
June	64.42	27.53	62.78	2.28	1.64	35.25
July	0.00	0.00	0.00	0.00	0.00	0.00
August	68.58	29.03	66.83	2.30	1.75	37.81
September	443.69	145.78	432.72	2.97	10.97	286.94
October	1,356.83	482.14	1,319.50	2.74	37.33	837.36
November	2,312.89	802.36	1,887.19	2.35	425.69	1,084.83
December	3,025.39	745.56	1,701.53	2.28	1,323.86	955.97
Total	**16,848.97**	**4,839.44**	**11,787.94**	**2.44**	**5,061.03**	**6,948.50**
Annual Percent Energy Savings						**41 percent**

As expected, the potential savings yielded from use of an ASHP based on these calculations are less than 50 percent. However, the savings calculated are in keeping with those savings suggested by ASHP manufacturers. For example, Mitsubishi suggests up to 53 percent savings over a gas furnace for their Zuba model[5]. The COP of the evaluated heat pumps is also in keeping with the minimum efficiency standards established by Caneta (2010).

Ultimately the pattern for annual savings calculated in this model support the use of a “supplementary” system to provide heat in the winter months when heating demand is highest but ASHP capacity is at its lowest. This simulation does not incorporate maintenance costs and summer cooling, which may reduce savings, or the influence of different secondary systems on heating. To evaluate the impact of these factors Energy Solutions Centre conducted an inventory survey in the winter of 2012 of Yukon heat pump owners to establish the real world functioning of these systems in the residential and commercial sectors. The results of these interviews are provided in the following section.

4.0 Survey of air-source heat pump use in a Residential and Commercial Setting

Interviews with Yukon ASHP owners were completed between December 2012 and February 2013 to add depth to this evaluation of ASHPs by examining the real-world experience with these heating systems. Five individuals who were willing to participate in the inventory were identified. In general these participants had installed ASHPs in a residential setting; only one participant reported a commercial application. Four participants reported that they currently work with or had worked directly with ASHPs prior to purchasing one. One participant reported no direct experience prior to installing an ASHP. Four respondents reported owning their current ASHP for less than 5 years. One participant reported owning their current AHSP for less than 10 years. Two participants reported owning more than one ASHP. One reported owning the old heat pump for more than 10 years and the other was not clear about how long they had owned their prior system. The relatively low level of identified system owners along with the short period of time in which these systems have been installed clearly indicate that this technology is still in the early adopter phase within Yukon.

Each participant reported owning a different model of ASHP and some reported owning more than one model over the period that they have been using ASHPs. The models reported in interviews were:

- Mitsubishi Zuba Central
- Goodman Heat Pump
- Lennox 2-ton Heat Pump
- Mitsubishi 18-ton Heat Pump
- Amana 4-ton
- Lennox HP29 5-ton

[5] http://www.mitsubishielectric.ca/en/hvac/zuba-central/zuba_central_vs_traditional_furnaces.html

All respondents were satisfied with their installed model of ASHP, with the exception of the owner of the Amana 4-ton.

The reasons given by respondents for installing their ASHP were:

- To lower yearly heating costs (3);
- For environmental reasons (3);
- To save on labour (1); and
- For cooling (1).

Three of the currently used ASHPs were installed in newly constructed housing, one retrofit was reported and the final participant (who owned two ASHP systems) declined to comment. In discussions of system components, no evaluation of the specific components of the ASHP system were reported by participants, nor were components reported to play a role in the decision to install and operate an ASHP. However, three participants did stress the importance of installing new insulation and ensuring adequate building envelope performance as an integral factor in their decision to install an ASHP. The appropriate sizing of an ASHP unit was also recognized as being important. Eighty percent (i.e., four) of participants were familiar with the importance of a good heat load calculation at the time of installation. Two of the five participants had the heat load calculation completed by an expert before installing their ASHP.

Noise associated with the operation of an ASHP was not reported as a concern by any participant.

Only one participant suggested that they use an ASHP for heating throughout the winter. The remainder of participants reported satisfactory heat to -20°C. Automatic systems, ranging from an installed interlock system/HVAC unit to a home-made LED indicator system were reported to shut off the ASHP between -25°C to -28°C, at which point a secondary heating appliance was utilized. Use of the ASHP was reported to be easy in all installations.

Back-up/alternate heating systems varied between interview participants and included:

- None (1)
- Wood (2)
- Oil (3)

A major repair was reported in four of the six installed ASHPs in the first or second year. These repairs were:

- Compressor malfunction (2)
- Icing (1)
- Faulty wiring (1)

A second major compressor malfunction was also reported at year four of an installed system. One participant, a local installer, further reported having completed repairs to “many” ASHPs.

Annual maintenance was not reported by four participants. Only one participant reported changing the system's air filters every three months.

The savings associated with operating an ASHP, qualitatively comparing heating costs pre-and-post installation of the ASHP, suggested amounts between 33-50 percent of pre-installation heat expenses, as reported by the two participants who replaced their old heating system with an ASHP. Of the five participants interviewed, three respondents reported that their heating costs dropped less than expected, one participant wasn't sure what their savings were and one reported that savings wasn't a factor in their satisfaction with the system. In one case the repair costs to the installed ASHP were considered sufficient to render any savings moot.

Four out of five participants felt that a rebate should be offered by either the government or the utility to support ASHP installation. One respondent felt that this rebate should be offered by the local electrical utility rather than Yukon government. The average rebate suggested by supportive participants was 10-25 percent of the installation cost (~$1,000-2,000).

While inconclusive due to the small sample size of participants, these interviews do provide some insights into the real world experience of ASHP use in cold climates.

The majority of respondents (i.e., four) use their ASHP in the manner anticipated at the outset of the inventory (e.g., seasonally). These four participants were aware of the limitations of their ASHP, and all had compensated for these limitations through the incorporation of back-up heating systems and automated transfer systems. Reliance on back-up systems was also found to address the influence of prolonged cold on heat pump performance. As anticipated the components of the ASHP did not play a significant role in selection of their model of ASHP. The savings reported by residents were also within the anticipated range (up to 50 percent), although it is interesting that some respondents reported disappointment with the savings reported. Also of interest is the high prevalence of major repairs in the first year of use, the lack of annual maintenance reported on ASHPs, and the interest in summer cooling. Annual maintenance, if only the manual cleaning of filters every few months, is a common undertaking reported in Alaska, and recommended by regulators and manufactures (Cold Climate Housing Research Centre, 2013). While cooling was only reported as a priority by one respondent, it is still possible that by promoting this technology Yukon government might unknowingly support increased energy use for summer cooling at installations in Yukon.

5.0 Recommendations for Inclusion of Air Source Heat Pumps in the Government of Yukon's Energy Efficiency Product Promotion Initiatives

Cold Climate ASHPs are being utilized in Yukon at an increasing rate. This study set out to evaluate the implications of increased usage of ASHPs as a product of their inclusion in Yukon government's energy efficiency product promotion initiatives by answering three questions:

1. Will ASHPs perform in Yukon as indicated by performance specifications for cold climate systems?
2. Will consumers use ASHP systems in the manner necessary to ensure the use of diesel generated electricity is not increased? For example, will users seasonally stop use of ASHP systems when they cease to perform efficiently?
3. Do the necessary conditions, such as electricity and heating prices, exist and are they projected to continue, to make ASHP systems economically viable for use in Yukon?

Based on the best information available to us at this time, ASHP performance in Yukon does appear to align with performance specifications set out by manufacturers of this technology. In addition, responses by consumers in the residential and commercial sector do indicate that heat pump systems are likely to be used in a manner that minimizes increases in extreme cold climate electrical usage and corresponding increases in the use of diesel electric generation, especially if trends for the inclusion of automatic transfers to alternate heating systems continue. Further, the cost savings of heat pumps are within the range anticipated (up to 50 percent) and the conditions necessary to make these systems economically viable in the future are likely to continue. The evaluation of the environmental impacts and cost considerations do not include the potential impacts of increased reliance on electric heat on diesel consumption and the implications of demand-side management on diesel consumption given the complexity of these subjects and the inconclusive findings of the survey.

As a result, the recommendation of this evaluation is that cold-climate ASHPs should be included in the Government of Yukon's suite of energy efficient product promotion initiatives.

Several potential risks do exist with regard to the promotion of ASHP technology in Yukon. The high incidence of major repairs to heating systems within the first year of service indicates that some training for contractors may be required to ensure that these appliances are installed and maintained properly. The disappointment in savings reported in the interviews also suggests that promotion of ASHP technology without some consideration of how heat pumps are perceived may yield negative results.

The following recommendations are provided with regard to these considerations and to support the development and implementation of a rebate to support ASHP installation.

Contractor training should be implemented along with technology promotion to enhance the capacity of the industry to install ASHPs.

The high incidence of major repairs reported in the first few years of owning an ASHP suggests that some training is required for contractors who install these systems. Merit for enhancing contractor capacity is also indicated by the reliance of customers on automated transfers, the lack of annual maintenance reported by participants and the potential need for heat load calculations to be done prior to installation by contractors to improve the capacity of the industry to install heat pumps with consistency. The curriculum for this training program should be based on best-practices elsewhere and on the experience of local contractors.

Educational materials should be provided to clients interested in ASHP technology.

Educational materials that outline potential savings, maintenance requirements and other considerations associated with ASHPs should be provided to interested customers and would be invaluable in managing future issues associated with heat pumps. The need for enhanced education of consumers was evident in the interviews in which respondents expressed disappointment in the savings associated with heat-pumps despite the apparent correlation of potential savings with observed savings. Education should also be provided to manage the potential interest in cooling and the implications of little-to-no reported maintenance on the operational life of the heat pump.

Promotion of ASHPs should be supported by further evaluation and monitoring.

Several uncertainties linger with regard to widespread use of ASHPs, such as the demand on the electrical grid for increased energy if the systems are used improperly or for cooling. For example, an increased demand for summer cooling may not be relevant given surplus hydro in the summer. However if circumstances change (i.e., a major mine uses the available summer surplus), then summer cooling demands may lead to the burning of diesel, which is certainly not the intent of the rebate. The evaluation of such contingencies was outside the scope of this report. Given the small size and inconclusive findings of the interviews, additional evaluation and monitoring of ASHPs is recommended. Such monitoring will enhance our understanding of the opportunities and limitations of heat pump technology. Clients claiming the rebate could be asked to sign a waiver committing them to submit their electricity bills for the first and second year of use and to complete a survey similar to that used in this evaluation. The information gathered should be utilized to gather a more conclusive evaluation of ASHP use in the residential and commercial sector.

6.0 Literature Cited

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Appendix A: Literature Review and Preliminary Analysis for Interviews

21 December 2012

The following literature was prepared in December 2012 to establish a foundation for the main body of this report. It is provided here for the purposes of expanding on the brief background provided in Section Two and to provide additional resource material for the reader. Some repetition may therefore occur.

An air-source heat pump (ASHP) is an electrically-powered mechanical device that transfers heat energy from the outside air into the house, providing relatively low-cost primary and secondary heating to cold-climate areas of North America and Europe. ASHP systems are an emerging option for providing heat in Yukon. This study of ASHP was initiated in November 2012 by the Energy Solutions Centre to evaluate the residential performance of AHSP, in cold climates similar to Yukon, given uncertainties about the effectiveness of ASHPs in the territory, where annual average temperatures are between -0.7°C to -3.9°C and daily minimum January temperatures range from -22°C to -32.8°C[6]. The vision for this project is to determine the economic and technical feasibility of operating ASHPs in the North so as to determine whether or not this product is appropriate for inclusion in the *Good Energy* rebate program. The primary objective of the *Good Energy* rebate program is to provide incentives to increase the portion of Yukon residents operating high efficient, "best-in-class" technologies (ESC, 2010).

The Energy Star rating is central to the *Good Energy* rebate program, which is why the Canadian climate zones have been used to determine a cold climate. For the purposes of this study, a cold climate is defined by Zones C and D of the broad Canadian climate zones established for Energy Star qualification purposes (Figure 1). A cold climate is therefore defined as one having more than 5500 heating degree days (Canada, 2011). A heating degree day (HDD) is the annual sum of the degrees of the average daily temperature for all days below 18°C. This accumulated sum is averaged over a 30-year period to provide a good indication of the average temperature in a given location. The higher the average HDD value, the colder the location is and the longer the heating season will be (Canada, 2011).

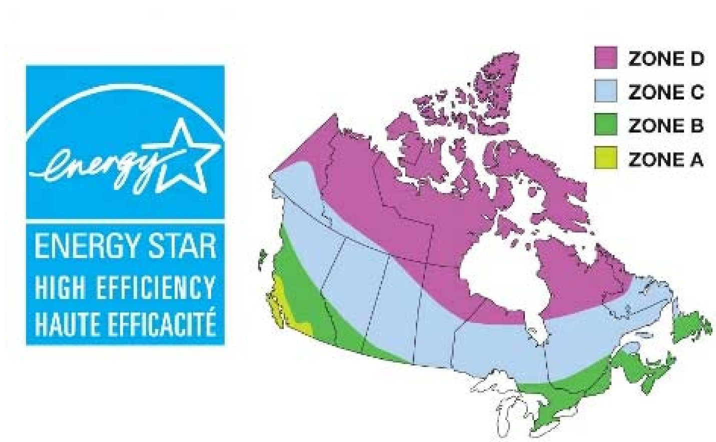

Figure 1: Canadian Climate Zones (NRCan, 2011)

[6] Based on the 1971-2000 climate normal for five weather stations in Yukon (Burwash, Mayo A, Pelly Ranch, Watson Lake A, Whitehorse A), http://www.climate.weatheroffice.gc.ca.

Interim Paper #1 provides a brief overview of ASHP technology for use as a starting point to the greater evaluation of ASHPs by Energy Solutions Centre. Phases included in the scope of work for the evaluation are:

I. Literature Review
II. Inventory of ASHPs in relevant jurisdictions (Yukon, Northern British Columbia and Alaska)
III. Broad Energy Model Development
IV. Development of Draft Report
V. Review of Draft Report
VI. Completion of Final Report.

The literature review establishes an understanding of the benefits and constraints of ASHP systems in a cold climate, provides an overview of the ASHP technology and its components and identifies some additional key points of interest to the study of ASHPs. The literature review concludes with some recommendations for the development of an interview guide for use in Phase II of this project.

Benefits Provided by air-source heat pumps in Cold Climates

ASHP technology represents a significant potential to lower energy costs when compared with other heating systems (Cantera, 2010; Brown et al, 2011). Heating costs may be reduced by up to 50 percent if circumstances such as climate, the efficiency of the heat pump (most notably the compressor), the efficiency of the heating system being replaced, the cost of fuel and electricity and the size of the heat pump allow (Canada, 2004). ASHPs can also reduce greenhouse gases and provide a more sustainable and environmentally responsible heating option to Yukon residents (Green and Bradford, 2010).

As is evident, the benefits of ASHPs are subject to a number of constraints. First and foremost, the lower the temperature of the ambient air, the more energy is needed to extract heat from it (Bertsch et al, 2005; Dieckmann et al, 2004). The exact temperature at which heat pumps cease to be effective in cold climates is debatable but has often been placed at -18°C (0°F) (Cantera, 2010; Dieckmann et al, 2004); however, ASHP manufacturers' claims for the latest heat pump technologies are that ASHPs can perform efficiently in temperatures as low as -30°C[7]. Another constraint of cold climate ASHPs is reduced efficiencies resulting from the performance of components such as the system compressor or fans (Dieckmann et al, 2004). For example, a cost savings assessment in Minnesota has shown that many users of ASHPs actually experienced an increase in electricity consumption because of system inefficiencies (Brown et al, 2011). The performance of ASHPs in cold climates is further reduced by the need for defrosting in temperatures as "warm" as -4°C (Lu Aye, 2003).

[7] Mitsubishi claims a COP of at least 1.4 at -30°C for the Zuba-Central (http://www.cozyworld.ca/zuba-central-heat-pump.pdf).
Amana claims a COP of 1.4 at -23°C for their RHF24C2, CHA3OTCC and BBA24A2A models (http://johnstonesupply9.com/TechDocs/Amana/Heat%20Pumps/RHF%20Heat%20Pump/RHF_SPEC.pdf).

Another factor that may influence the effectiveness of ASHP in cold climates is limited contractor capacity to install ASHPs in remote communities. Installation concerns include purchasing of the appropriate system for residential use, installation of the heat pump to the required specifications and to the standards of the manufacturer. Another important consideration is proper maintenance of the system after it has been installed (Roy et al, 2010).

Many of the benefits, and limitations, of ASHP are associated with a given system's components. For example, the efficiency of an AHSP is largely dependent on the type of compressor and refrigerant used, and these components vary between systems. Different components will also be easier to install than others. These trade-offs ultimately determine if and which ASHP systems will work best in a cold climate such as Yukon's. Prior to discussing the impacts of components on performance, however, it is useful to examine ASHP systems overall to understand the basics of how the system operates.

Air-source heat pumps: The Basics

Heat pumps are generally well understood. The technology has been available in its current form more or less since the 1930s, although not reliable or economically feasible until the 1960s, nor applied in cold climates until the late 1970s/1980s (Abdelaziz et al, 2012). An electric heat pump system essentially operates by pulling heat out of the outside air and forcing it into an insulated space such as a residential area (Dieckmann et al, 2004). The heat is extracted from the air by a refrigerant, or working fluid, in a cycle that pulls heat from the outside air as it vaporizes and releases heat when it is condensed (Alaska Energy Authority, 2011). Vaporization and condensation of the working fluid is facilitated by the use of a pump (hence "heat pump"), which forces the air through an evaporator and then into a condenser. The working fluid releases heat as it is forced to condense into a high pressure liquid. In turn, heat is absorbed by the system as the liquid evaporates, a cycle illustrated in Figure 2 (Roy et al, 2010). Electricity is required by the system to drive the pump (Roy et al, 2010).

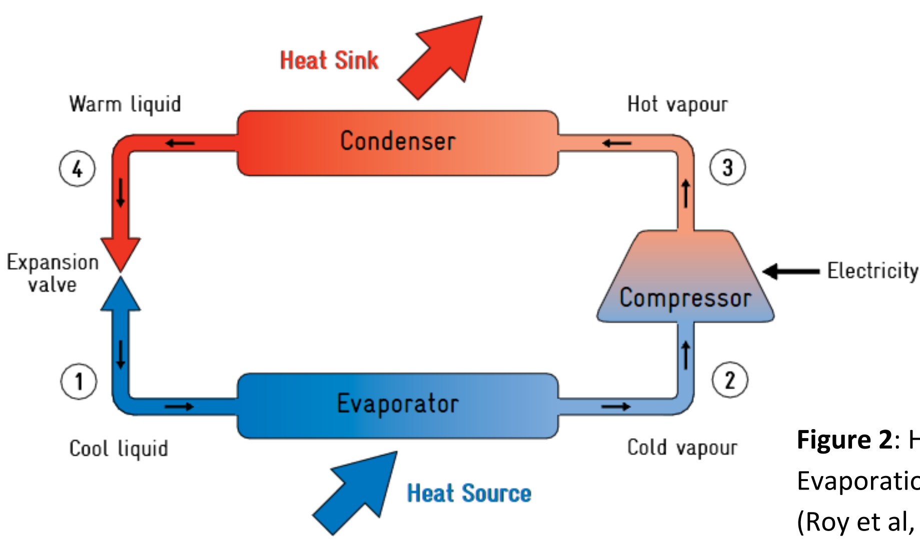

Figure 2: Heat Pump Evaporation/Condensation Cycle (Roy et al, 2010)

While models of ASHPs to vary widely, the United States Department of Energy (2001) has broadly grouped them into three basic types: split systems, packaged systems and ductless room heat pumps.

Split system ASHPs are the most common type of ASHP. These systems have one coil indoors and one coil outdoors. The compressor, located outdoors, compresses the working fluid into a liquid form. The working fluid is then forced indoors, where it releases heat into the supply ducts. Once in the duct system heat is moved through the house by a fan (air handler). The working fluid then moves through the expansion valve outdoors, where it evaporates into a gas, absorbing heat, before being returned indoors. Cool air indoors is circulated back to the fan via return ducts (DOE, 2001).

Packaged systems house both the coils and the fan outdoors. Heated air is then delivered indoors through a duct system (DOE, 2001).

Ductless room heat pumps are essentially another form of packaged system that does not use ductwork (DOE, 2001). A common form of ductless heat pump is currently the *mini-split heat pump*. As with split systems, mini-split systems have two loops, one located indoors and one located outdoors. Heated air is delivered directly into the room or space where it is located (Caneta, 2010).

Hybrid systems are a fourth broad type of ASHP[8]. These systems are essentially one of the above ASHP types that are permanently coupled with variable electric heating (Brown et al, 2011).

The relative performance of ASHP systems, especially in cold climates, relies primarily on their components. The components used to make up the ASHP, the trade-offs with each and their effectiveness in cold climates will determine the efficiency of the system. Some important components and attributes of ASHPs that determine their efficiency and energy savings potential include compressor type, ductwork, system size and type of working fluids. Some considerations associated with each component in a cold climate are reported next.

Components of Cold Climate Air Source Heat Pumps

The components that make up the ASHP determine its performance. Performance of an ASHP can be presented as its energy efficiency rating (EER), its heating seasonal performance factor or its coefficient of performance (COP), among others. In this report the performance of an ASHP is presented as a measure of its COP. A COP is a long-term measurement of performance taken at a particular instant, measured as:

$$COP = \frac{Q_{in}}{P_{out}}$$

Where: Q_{in} is the rate of heat production and P_{out} is the corresponding power input (Martin and Watson, 2008).

[8] As defined by Franklin Energy.

For reference, a minimum COP of 2 has been recommended as a guideline for good energy efficiency in Yukon (Caneta, 2010). This section documents some important components of an ASHP and their influence on its COP.

Compressors influence the performance of an ASHP by affecting the efficiency of the system. Energy is typically lost by the system during start-up or shut-down of the compressor, affecting its COP, making the compressor the critical element of the system (Canada, 2004). Modifying the compressor can reduce the amount of energy lost by the system when activated. The most common form of compressor is a single-stage reciprocating compressor (Canada, 2004), which uses a piston to compress the volume of the working fluid (Maclaren et al, 1974). Single stage compressors are also the least efficient compressor for ASHPs (Deickmann et al, 2004).

The use of a scroll compressor to condense the working fluid will improve an ASHP's efficiency. A scroll compressor is made up of two scrolls, one fixed and one that moves, or "orbits." Compression occurs when the moving scroll revolves around the stationary scroll to form a sealed chamber after the working fluid has entered the compressor. As the scrolls orbit they compress the gas, increasing the temperature and pressure of the fluid (Caneta, 2011). While ordinary scroll compressors can only be turned on or off, allowing 0 percent or 100 percent efficiency, a modulating ring can be added to the system that allows increased variation on compression and improves efficiency, allowing for modulations of 10 to 100 percent of compressor capacity without turning the compressor off (Caneta, 2011). The advantage of the modulating ring is that it improves the efficiency of the system by reducing the number of times it has to start from 0 percent (i.e., the number of times it needs to be turned on) (Kavanaugh, 2010).

Energy efficiency can also be modified through the provision of energy to the system (Karlsson, 2007). For example, multi-capacity or variable speed ASHPs utilize a frequency converter to change the frequency of the electrical supply to the compressor motor. As the frequency shifts, so does the speed of the motor, which changes the speed of the compressor and the flow of the working fluid. A change to the compressor speed, or variable speeds, improves the energy efficiency of the ASHP (Karlsson, 2007).

In cold climates, dual capacity scroll compressors have been found to be more efficient than reciprocating compressors (Ma, 2004). Variable speed compressors have been found to also perform better than single-stage reciprocating compressors, achieving a COP of 2 at -30°C (Tian et al, 2006). Multiple compressors have also improved COP at cold temperatures by addressing "…mismatched loads by sizing compressor capacity to meet heating design loads at full capacity" (Dieckmann et al, 2004: 115).

Duct Systems influence COP in a fairly straightforward manner. Duct systems lose heat in two ways, either through air leakage through small cracks, or through conduction of heat through the duct wall (Andrews, 2001). The more heat lost through poorly designed or aging duct systems, the lower the COP for the ASHP. Heat pump systems generally require larger duct systems than other central heating systems (Canada, 2004). Limitations in an existing duct system can reduce the cost effectiveness of ASHPs in cold climates, especially in retrofit homes. For example, relatively few homes in Alaska have duct systems, limiting the use of ASHPs in the state (Alaska Energy Authority, 2012). Mini-split systems have been successfully used to overcome shortcomings with duct systems in cold climates (Alaska Energy Authority, 2012). The success of these systems has been closely linked with the weatherization of homes, through improved home insulation and duct sealing, which improves the efficiency of space heating (Alaska Energy Authority, 2012).

Sizing of the ASHP is critical to achieving an energy efficient ASHP (Green and Bradford, 2010). Over-sized pumps will start and stop more often than a properly sized pump and decrease the efficiency of the system. Frequent start-ups and stops are also harder on the components (Brown et al, 2011; DOE, 2001). Heat pumps in cold climates should be sized to meet the heating, rather than the cooling, loads (Brown et al, 2011). In fact, the cooling load is largely irrelevant in Yukon (Cantera, 2010). While this idea may seem intuitive in cold climates such as Yukon, recommendations in literature suggest that ASHPs should be sized for cooling loads in the cold climates of Canada (Canada, 2004), which is not conducive to system efficiency (Brown et al, 2011). In addition to sizing the ASHP to meet the heating loads, sizing issues in cold climates can be addressed by using variable speed compression systems (Karlsson, 2007).

Working Fluids, by virtue of their ability to extract heat from the air, are another imperative component of ASHPs (Canada, 2004). To be effective, the operating temperature of the working fluid in the evaporator must be colder than the relative temperature in the condenser in order to facilitate heat transference (Wu, 2009). The performance of the system is affected when the balance between the energy put into the system and the resulting heat is not optimal (Dieckmann et al, 2004). While much of this balance is determined by the compressor, effective performance in cold climates can also be determined by the working fluid (Dieckmann et al, 2004). Carbon dioxide (CO_2) refrigerant cycles have been found to improve system efficiency by 35 percent at -8°C, reducing energy inputs into the system and enabling improved COP (Dieckmann et al, 2004). Subcooling the working fluid mechanically, which involves cooling the working fluid after is has been condensed (Pacific Gas and Electrical Company, 2011) can also enhance the COP of an ASHP by approximately 10 percent (Dieckmann et al, 2004).

Combinations of these components can yield improved COP ratings of ASHPs in cold climates. Experimental testing to improve COP is ongoing and beyond the scope of this report and only a limited number of cold climate ASHPs are currently manufactured and distributed in Yukon. Cantera (2010) reported three systems to Energy Solutions Centre: the Hallowell Acadia, the York YZH and Mitsubishi Heat Pump. In Yukon:

- The Acadia demonstrated a COP of 2.5 at -8°C and 2.3 at -18°C.
- The York YZH demonstrated a COP of 3 at -8°C and 2.4 at -18°C.
- The Mitsubishi demonstrated a COP of 2.4 at -8°C and 2.0 at -18°C.

The three models demonstrated various trade-offs between heating capacity and payback period. No clear best-in-class technology was demonstrated in the report, although a performance standard COP of 2 was established for Yukon (Cantera, 2010). The picture of best-in-class ASHP technology in cold climates has since become murkier. Field tests of the Hallowell Acadia demonstrated mechanical problems, compressor failures, refrigerant leakages and other technical difficulties. Hallowell International went out of business in 2011 (Russell, 2011).

As noted, the inconclusive findings of cold climate ASHP performance in a Yukon climate provided the incentive for a broader study of the experience of ASHP users in Zones C and D. This literature concludes with the discussion of some key areas of interest in order to establish the direction of interviews with ASHP users in these zones.

Key Areas of Interest

As demonstrated by Cantera (2010), albeit indirectly, determining whether ASHP are suitable for including in the *Good Energy* rebate is a larger issue than estimating its COP. Cantera found that (at minimum) the payback period, operating costs and prior energy consumption influence the benefits of ASHPs. Prior energy consumption refers to the influence of energy savings on payback. Greater energy savings are relative to the changes being made to the home. For example, under specific circumstances, the payback period for a mini-split heat pump could be more reasonable in homes with poor insulation than a more conventional heat pump in a home built to SuperGreen standards (Cantera, 2010).

In addition to those considerations put forward by Cantera, the thermal and economic balance points of ASHPs, are worthy of consideration. These points likely influence the useful period where ASHPs can provide heat. Neither point is technically well understood in a Yukon context.

Thermal balance point is the "…temperature at which the amount of heating provided by the heat pump equals the amount of heat lost by the house. At this point, the heat pump capacity matches the full heating needs of the house. Below this temperature, supplementary heat is required from another source" (Canada, 2004: 7). Given that an ASHP system cannot accommodate the heating load of a Yukon residence and requires a supplementary heating system, the thermal balance point is an important indicator of the effectiveness of AHSPs in Yukon. This thermal balance point is not currently known.

The *Economic balance point* is the "the temperature at which the cost of heat energy supplied by the heat pump equals the cost of heat supplied by a supplementary heating system. Below this point, it is not economical to run the heat pump" (Canada, 2004: 7). The economic balance point for ASHP in Yukon is also not known and will be important in determining whether heat pump systems are a best-in-class technology for inclusion in the *Good Energy* rebate program.

Both balance points are important for determining the potential energy improvements that AHSP could provide. Although determining exact balance points may be beyond the scope of this assessment, they will certainly provide some basis for the model developed in Phase 3.

Some Preliminary Thoughts and Suggested Interview Guide

Based on this literature review, the following threads are evident:

- The components of the ASHP are fundamental to its performance. However, given the experimental nature of the literature cited and small number of ASHP models readily available for installation in Yukon, these will likely not play a role in determining the performance or implications of ASHPs in this report. Therefore some thought needs to be given to which components interviewees should be questioned on. Participants may have some interesting thoughts on ductwork, insulation, etc., that may influence cost and benefits of ASHP installation.
- Literature was interestingly vague on the benefits of ASHPs, especially in cold climates. Benefits were largely associated with heat provision and relative cost savings but subject to an enormous list of constraints. The preliminary conclusion of this literature review is that interest in cold climate heat pumps is largely driven by perceived (rather than proven) benefits and the expected (rather than proven) savings the technology could provide in cold climates. Perceived benefits need to be inventoried and accounted for through interviews. Perceived benefits then need to be weighed against projected actual benefits of ASHPs in Yukon.
- Cantera's assessment of COP would appear to be accurate and remains a current indicator of performance. A COP of 2 is therefore still a working benchmark for performance. Other measures of performance such as the thermal and economic balance points, among other measures of performance, are unknown for Yukon. Relevant measures of performance necessary to project actual versus perceived benefits need to be identified as a component of the scope of work in this project. Interviews provide an opportunity to gather needed information from participants.
- The seasonal nature of ASHPs is the primary limiting factor. If a COP of 2 is used as an indicator of heat pump capacity (i.e., the ability of a heat pump to meet the full heating needs of a house), then the thermal balance point of a heat pump in Yukon likely occurs in November and in February[9]. In actuality, the thermal balance point likely occurs at a lower COP, and supplementary heat will be required for a longer duration in Yukon. The full implications of these limitations for users are unclear. For example, if a perceived benefit of ASHP use is reduced greenhouse gas emissions, but winter use of ASHPs when grid load demand is highest will lead to increased diesel reliance, then the user may not be satisfied with their ASHP over the long-term. Participants should be questioned on when they turn their ASHP on or off. The user-friendliness of the system should also be assessed.

[9] Based on 1971-2000 climate normal for the Whitehorse A weather station, http://www.climate.weatheroffice.gc.ca.

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Appendix B: Interview Guide: Energy Solutions Centre Air Source Heat Pump Study

28 December 2012

The Government of Yukon's Energy Solution Centre (ESC) has commissioned a project to determine how well cold-climate air source heat pumps (ASHP) function in Yukon. ASHPs are electrically powered systems that transfer heat energy from outdoors to indoors at a relatively low cost. Cold-climate AHSPs may be able to cost effectively transfer heat when outdoor temperatures are as low as -30°C. However, given how new these systems are, there is much about their performance that we don't know.

We are asking residents operating ASHPs in Natural Resources Canada zones C and D (below) to share their experiences with us. Through these interviews we want to establish:

- The period during which your ASHP works best;
- The benefits of operating your AHSP;
- Requirements of operating your ASHP;
- The costs of operating your AHSP; and
- Whether or not this product is appropriate for inclusion in the *Good Energy r*ebate program.

The following interview should take about an hour. While we have prepared a list of questions for interviewees to respond to, these questions are only a guide, and we appreciate any details about your ASHP that you are willing to share. If you have any questions or would like to follow up with ESC on the status of this project, please contact:

Ryan Hennessey, Primary Investigator, Energy Solutions Centre
867-393-6381, ryan.hennessey@gov.yk.ca.

Figure 1: Canadian Climate Zones (NRCan, 2011)

Opening Questions:

1. How long have you had your ASHP?
2. How did you first learn about ASHPs?
3. What model of ASHP are you operating?
4. Why did you select this model?
5. Are you satisfied with the ASHP in general?

Benefits of Your ASHP:

6. Why did you install your ASHP? (e.g., for energy efficiency? Cost benefits? Labour saving? Lower greenhouse gas emission/environmental stewardship?)
7. Have you found your ASHP meets your expectations?
8. Do you think your ASHP will help you to achieve your goals over the next 10-20 years (potential service life of ASHP)?

Requirements of Operating an ASHP:

9. Have you been satisfied with the installation and maintenance of your system? What have your experiences been like? How was your system installed? Was it installed by a local company or a company from outside of Yukon? Were you satisfied with the quality of the installer's work?
10. What energy retrofits have you done to your house other than change your heating system? Were these done before you installed your system? Did you have to make any unanticipated retrofits to support the installation of your ASHP?
11. Are you aware of the components of your ASHP (such as its compressor, duct work, etc.)? Did the components of your ASHP play a role in its selection by you?
12. Did you have a heat loss calculation done, to help you correctly size your ASHP to meet your heat load?
13. Have you found the size of your ASHP to be an important factor in its installation? If yes, did you know that size was important prior to its installation? How was it sized?
14. Have you been satisfied with the quietness of your system? If installed outdoors, have you had any complaints from your neighbours about the noise of your system?
15. How do you use your heat pump seasonally? When do you turn it on/off? Do you ever find yourself getting cold while the ASHP is in use?
16. What is your back-up heating system? How did you choose your back-up heating system?
17. How easy has the system been to operate? What are your recommendations for others?
18. Have you had to have any part of your ASHP system repaired or altered since it was installed? Who did the repairs/alterations (i.e., local company or other). Were you satisfied with the repairs/alterations?

Costs of Operating Your ASHP

19. What were your heating and electrical bills for each month of the year before and after you installed the system? If you are not aware of these costs, can we have permission to get them from your energy providers?

20. Have the costs of your ASHP been what you expected? Why/why not?
21. What type of maintenance is required for your ASHP and how often? What maintenance have you done, or had done? How much did it cost?

Inclusion of ASHPs in the* Good Energy *rebate program

22. Would you recommend your ASHP for widespread use? Why/Why not?
23. Do you think ESC should provide a rebate for ASHP installation?
24. What are your thoughts on a rebate amount? What percentage of the total ASHP system costs, covered by a rebate, do you think would be considered significant enough to convince someone to buy an ASHP?
25. Do you know anyone else with an ASHP who would be willing to participate in this study?
26. Would you be open to us following up this interview with further questions on your system as we continue our research on this topic?