HEAT PUMPS IN THE CANADIAN RESIDENTIAL SECTOR

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Abstract:
This paper presents a market overview of the current residential heating and cooling market in Canada. Through the use of air or ground as a renewable energy source, heat pumps can have a large impact in this sector offering up to four times the efficiency compared to conventional heating systems. This paper presents an analysis conducted on the Canadian 1980's construction housing market to compare the annual energy savings, greenhouse gas emission reductions and economics that heat pumps can obtain in various Canadian regions compared to the conventional heating and cooling systems. It was shown that heat pumps can achieve up to 66% secondary energy savings and up to 84% in greenhouse gas emission reductions. While annual utility costs can be reduced up to 50%, simple payback periods varied depending on the region, ranging between 2 years to greater than 40 years. Cold climate air source heat pumps were shown to be the most economical in the eastern provinces having the lowest 20 year life cycle cost, while the low natural gas rates make it challenging for heat pumps to be cost competitive in the western provinces.

Key Words: Heat Pumps, Air Source, Ground Source, Cold Climate, New Technologies

1. INTRODUCTION

The Canadian residential building sector accounts for 16% of Canada's secondary energy end use and 15% of the country's greenhouse gas (GHG) emissions where space heating and domestic hot water account for 81% of this energy end use (NRCan 2009). Through new building codes and equipment efficiency standards, the energy efficiency of new homes has greatly increased. However, 76% of the current residential building stock was constructed prior to 1989 (NRCan 2010). Thus, in order to achieve widespread savings, efficiency measures addressing the existing building stock are of the utmost importance.

The climate in Canada varies depending on the region. In Eastern Canada (Maritimes, Quebec, Ontario) the climate is cold & humid with an annual average temperature between 6°C to 8°C. Westward, the Prairies (Manitoba, Saskatchewan, and Alberta) have much colder winters and hotter summers with the average annual temperature in the largest city (Edmonton) approximately 3°C. Along the Pacific (British Columbia), a cool-marine climate prevails with mild winters and cool summers. The average annual temperature in this region is approximately 10°C. Climate data across Canada is provided in Table 1 (NRC 2010).

Table 1: Climate data across Canada

Climate Data	Atlantic	Quebec	Ontario	Prairies	Pacific
Province	Nova Scotia	Quebec	Ontario	Alberta	British Columbia
Respective City	Halifax	Montreal	Toronto	Edmonton	Vancouver
Heating Degree Days	4,000	4,200	3,520	5,120	2,825
Cooling Degree Days	813	1,192	1,317	594	853
Heat Design Temp. (°C)	-16	-23	-18	-30	-7
Cool Design Temp. DB/WB (°C)	26/20	30/23	31/23	28/19	28/20

Similar to the climate, electricity production sources, utility rates and ultimately the primary heating fuel varies depending on the region. Thus, while the site energy consumption in each region may be similar, the primary energy (raw fuel) consumption can vary significantly depending on the region being evaluated due to the fuel used to produce electricity. Similarly, the GHG emission factors vary depending on the fuel source for electricity production. Representative electricity production sources and associated greenhouse gas (GHG) emissions are summarized in Table 2, with data taken from the National Inventory Report of GHG emissions in Canada (Environment Canada 2009). Table 2 also summarizes the most recent relative utility rates in the various regions across Canada.

Table 2: Primary Electricity Generation, GHG Emissions and Utility Rates across Canada

Region Characteristics	Atlantic	Quebec	Ontario	Prairies	Pacific
Province	Nova Scotia	Quebec	Ontario	Alberta	British Columbia
Primary Electricity Generation	Thermal (Coal)	Hydro	Nuclear (50%) Thermal (30%) Hydro (20%)	Thermal (Coal)	Hydro
Greenhouse Gas Emissions (g CO_2/kWh)	800	10	260	800	20
Respective City	Halifax	Montreal	Toronto	Edmonton	Vancouver
Electricity Rate ($/kWh)	0.15	0.07	0.13	0.14	0.08
Natural Gas Rate ($/GJ)	21.17	14.17	6.75	5.00	8.00
Fuel Oil Rate ($/L)	1.07	1.32	1.38	N/A	1.30

Heat pumps are widely used to upgrade free heat from renewable energy sources in order to meet space heating and cooling demands, and can thus provide a dramatic reduction in energy consumption and GHG emissions. However, heat pumps are relatively costly and their efficiency is sensitive to the ambient operating temperature. Hence, due to the extreme low winter temperatures in Canada, the low cost of energy, the potentially high cost of the heat pump system and the lack of familiarity, the adoption of heat pumps in the Canadian building sector has been hindered.

This paper presents an overview of the current heat pump market in Canada and discusses its market and climate barriers as well as its potential to reduce energy and greenhouse gas emissions in the building sector. As an illustration, an analysis is provided on the Canadian 1980's construction residential housing market to evaluate and quantify the impact heat pump technologies can have in regards to secondary (site or homeowner) energy savings, GHG emission reductions and utility cost savings. The study presents a comparison of traditional housing heating and cooling systems with a market available air source heat pump (ASHP), a cold climate air source heat pump (CC ASHP) and a ground source heat pump (GSHP) in five different Canadian regions.

2. OVERVIEW OF THE EXISTING RESIDENTIAL HEATING AND COOLING MARKET

The predominant residential heating and cooling systems in the Canadian market are central air furnaces with split air conditioning systems. The furnace and air conditioning market has been very stable over the past five years with approximately 300,000 to 350,000 furnaces sold annually and around 300,000 split air conditioning units (HRAI 2014) (Figure 1), from which ASHPs accounts for no more than 10%.

Despite the many benefits (energy and GHG savings) and small incremental cost of an ASHP in comparison to a central air conditioner (around 20% (AC Direct 2014)), these units have had difficulty in penetrating the Canadian market. This can be explained by the fact that ASHPs are not well adapted to the Canadian climate as their performance and capacity drops significantly at temperatures below -10°C. Moreover the return on investment for heat pumps in general is hindered by the low electricity rates and the extremely low natural gas rates across Canada. There is also a lack of awareness and information dissemination in Canada on the benefits of heat pumps. If some of these barriers were overcome, the percentage of reversible ASHPs among air-conditioners sold in Canada could be much higher than 10%. Assuming that a third of the air conditioner shipments were reversible ASHPs, a reduction of 175,000 tons of CO_2 emissions per year (based on the analysis from this paper) could be achieved.

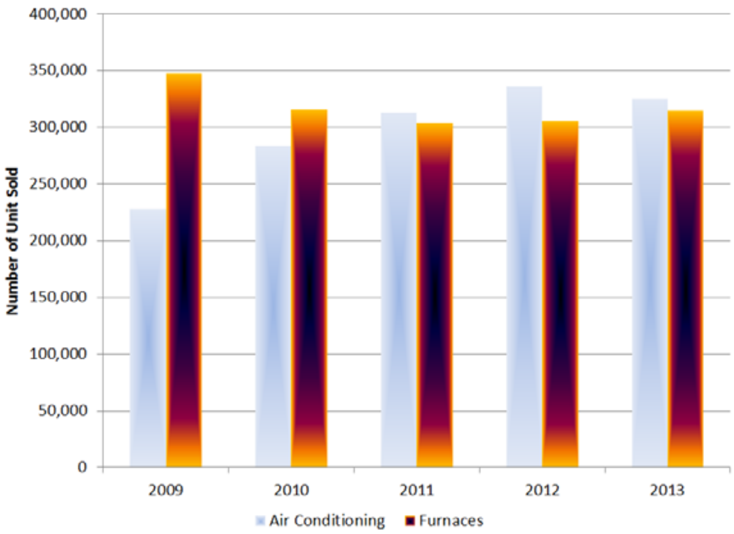


Figure 1: Historical furnace and air conditioning Canadian shipment data (HRAI 2014)

GSHPs do not have the technical limitations of ASHPs but have higher initial capital costs. The Canadian GeoExchange Coalition (2012) has tracked GSHP installations since 1996. From 1996 to 2004, approximately 1,000 to 2,000 GSHP systems were installed annually. From 2004 to 2009, a steady increase in system installations was seen, peaking at approximately 16,000 in 2009 (due to government incentive programs). In 2010 the number of systems installed significantly dropped, and was projected to stabilize around 12,000 systems from 2011 onward. If the number of annual GSHP installations increased to 50,000, CO_2 emissions could be reduced by 175,000 tons annually (based on the analysis from this paper and taking into account the average 1980's constructed house heated floor area).

3. EVALUATION OF HEAT PUMP TECHNOLOGIES IN THE CANADIAN 1980'S CONSTRUCTION HOUSING MARKET

To evaluate the potential of various heat pump technologies in the Canadian 1980's construction housing market, housing models representative of five Canadian regions were developed. To obtain the typical characteristics of each region, the Canadian Single Detached and Double Row Housing Database (CSDDRD) was consulted (Swan et al. 2009). The database is comprised of over 17,000 houses representative of the Canadian building stock and provides detailed information of each house (building envelope characteristics, primary heating system, and infiltration rates). The database is divided into five regions (Atlantic, Quebec, Ontario, Prairies and British Columbia). The city with the largest housing market in each respective region (Halifax, Montreal, Toronto, Edmonton and Vancouver) was selected and a representative housing model was developed using the TRNSYS simulation tool (Klein et al. 2010). The Canadian Centre for Housing Technologies (CCHT) twin research house footprint (Swinton et al. 2003) was used as the shell for the respective houses (representing a typical Canadian home) and the characteristics determined from the CSDDRD for each region and construction decade were implemented. The CCHT house was used as a footprint, as although the CSDDRD database provided housing dimensions, it was not found to be suitable in defining a typical housing archetype. The CCHT house is a two storey single detached home with an unheated garage and an unfinished basement. The above ground floor area is 210 m² and the houses have a 16 m² of south facing window area. Table 3 summarizes the key housing characteristics for each region.

Table 3: Key housing characteristics for the 1980's housing market

Characteristic	**Atlantic (Halifax)**	**Quebec (Montreal)**	**Ontario (Toronto)**	**Prairies (Edmonton)**	**British Columbia (Vancouver)**
Wall RSI (m²°C/W)	2.81	2.79	2.33	2.66	2.17
Roof RSI (m²°C/W)	5.00	4.80	4.96	5.18	4.28
Window u-value (W/m²°C)	2.92	2.92	2.86	2.81	3.71
Infiltration (ACH @ 50 Pa)	5.24	5.90	4.65	3.91	8.77
Primary Heating Fuel	Electricity	Electricity	Natural Gas	Natural Gas	Natural Gas
Heating System	Baseboards	Baseboards	Furnace	Furnace	Furnace
Thermal Efficiency	100%	100%	78%	80%	74%
DHW Fuel	Electric	Electric	Natural Gas	Natural Gas	Natural Gas

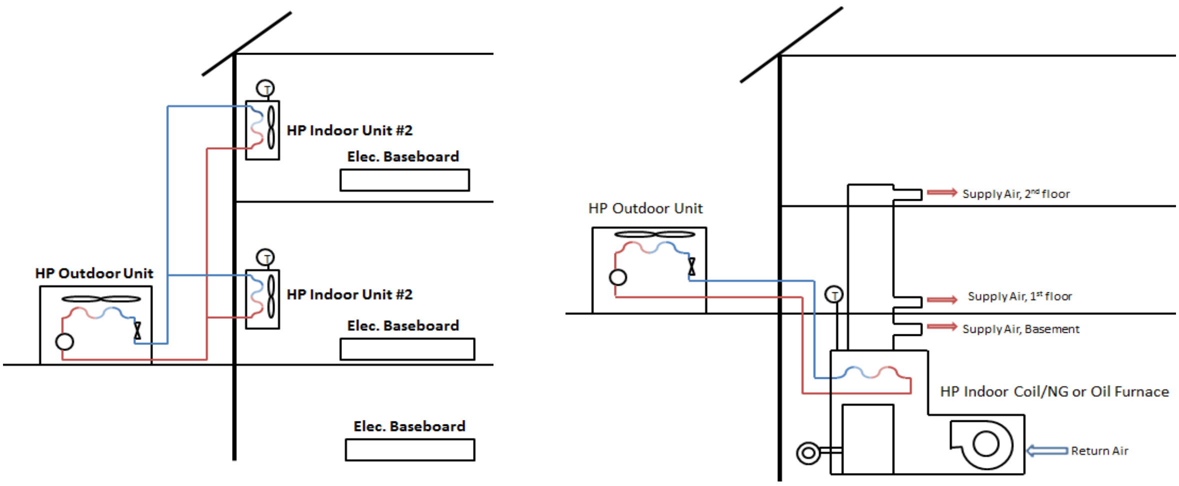
A second Halifax housing model was created using fuel oil for primary heating to reflect the 30% of Atlantic houses with this type of system. The housing characteristics for the primarily fuel oil heated houses were similar to the electrically heated houses.

3.1 Base Line Energy Consumption

The developed TRNSYS models were run with a 5 minute timestep and each region's respective TMY2 weather file. Part load performance curves for the space heating and cooling equipment (Los Alamos Scientific Laboratory 1980) were implemented to account for reduced efficiencies when the systems were not operating at full loads over the timestep.

3.2 Standard Air Source Heat Pump Implementation

The first type of system investigated was a standard ASHP system. For the Halifax and Montreal homes with standard baseboard heating, a ductless split system is proposed in order to minimize installation costs (Figure 2a). A ducted ASHP unit is examined in all homes with natural gas or oil furnaces (Figure 2b). Each heat pump installation also has a fully sized auxiliary heating system due to the performance degradation at low ambient temperatures.



(a) (b)

Figure 2: (a) Ductless multi-split air source heat pump system configuration and (b) Ducted split air source heat pump system configuration

Table 4 summarizes the AHRI rated performance of the ASHP units analyzed for this study (Carrier 2008a, Carrier 2008b).

Table 4: Rated performance of ASHP units

Performance Characteristic	Ductless	Ducted
Heating Capacity (kW)	6.4	10.4
Cooling Capacity (kW)	6.6	9.9
AHRI Heating COP	3.0	3.6
AHRI Cooling COP	3.4	3.1
Minimum Operating Temperature (°C)	-10	-18

3.3 Cold Climate Air Source Heat Pump Implementation

With Canada's cold climate, there can be substantial periods where no benefits from a standard ASHP are attained. Cold climate air source heat pumps (CC ASHP), which are relatively new to the market, address this issue and have the capability to operate down to temperatures as low as -30°C maintaining a suitable heat capacity (Mitsubishi Electric 2011). A comparison of ASHP and CC ASHP performance curves is shown in Figure 3.

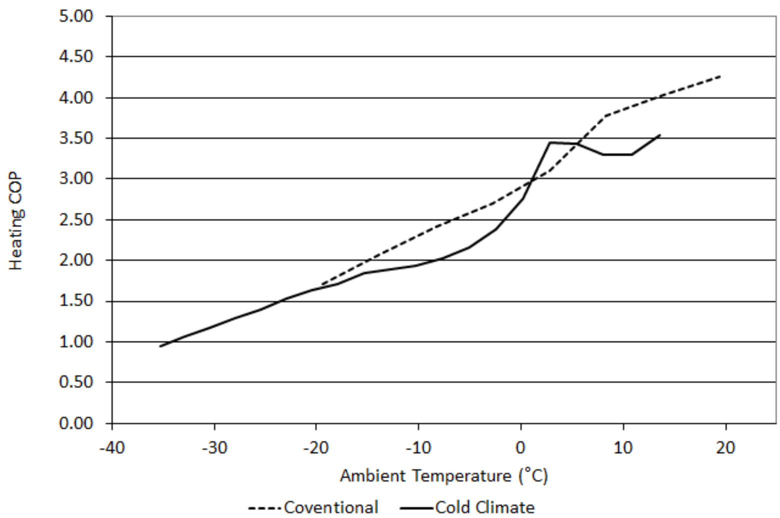


Figure 3: Performance comparison of a conventional and cold climate air source heat pump

While the capital cost of the CC ASHP can be much higher than a standard ASHP, the benefit of having the capability to operate beneficially at low ambient temperatures could substantially reduce the housing space heating energy consumption. To evaluate the CC ASHP system, a ductless system is proposed for electrically heated homes while a ducted system is proposed for homes with natural gas or oil furnaces. A summary of heat pump performance is provided in Table 5 (Mitsubishi Electric 2011).

Table 5: Rated performance of CC ASHP units

Performance Characteristic	Ductless	Ducted
Heating Capacity (kW)	7.3	11.1
Cooling Capacity (kW)	6.5	10
AHRI Rated Heating COP	3.9	3.0
AHRI Rated Cooling COP	2.6	3.5
Minimum Operating Temperature (°C)	-25	-30

For the ducted system, an electric back-up heater is installed to ensure that the heating load can be met. Electric baseboards provide supplemental heating for the proposed ductless system. The CC ASHP integration is very similar to the ASHP system (Figure 2), without a fully sized auxiliary heating system.

3.4 Ground Source Heat Pump Implementation

GSHPs utilize the large thermal capacity of the earth which provides a stable, constant source/sink temperature for the heat pump. Ductless systems are specified for electrically heated homes in Montreal and Halifax (Figure 4a). Ducted systems are specified for homes with natural gas or oil furnaces (Figure 4b). All systems are equipped with an electric back-up heater in the event the heat pump is unable to meet the building heating load.

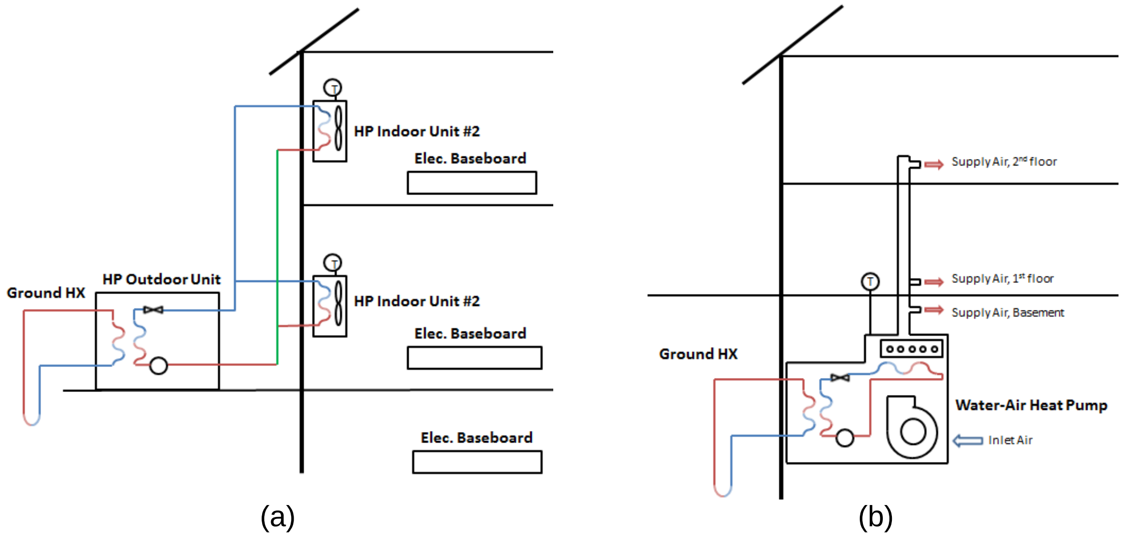


Figure 4: (a) Ductless multi-split ground source heat pump system configuration and (b) Ducted ground source heat pump system configuration

A summary of ISO 13256 rated heat pump performance for each GSHP is provided in Table 6 (Trane 2014, McQuay 2010). A range of ducted GSHP systems were examined, with each heat pump sized based on the heating loads of the home.

Table 6: Rated GHSP performance

Performance Characteristic	Ductless	Ducted
Heating Capacity (kW)	10.8	8.9 to 13.8
Cooling Capacity (kW)	14	11.8 to 19.1
ISO 13256 Rated Heating COP	3.8	3.4 to 3.6
ISO 13256 Rated Cooling COP	4.7	4.6 to 5.1

The number of boreholes and the total borehole length and heat pump size for each region are summarized in Table 7. Soil types were taken from a report evaluating the economic and GHG benefit of GSHPs in Canada (Hanova et al. 2007), while soil properties were taken from ASHRAE Fundamentals (2013). The boreholes were sized to meet the peak hourly, monthly and annual heating load on the ground ultimately over-sized to ensure the ground energy is not depleted after 20 years due to the heating dominated climate. The electricity consumption of the borehole fluid pumping circuit is included in the analysis.

Table 7: Ground source heat pump sizing details

Region	Heat Pump Size	Number of Boreholes	Total Borehole length
Halifax	14.1 kW (4 ton)	2	244 m
Montreal	14.1 kW (4 ton)	2	181 m
Toronto	12.3 kW (3.5 ton)	2	239 m
Edmonton	17.6 kW (5 ton)	2	308 m
Vancouver	10.6 kW (3 ton)	2	156 m

3.5 Results Summary

The predicted annual energy consumption, GHG emissions and utility costs of the systems evaluated for each region are summarized in Table 8 to Table 13 .

Table 8: System performance for Halifax (All electric base case)

		Base	ASHP	CC ASHP	GSHP
Site Energy	Electricity (GJ)	134	107	105	67
GHG	Electricity (ton CO_2)	30.0	23.9	23.5	15.1
Utility	Electricity ($)	$5,675	$4,403	$3,803	$2,929

Table 9: System performance for Halifax (Fuel oil base case)

		Base	ASHP	CC ASHP	GSHP
Site Energy	Electricity (GJ)	52	75	95	67
	Fuel Oil (GJ)	130	67	0	0
GHG	Electricity (ton CO_2)	11.7	16.8	21.4	15.1
	Fuel Oil (ton CO_2)	9.8	5.1	0.0	0.0
Utility	Electricity ($)	$2,297	$3,208	$3,983	$2,929
	Fuel Oil ($)	$3,507	$1,809	$0	$0

Table 10: System performance for Montreal

		Base	ASHP	CC ASHP	GSHP
Site Energy	Electricity (GJ)	150	134	110	78
GHG	Electricity (ton CO_2)	0.3	0.2	0.2	0.1
Utility	Electricity ($)	$3,135	$2,660	$2,177	$1,575

Table 11: System performance for Toronto

		Base	ASHP	CC ASHP	GSHP
Site Energy	Electricity (GJ)	39	58	77	56
	Natural Gas (GJ)	166	82	18	22
GHG	Electricity (ton CO_2)	2.4	3.5	4.7	3.4
	Natural Gas (ton CO_2)	9.2	4.6	1.0	1.2
Utility	Electricity ($)	$1,592	$2,302	$2,915	$2,219
	Natural Gas ($)	$1,299	$765	$361	$382

Table 12: System performance for Edmonton

		Base	ASHP	CC ASHP	GSHP
Site Energy	Electricity (GJ)	40	55	94	66
	Natural Gas (GJ)	213	123	20	20
GHG	Electricity (ton CO_2)	11.4	15.4	26.4	18.7
	Natural Gas (ton CO_2)	12.1	7.0	1.1	1.1
Utility	Electricity ($)	$1,603	$2,067	$3,301	$2,428
	Natural Gas ($)	$1,362	$954	$491	$491

Table 13: System performance for Vancouver

		Base	ASHP	CC ASHP	GSHP
Site Energy	Electricity (GJ)	34	63	64	54
	Natural Gas (GJ)	147	43	17	17
GHG	Electricity (ton CO_2)	0.2	0.4	0.4	0.4
	Natural Gas (ton CO_2)	8.3	2.5	1.0	1.0
Utility	Electricity ($)	$797	$1,669	$1,695	$1,413
	Natural Gas ($)	$1,345	$498	$282	$282

As anticipated, all heat pump systems demonstrated energy and GHG emission savings compared to the base case. While ASHP systems were also able to obtain utility cost savings in Halifax and Montreal, lower natural gas prices in central and western Canada presented an economic challenge to ASHPs in this portion of the country. ASHPs could be made more competitive in these regions through a comprehensive analysis of heat pump sizing and cut-off temperature (transition between heat pump and auxiliary) requirements. For example, using a 3 ton (10.6 kW) heat pump in Toronto with a cut-off temperature of 0°C results in a small utility cost savings, but reduces total energy savings from 32% to 24%. Similarly, using a 2 ton (7 kW) heat pump would result in a 3% reduction in utilities, but energy savings of only 18%. Future studies will be conducted to determine the most suitable heat pump size and operating strategy for these regions to determine if an ASHP system can be cost viable.

The CC ASHP systems demonstrated a similar trend as the standard ASHP systems, with improved energy savings and GHG emission reductions in all regions compared to the ASHP. This was anticipated because of the improved performance of the CC ASHP at lower ambient temperatures, which reduces the use of the back-up heating systems. Similar to the ASHP cases, only the Halifax and the Montreal region saw annual utility cost savings. In Toronto and Edmonton, the annual utility costs significantly increase as use of natural gas is eliminated. With electricity only 2.5 times the cost of natural gas in Vancouver, the improved performance of the CC ASHP at lower temperatures resulted in close to 10% annual utility cost savings over the base case.

In all regions, the GSHP system demonstrated the greatest energy savings, GHG emission reductions and utility cost savings compared to the base cases. With the stable source/sink temperatures, energy savings up to 65% and GHG reductions up to 85% were predicted. Even in the regions where natural gas is significantly less than the price of electricity, the GSHP demonstrated an annual benefit.

4. LIFE CYCLE COST AND SIMPLE PAYBACK PERIOD ANALYSIS

A 20 year lifecycle cost analysis was performed to determine the most suitable system in each region. The simple payback period was also calculated since this is one of the compelling selling points of the systems to the end consumer. Simple payback periods were calculated dividing the estimated incremental system cost by the annual utility cost savings. Lifecycle costs include capital, utility, and maintenance costs. An annual inflation rate of 1.5% and a discount rate of 4% are assumed for the analysis based on the current Canadian financial market. The annual maintenance fees for the residential systems were estimated at $150 per year for a furnace and an air conditioner, $150 per year for an ASHP and $225 per year for a GSHP (Haven Home Climate Care 2014). Maintenance and fixed utility rates were assumed to follow the inflation rate. The 20 year electricity, natural gas and residential fuel oil escalation rates were taken from the National Energy Board (2011) and are summarized in Table 14.

Table 14: Assumed energy escalation rates (not including inflation)

Region	Energy Escalation Rates		
	Electricity	Natural Gas	Fuel Oil
Halifax	1.2%	N/A	0.9%
Montreal	0.8%	N/A	N/A
Toronto	1.7%	0.8%	N/A
Edmonton	1.7%	1.1%	N/A
Vancouver	0.9%	0.7%	N/A

Capital costs of each system (furnace, heat pumps, controls, ducting) were estimated using RSMeans (2013) and cross-referenced with market surveys. Borehole drilling costs were estimated from Kummert and Bernier (2008) at an average of $80 per meter. The 20 year life cycle costs and simple payback periods for each region are summarized in Table 15 to Table 20.

Table 15: Lifecycle cost and simple payback period for Halifax (All-electric)

	Base	ASHP	CC ASHP	GSHP
Capital Cost	$8,565	$12,921	$16,501	$29,895
Lifecycle Utility: Electricity	$84,591	$65,186	$56,033	$42,694
Lifecycle Maintenance	$3,811	$3,811	$3,811	$4,849
Total Life Cycle Cost	$96,967	$81,918	$76,344	$77,438
Simple Payback Period (Years)	--	3.4	4.2	7.8

Table 16: Lifecycle cost and simple payback period for Halifax (Fuel Oil)

	Base	ASHP	CC ASHP	GSHP
Capital Cost	$11,951	$13,594	$17,373	$33,781
Lifecycle Utility: Electricity	$33,058	$46,956	$58,779	$42,694
Lifecycle Utility: Fuel Oil	$51,990	$26,818	$0	$0
Lifecycle Maintenance	$5,874	$5,874	$3,811	$4,849
Total	$102,873	$93,242	$79,963	$81,324
Simple Payback Period (Years)	--	2.1	3.0	7.8

Table 17: Lifecycle cost and simple payback period for Montreal

	Base	ASHP	CC ASHP	GSHP
Capital Cost	$10,111	$14,428	$17,622	$26,180
Lifecycle Utility: Electricity	$43,835	$36,865	$29,776	$20,930
Lifecycle Maintenance	$4,062	$4,062	$4,062	$5,100
Total	$58,008	$55,355	$51,461	$52,211
Simple Payback Period (Years)	--	9.1	7.8	10.3

Table 18: Lifecycle cost and simple payback period for Toronto

	Base	ASHP	CC ASHP	GSHP
Capital Cost	$13,171	$14,628	$19,730	$35,318
Lifecycle Utility: Electricity	$21,598	$32,982	$42,811	$31,647
Lifecycle Utility: Natural Gas	$15,603	$7,741	$1,778	$2,092
Lifecycle Maintenance	$10,728	$10,728	$8,665	$9,704
Total	$61,101	$66,079	$72,986	$78,761
Simple Payback Period (Years)	--	> 40	> 40	> 40

Table 19: Lifecycle cost and simple payback period for Edmonton

	Base	ASHP	CC ASHP	GSHP
Capital Cost	$13,464	$14,953	$20,978	$46,345
Lifecycle Utility: Electricity	$21,534	$28,926	$48,618	$34,684
Lifecycle Utility: Natural Gas	$14,532	$8,368	$1,356	$1,356
Lifecycle Maintenance	$13,041	$13,041	$10,978	$12,017
Total	$62,572	$65,289	$81,930	$94,402
Simple Payback Period (Years)	--	> 40	> 40	> 40

Table 20: Lifecycle cost and simple payback period for Vancouver

	Base	ASHP	CC ASHP	GSHP
Capital Cost	$12,367	$13,812	$18,929	$26,365
Lifecycle Utility: Electricity	$10,982	$23,957	$24,343	$20,153
Lifecycle Utility: Natural Gas	$17,605	$5,211	$2,047	$2,047
Lifecycle Maintenance	$6,838	$6,838	$4,775	$5,813
Total	$47,791	$49,817	$50,094	$54,378
Simple Payback Period (Years)	--	> 40	39.8	31.3

The CC ASHP demonstrated the lowest 20 year lifecycle cost in Halifax and Montreal. Although this system had a significantly higher capital cost than the ASHP, this increase was offset by larger energy savings resulting from a minimization of auxiliary heating. In Toronto and Edmonton, none of the heat pump systems had a lower 20 year life cycle cost than the base case system. The improved heating efficiencies of the systems were unable to overcome the low natural gas costs. In Vancouver, the base case also had the lowest life cycle; however, the standard ASHP and CC ASHP had only a slightly higher life cycle cost. A smaller ASHP system or an alternative control strategy could likely make the ASHP a cost viable solution for the Vancouver market.

All air source heat pump systems demonstrated energy and GHG reduction savings. In the regions with low natural gas rates, the incremental cost of a heat pump is difficult to overcome – in particular when an auxiliary heating system is required at low ambient temperatures. While current market available CC ASHPs address this issue, these systems have high initial costs, creating a further initial investment burden.

From a simple payback period perspective, only the ASHP and CC ASHP demonstrated an interesting payback periods for the consumer of less than 4 years. In all other regions payback periods were close to 10 years and above primarily due to the current utility rates. Thus, there is the obvious challenge that in order to gain widespread adoption of heat pumps in the Canadian market, there must be either an increase in utility rates or incentive programs developed to assist homeowners overcome the high capital cost of such a system.

It is clear from the above results that GSHP systems result in the most significant energy savings, GHG reductions, and utility cost savings. However, these savings are often countered by the high costs associated with the borefield. An analysis was conducted to determine the required borefield drilling cost to make a GSHP system cost competitive in each region based on the 20 year life cycle cost. Table 21 summarizes this analysis comparing the assumed borefield drilling costs to the calculated cost competitive drilling costs.

Table 21: Required borefield drilling costs to make GSHP economically viable

Region	Assumed Borefield Cost	Require Borefield Cost
Halifax (Electric)	$80/m	$70/m
Halifax (Oil)	$80/m	$67/m
Montreal	$80/m	$77/m
Toronto	$80/m	$13/m
Edmonton	$80/m	-$12/m
Vancouver	$80/m	$40/m

The Halifax region and Montreal region required borefield costs are within the range quoted by Kummert and Bernier (2008) (between $60 to $100 per meter). Toronto and Vancouver would likely require an incentive to make GSHP economically viable and as anticipated, a significant incentive would be required to make GSHP systems economically viable in

Edmonton. The negative borefield drilling cost in Edmonton highlights that even if the borefield costs were free, the system would still not be cost competitive with the base case system under the assumed energy escalation rates. Additional conclusions could be drawn from this analysis on other incentives required if the objective was to reduce simple payback periods below 4 years to entice homeowners to invest in heat pumps.

5. CONCLUSION

Heat pump installations have steadily increased across Canada over the years, but not to the extent of making a large impact in secondary energy reductions or GHG emissions. To evaluate the impact, benefits and challenges heat pump technologies have in addressing the high space heating energy end use, an analysis on the 1980's Canadian residential housing market was market was performed. An energy model of a typical 1980's constructed house was developed for five different Canadian regions (Halifax, Montreal, Toronto, Edmonton and Vancouver). The annual energy consumption, utility costs and GHG emissions were estimated for a typical home heating and cooling system, an ASHP, a CC ASHP and a GSHP. In all regions, the GSHP demonstrated the most energy, utility and GHG emissions savings. System lifecycle costs were also examined, where it was shown that all heat pump systems in Halifax and Montreal have lower 20 year life cycle costs than the base system. In the other regions, the base case system proved to have the lowest lifecycle cost. ASHPs and CC ASHPs were also shown to have a simple payback period four years and below in the Atlantic region highlighting the existing potential market adoption of these systems in this region. Simple payback periods were 8 years and above in the other Canadian regions, highlighting the importance of incentive programs to initiate a stronger market adoption.

One of the predominant challenges in making heat pumps commercially viable in Canada is the competition with current low natural gas rates and electrical baseboard prices. Future studies will look into optimizing the size and operating cut-off temperature of ASHPs in the Toronto, Edmonton and Vancouver regions. With GSHPs yielding the greatest energy savings, utility savings, and GHG reductions, the potential borefield cost to make each system economically viable was estimated. A borefield cost reduction of 15% would make the GSHP system the most economically viable from a 20 year life cycle cost analysis perspective in the Halifax and Montreal regions, whereas a 50% and 85% reduction would be required in the Vancouver and Toronto regions, respectively. In Edmonton, other incentives would need to be given as even with no borefield cost, the base case system still had a lower 20 year life cycle cost.

Natural Resources Canada is conducting research on two fronts in order to address some of the challenges that heat pumps face in Canada. This includes examining the integration of ejectors with air-source heat pumps, which will allow for improved efficiencies and heat capacities at low ambient temperatures with only a minimal increase in capital costs. Early results of these units demonstrate potentially beneficial lifecycle costs in Halifax, Montreal, and Vancouver. Extensive research is also being conducted using CO_2 as a refrigerant in GSHP systems in order to significantly reduce borehole sizes and costs. With a 20% reduction in the borefield size, the GSHP system would become the preferred option in the Halifax and Montreal regions. Additional work will also be conducted on optimizing the heat pump size and control strategies to enhance the economic benefits offered by these systems. Finally, heat pump water heaters will be examined in order to address the domestic hot water heating loads.

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