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Cold-Climate Air Source Heat Pumps: Assessing Cost-Effectiveness, Energy Savings and Greenhouse Gas Emission Reductions in Canadian Homes

"CanmetENERGY- Ottawa leads the development of energy science and technology solutions for the environmental and economic benefit of Canadians."

Canada

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Summary

In this report, CanmetENERGY examined the cost-effectiveness of new cold-climate air-source heat pump (CC-ASHP) technology in Canadian homes. This study focused on comparing the energy costs of CC-ASHPs relative to conventional electric, gas and oil furnaces. CanmetENERGY researchers considered the integration of CC-ASHP technology in four different types of Canadian homes, ranging from pre-1980 construction to Net-Zero-Energy Ready levels of performance.

Results from this study showed that CC-ASHPs were more efficient and cheaper to operate than electric resistance or oil furnaces. Homeowners choosing CC-ASHP systems instead of electric resistance heating systems can expect to save $700-1900 each year on utility costs, while homeowners choosing CC-ASHP systems over oil furnaces can expect to save between $1000 and $3500 annually (depending on region and home performance level).

Utility bill savings relative to natural gas furnaces are smaller – ranging from $50-150 in most parts of Canada, but higher in Quebec and the Atlantic provinces. In regions west of Quebec, the largest share of these savings come from fixed charges associated with the natural gas connection to the home. Homeowners that replace gas furnaces with CC-ASHP equipment but elect to retain a gas connection for use in other appliances may see an increase in their utility bills.

This study also examined the potential for gas-hybrid systems, which can combine CC-ASHP technology with conventional gas furnaces. Smart controls can be implemented, which choose from the lowest-cost heating source depending on the climate, building loads and energy prices. In these scenarios, the hybrid technology costs less to operate than the gas-furnace and delivers a 15-35 % reduction in energy use and greenhouse gas emissions.

Note: Readers should note that the results of this study are limited to the home archetypes, energy prices and equipment performance levels assessed and should not be assumed to uniformly apply to other house archetypes, energy prices and/or equipment performance levels.

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1. Introduction

Canadian households use more energy for space heating than all other end-uses combined [1]. This is no surprise – much of Canada experiences harsh winters, and significant amounts of heat are needed to keep Canadians comfortable in cold weather.

Traditionally, Canadians have used a variety of technologies and fuels to provide this heat. In 2017, 4.8 million low rise Canadian homes were heated with natural gas furnaces, 3.4 million with electric resistance, and 1.1 million with oil furnaces and boilers. [2]

In recent years, heat pumps have emerged as an attractive alternative. Heat pumps use the same vapour compression technology found in refrigerators and air conditioners to move heat from outdoors to indoors. When their energy consumption is compared, heat pumps can achieve much higher levels of efficiency than conventional furnaces, boilers and electric baseboards.

Past generations of heat pumps were notable for their limited cold weather performance. Owners reported that products worked well in mild weather but failed to keep the house warm as temperatures fell. Some systems stopped working entirely in winter conditions.

Over the last decade, heat pump manufacturers introduced two-stage and variable capacity technologies to address cold weather performance problems. Colloquially known as *cold-climate heat pumps,* these innovations enable heat pumps to deliver efficient and dependable performance in cold Canadian winters [3]. CanmetENERGY has verified the performance of cold-climate heat pumps through independent field trials and laboratory testing. CanmetENERGY also provided results from these tests to support the development of a new voluntary performance rating procedure – CSA EXP07 [4]. This dynamic load-based performance rating procedure prescribes testing at colder temperatures than required by CSA C656 (among many other differences) [5].

Advances in technology and performance rating methods help explain why heat pumps represent a growing segment in the residential heating market. Today, 800,000 Canadian homes are heated with heat pumps – over three times as many as in 1990.

These developments notwithstanding, the decision to purchase a heat pump in lieu of a furnace or boiler confuses many Canadians. Most homeowners ask: "How much money can a heat pump save me?" But the answer is not straight-forward. Savings depend on:

- The local climate
- Regional utility rates
- The amount of heat that a home needs to stay comfortable through winter
- The type, size and performance levels of the heat pump used

Recognizing this uncertainty, CanmetENERGY examined the operating costs of different heating technologies in Canadian homes. The intent of the study was to estimate the typical utility bills associated with heating with gas, oil and electric resistance in different parts of Canada, and to quantify the year-over-year savings that could be expected from cold climate heat pump products.

As part of this work, CanmetENERGY also examined opportunities for combining cold climate heat pump technology with gas furnaces to create hybrid (or dual fuel) heat pump technologies. Hybrid heat pumps perform like conventional heat pumps but with additional flexibility: they can switch to a back-up gas furnace. Prior research by CanmetENERGY demonstrated that these systems can deliver energy, economic and emissions savings in regions where utility prices make all-electric heat pumps less competitive [6], [7].

2. Objectives

The objectives of this study were to:

- Compare the expected annual energy costs of cold climate air-source heat pumps to natural gas furnaces, electric resistance, and oil heating systems across Canada, and identify regions in which cold-climate heat pump technology is cost-competitive with these conventional technologies.
- Examine the efficacy of a hybrid heat pump based on cold-climate heat-pump technology, and identify regional switch-over temperatures to determine when such a system would use electricity or gas.
- Identify the minimum coefficient of performance that cold-climate heat pump technology would need to achieve for it to be cost competitive with gas heating systems in regions where it is not already cost competitive.

This study focused on annual energy costs. Ownership associated with equipment purchase, installation and maintenance and decommissioning were beyond its scope. The methods used in this study were limited to modeling, simulation and assessment using CanmetENERGY's various calculation tools. CanmetENERGY has previously conducted laboratory testing and field trials with cold climate heat pump products; reports detailing the observed performance of those systems can be found in the CanmetENERGY Publications portal.

3. Methodology

3.1. Archetype

For this work, four archetypes to represent current and future Canadian housing were used. Each archetype was drawn from Natural Resources Canada's EnerGuide for Housing database, and represents an actual home. To select the archetypes, average characteristics for different segments and vintages were first evaluated, after which individual archetypes that exhibited similar characteristics were identified.

The four archetypes used in this study were as follows:

Archetype A is a two-story detached home constructed before 1980. If located in Toronto, it would have a peak heating load of 10.7 kW. According to Statistics Canada's Survey of Household Energy Use, there are approximately 1.5 million homes like Archetype A across the country.

Archetype B is a larger, two story detached home constructed after 1980. Archetype B represents segments of housing that are typically heated with gas or oil furnaces. If located in Toronto, it would have a peak heating load of 9 kW. Archetype B resembles approximately 2.1 million homes across the country.

Archetype C is a smaller single-story, detached home constructed after 1980. Archetype B represents a segment of housing that is often heated with electric baseboards, and has slightly higher levels of insulation than larger, gas-heated homes from the same period. If located in Toronto, it would have a peak heating load of 5.6 kW. Archetype C resembles approximately 2.0 million homes across the country.

Archetype D is a two-story home built to Net-Zero-Ready (NZE-R) standards. It features much higher levels of insulation and air-sealing than the other archetypes used in this study. If located in Toronto, it would have a peak heating load of 2.4 kW. Presently, there are relatively few Net-Zero-Ready homes constructed in Canada. However, the 2018 BC Building Code introduced a new stepped framework for introducing progressively more stringent energy targets. The highest of these targets (Step 5) corresponds to NZE-Ready performance. Similar requirements are under consideration for Canada's National Building Code.

3.2. Load Calculations

For this study, HOT2000 [8] was used to compute each archetype's heating load in 16 Canadian locations. HOT2000 uses a monthly-bin model, which divides the monthly climate conditions into distinct temperature bins. For each bin, HOT2000 computes the building's heating and cooling requirements while accounting for conductive losses, infiltration and ventilation, as well as solar and internal gains.

The HOT2000 results were then used to extrapolate hourly load shapes for each archetype using a load fitting technique [9]. The resulting data provide an estimate of the building load at every hour of the year.

Figure 1 depicts the estimated load for each archetype when located in Toronto. The data are plotted according to the outdoor temperature (x-axis) and estimated heating load (y-axis). Each dot represents an observed outdoor temperature at one hour in the year, and the corresponding heating load at that hour. Each line depicts the linear best-fit regression between temperature and load. As expected, the estimated loads increase as temperatures drop. Not surprisingly, the Net-Zero-Ready home exhibits the lowest loads of the four archetypes, while the pre-1980's home exhibits the highest loads.

Figure 2 illustrates how the same data varies by time of day. In this plot, the estimated heating loads for Archetype B are binned according to hour of the day. Seasonal averages are illustrated with black lines. As expected, heating loads are generally lowest in the mid-afternoon, and peak in the early morning hours.

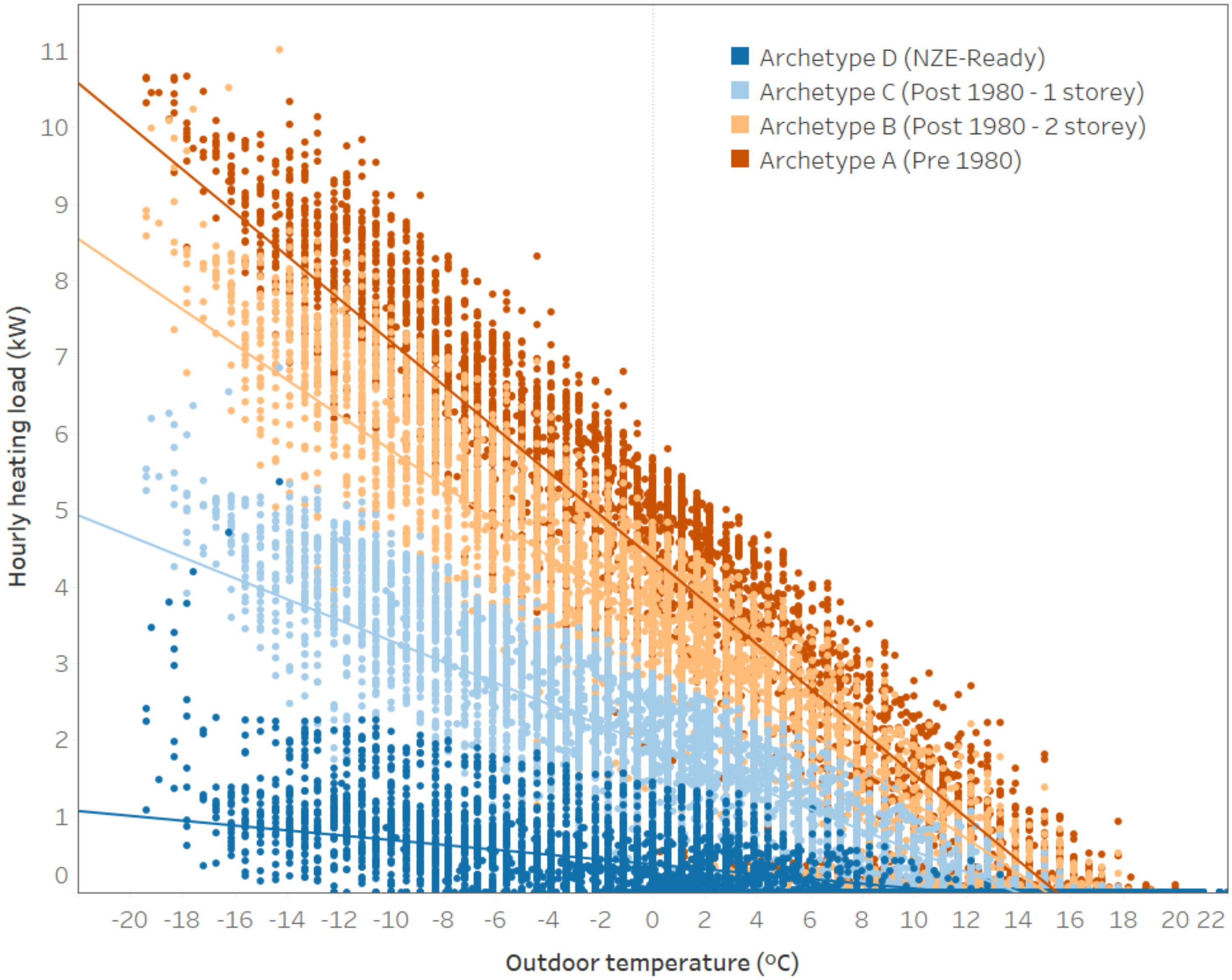

Figure 1: Estimated heating loads at each hour for Archetypes A, B, C and D, when situated in Toronto

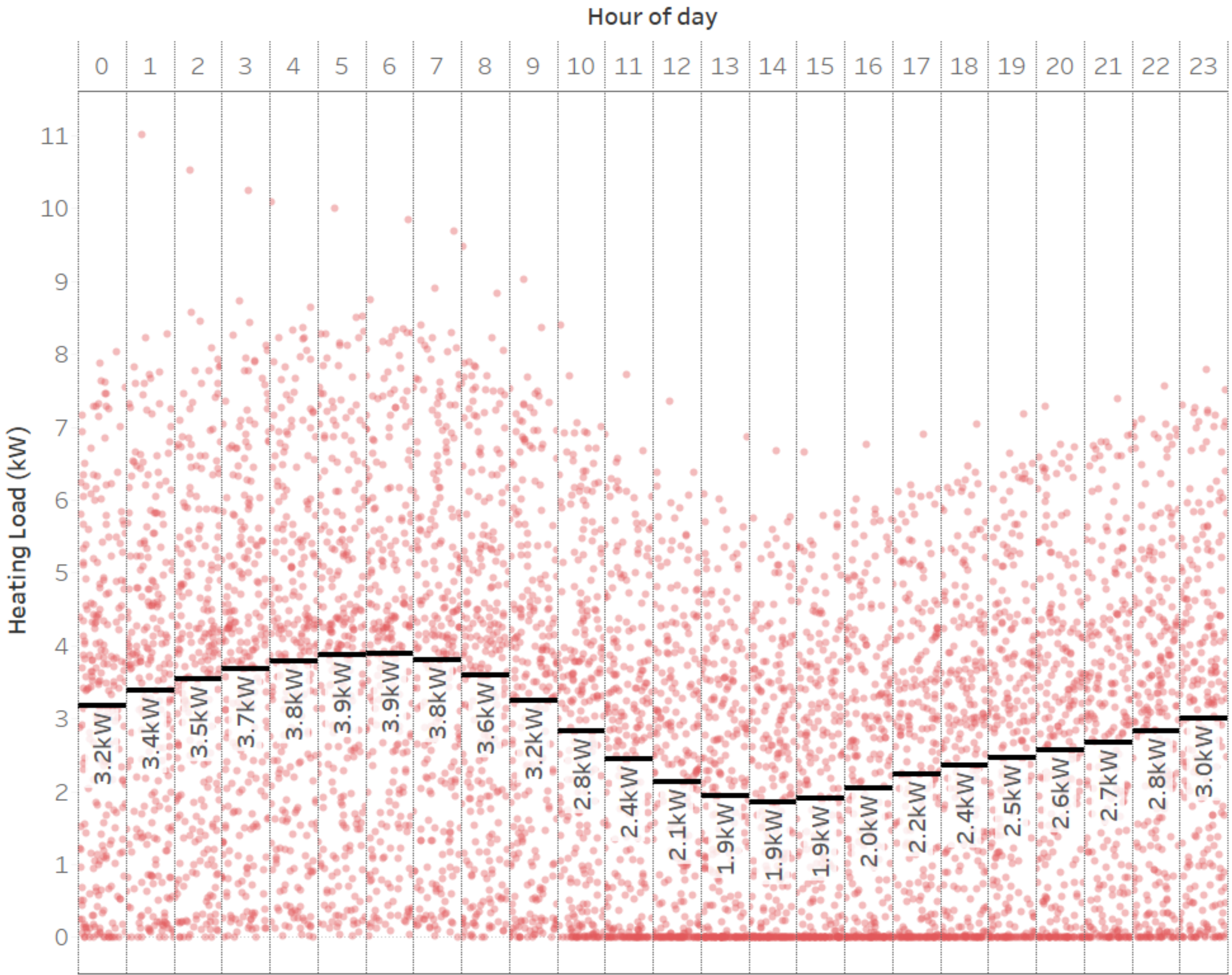

Figure 2: Estimated and average estimated loads by hour of the day, for Archetype B, when located in Toronto, ON.

To ensure results were relevant across Canada, the same load-calculation procedure was performed in 16 different locations. Table 1 presents the predicted peak heating loads for all four archetypes in each of these locations.

Table 1: Peak heating loads (kW) by location, for Archetypes A, B, C and D.

Region		A: Pre 1980	B: Post 1980 2-Story	C: Post-1980 1-Story	D: Net-Zero Ready
BC	Kamloops	10.0	8.2	5.2	2.2
	Prince George	13.7	11.5	7.4	3.2
	Vancouver	6.4	5.3	3.4	1.1
	Victoria	5.9	4.8	3.0	1.0
AB	Calgary	14.3	12.1	7.7	3.2
	Edmonton	16.8	14.1	9.0	3.9
SK	Regina	16.8	14.5	9.0	4.0
MB	Winnipeg	16.3	13.8	8.6	3.9
ON	London	12.4	10.4	6.6	2.8
	Ottawa	13.8	11.5	7.3	3.2
	Toronto	11.6	9.8	6.1	2.6
QC	Montreal	13.2	11.1	7.0	3.1
	Quebec	13.4	11.3	7.8	3.2
NB	Fredericton	14.4	12.2	7.8	3.2
NS	Halifax	13.2	11.1	7.1	2.9
NF	Saint Johns	11.4	10.0	6.1	2.7

3.3. Heat Pump Performance

As part of this project, three cold-climate air source heat pump systems that are reputed to maintain high capacity at cold outdoor temperatures were evaluated:

- Model 2 1/2 ton – nominal capacity: 9.9 kW
- Model 3 ton – nominal capacity: 11.6 kW
- Model 3 1/2 ton – nominal capacity: 15.7 kW
- The respective model performance tables used in the evaluation are presented in Appendix A.[1]
- For each archetype and in each location, the heat pump that most closely matched the building's design heating load was selected. The systems were selected to meet or exceed the design heating load. The heat pump's performance was then predicted by interpolating within these tables according to

[1] We did not consider higher capacity systems than these, given the challenge of maintaining cooling capacity within 80-125% of the design cooling load in many homes in Canada. Larger systems may also require larger airflows than many existing duct systems in Canadian homes would be designed to accommodate. Nevertheless, as discussed in this paper, there are market opportunities for larger capacity systems in some market segments.

both building load and outdoor temperature. With this method, the heat pump's capacity and COP was estimated for every hour of the year, for each of the four archetypes when situated in each of the 16 locations described in Table 1.

3.4. Energy Prices

The core objective of this project was to compare heat pump operating costs to those of traditional heating systems. While energy prices are obviously central to that objective, including energy price data in the analysis is not a trivial task. This is because Canadian energy prices vary according to region and season. Provincial policies on utility rates and economic activity also affect year-over-year variations in energy prices.

The ongoing pandemic added uncertainty to heat pump operating costs. Even so, life expectancies for heat pumps, furnaces and other residential heating equipment all exceed 15 years. This timeline extends well beyond pessimistic estimates for pandemic impacts. For this reason, the economic analysis was designed to minimize the impact of the COVID-19 pandemic on energy pricing. The approach taken included three steps:

1. Benchmarking current energy prices using the most recent available data
2. Analysing consumer price trends to quantify the effect that COVID-19 had on residential energy prices, and estimating energy prices for an alternative business-as-usual scenario
3. Adjusting those energy prices to reflect pending increases to the federal carbon tax.

Current energy prices

Figure 3 depicts effective provincial energy prices for electricity, natural gas and heating oil, as of August 2020. The electricity and natural gas rates illustrated in Figure 3 were obtained from utility and local distribution company websites; the heating oil rates were obtained from Statistics Canada. [10]

The effective energy prices reflect the total variable cost to consumers (per GJ supplied), including electricity generation, gas supply, transmission and distribution charges, and federal carbon taxes. Both Quebec and British Columbia use a tiered electrical rate tariff. These rate structures offer a lower rate for the first tier of electricity consumed, and then charge a higher rate for the second tier. For the purposes of examining HP performance, the higher tier electricity rate was used. In most Canadian homes, the electricity used in the home by appliances and lighting, and electric water heating (if installed) is enough to exhaust the first tier, and the balance of the space heating load would be charged against the higher rate.

Finally, most of Ontario's residential electrical customers pay by time-of-use rates. In Figure 3, the data point for Ontario's electricity price reflects the mid-peak rate for illustration; the analysis also applied the off-peak and on-peak rates to appropriate hours in the year.

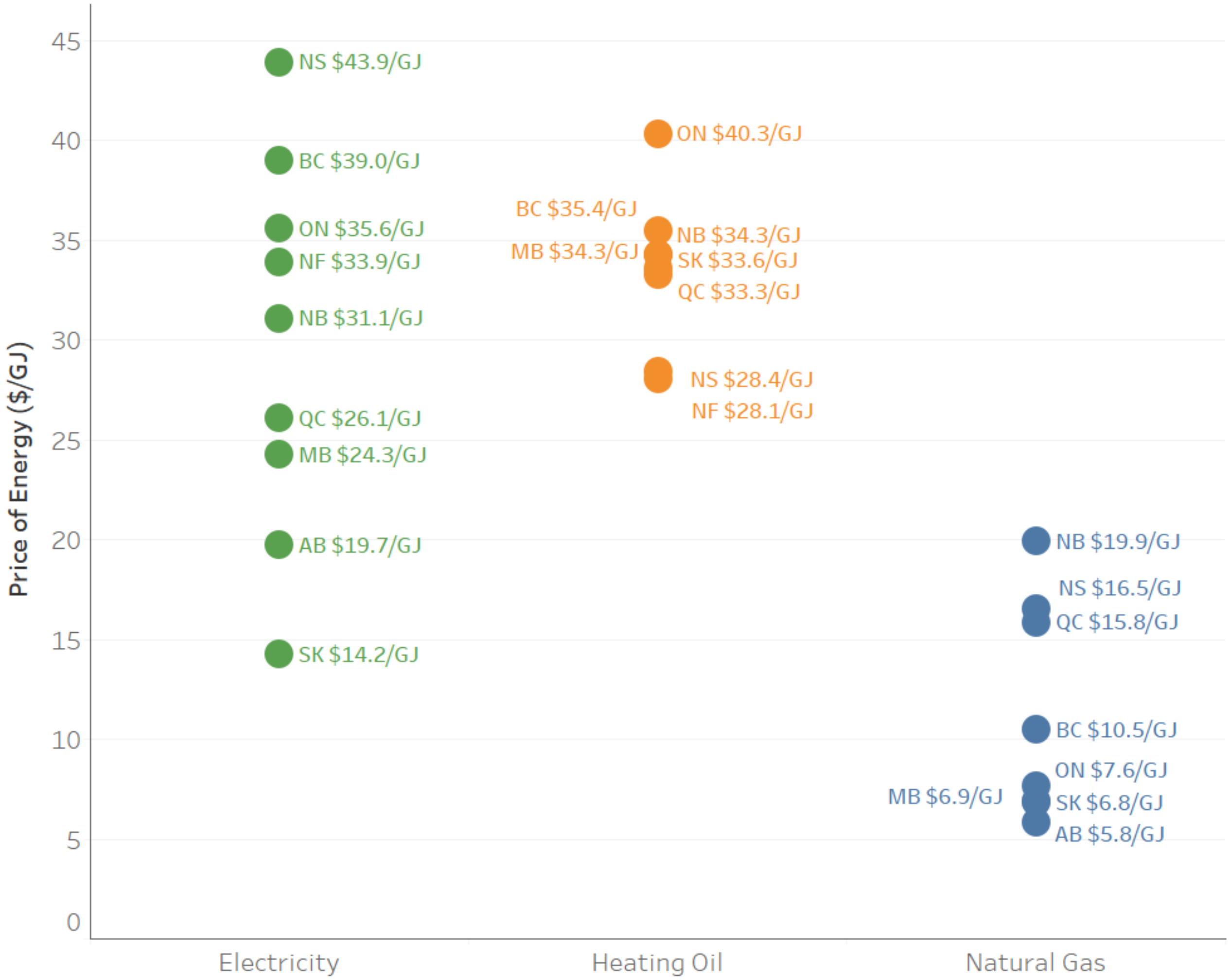

Figure 3: Effective electricty, natural gas and oil prices for residential customers (August 2020)

Energy price trends

Statistics Canada uses the Consumer Price Index (CPI) to track inflation of prices for common commodities. The CPI compares average prices to a benchmark price in 2002. The benchmark price is assigned a nominal index of 100, and each month, Statistics Canada compares current prices to that benchmark to establish the current index [11].

Figure 4 depicts Consumer Price Indices for electricity, natural gas and heating oil over the last five years. The impact of the ongoing pandemic is most apparent in the price of heating oil, which softened considerably since January 2020. Using the CPI index, it was estimated that prices (as of July 2020) were approximately 25% lower than typical prices in prior winters (October 2017-March 2018 and October 2018-March 2019). Accordingly, an adjusted price for heating oil that reflects pre-pandemic winters was computed.

The Consumer Price Index data suggests that electrical and natural gas prices had been somewhat less affected by the ongoing COVID-19 pandemic. Electricity prices exhibited a 7% reduction between February and May of 2020, but the June and July indexes showed prices had largely recovered to pre-pandemic levels. Natural gas prices remained largely unchanged through the COVID 19 pandemic. For these reasons, the current (August

2020), unadjusted natural gas rates were used. The unadjusted electricity rates for all provinces with the exception of Ontario were also used for the same reason.

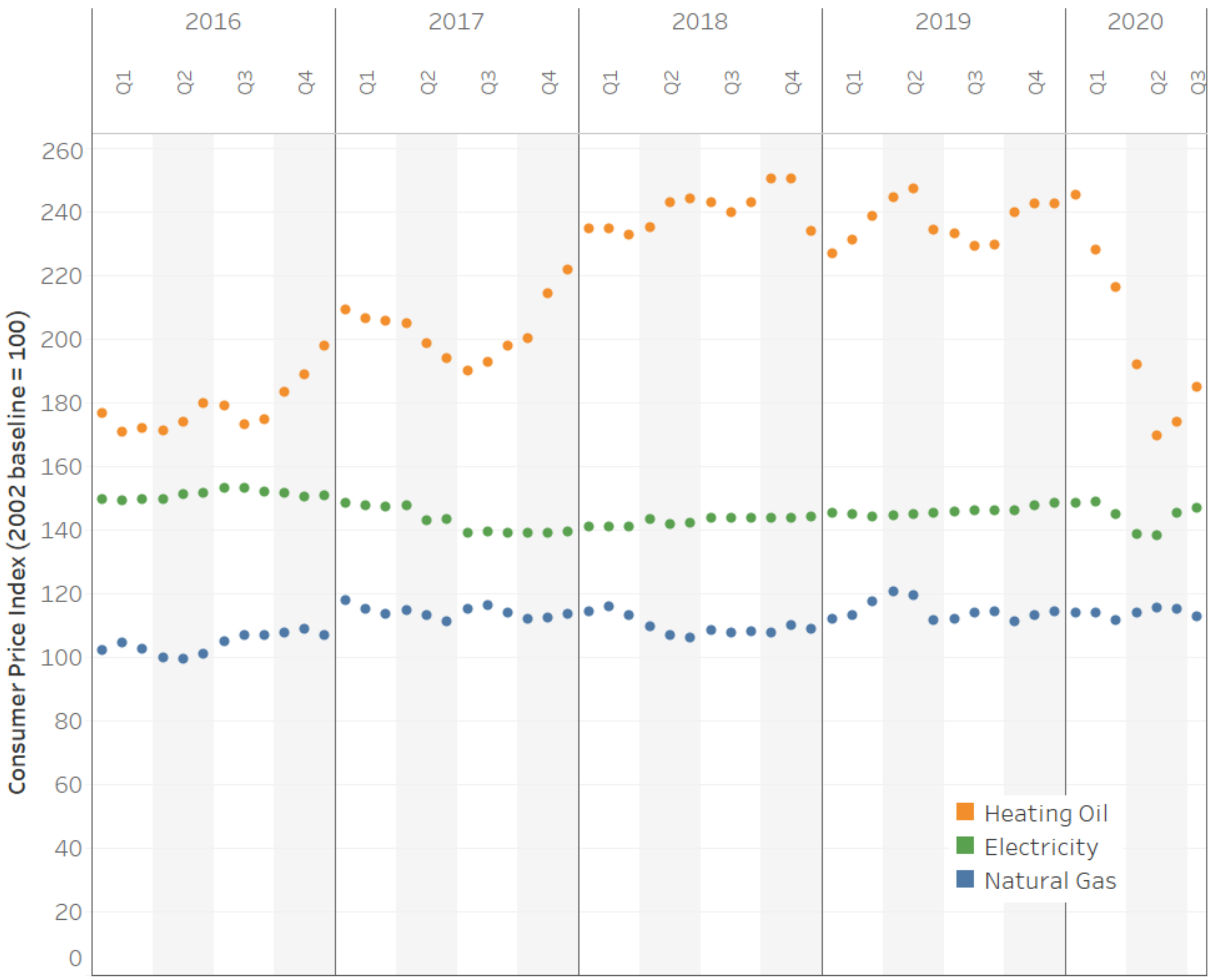

Figure 4: Monthly Consumer Price Index for electricity, natural gas and heating oil, 2016-2020 (Statistics Canada table 18-10-0004)

Time-of-use pricing in Ontario

Most residential customers in Ontario pay for electricity by time-of-use. Each 24 hour weekday is divided into three rate classes: 6 hours are designated as "on-peak", 6 hours as "mid-peak", and 12 hours as "off-peak". Weekends and holidays are designated as entirely off-peak. Electricity prices are highest in on-peak periods, and lowest during off-peak.

This rate structure has a significant impact on the economics of electric heat pumps. Heating loads are highest during night-time hours, and generally coincide with the off-peak period (7pm to 7am). Access to lower rates during these times can make electric heating more affordable.

Figure 5 depicts historical TOU rates in Ontario. Typically, rates are adjusted twice annually. In late 2019, Ontario electrical prices reached a historical high after two years of relative stability. This increase reflected legislation to ensure electrical rates more closely approximated the costs of supply. At this time, the Ontario government also implemented a new electricity rebate, funded with provincial revenues. The value of the Ontario Electricity Rebate was approximately 31.8% of electricity charges for residential customers.

In response to the COVID-19 pandemic, the Ontario government suspended time-of-use pricing. As of September 2020, Ontario residents payed 12.8 ¢/kWh for electricity generated within Ontario, along with transmission and distribution tariffs of approximately 2 ¢/kWh depending on location.

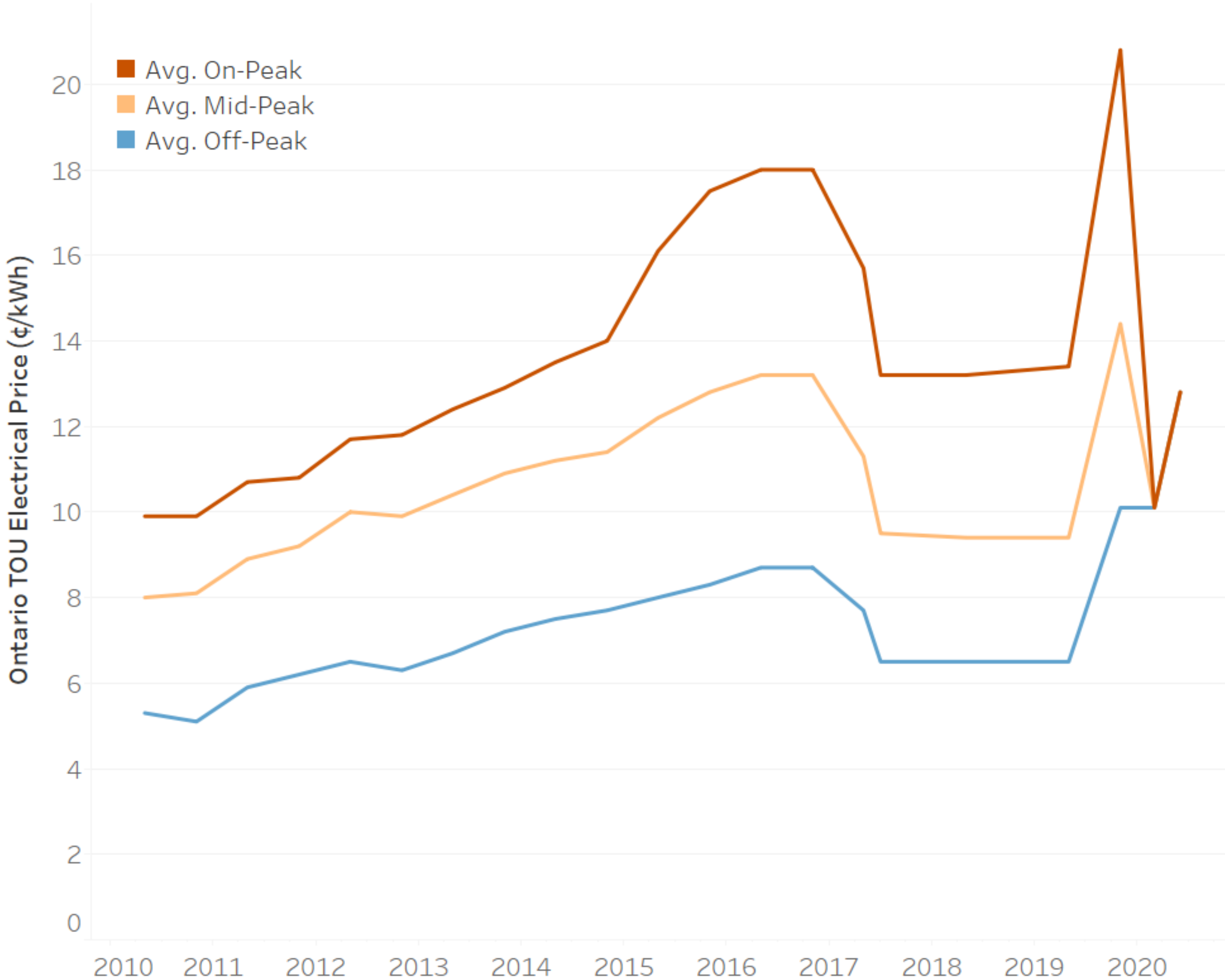

Figure 5: Historical Time-Of-Use rates in Ontario

Time-of-use rates were expected to return (at the time of writing) in November 2020, [12] but the Ontario Energy Board had yet to provide information on the TOU rate table. In the absence of such guidance, it was assumed that Ontario's TOU rates would continue to reflect the price of energy supply. With this assumption, the November 2019 rate table was used for the purposes of this project. It was also assumed that residential customers would continue to benefit from the Ontario Electricity Rebate, but a scenario in which this rebate would be suspended at a future date was also considered.

Carbon taxes

In 2019, the federal government introduced carbon pollution regulations across Canada. These regulations called upon provinces and territories to establish their own carbon pricing regulations. In provinces that opted not to establish their own regulations, the federal regulations imposed a $20/tonne tax that would rise by $10 each year until 2022.

The federal carbon tax was, at the time of writing, in effect in Manitoba, New Brunswick, Ontario, Saskatchewan and Alberta. The remaining provinces operate their own carbon pricing schemes. While provincial strategies differ in approach, each aligns with federal benchmarks for roll-out.

For the purposes of this project, it was assumed federal and provincial governments would continue to apply carbon levies consistent with Canada's carbon pollution pricing strategy. Table 2 presents carbon levies for 2020-2022, and associated carbon premiums for natural gas and heating oil.

Table 2: Federal carbon levies and carbon tax premiums, by fuel

Year	Carbon Levy ($/tonne CO_2-e)	Premium by fuel ($/GJ)	
		Natural Gas	Heating Oil
2020	30	1.58	2.96
2021	40	2.10	3.95
2022	50	2.63	4.93

While federal and provincial levies do not explicitly tax electricity, they do affect the price of fuels used to generate electricity. Residential electricity prices are regulated across Canada, but it is reasonable to assume that regulators would permit utilities to pass cost increases on to consumers.

The impact of carbon pricing on electricity prices depends on the source of electricity. Regions that depend on coal or natural gas for generation could expect significant price increases, while effects in regions with non-emitting generation (solar, wind, hydro and nuclear) would be more modest.

Table 3 presents the effective premiums on electricity prices that could be expected as carbon tariffs are passed on to electrical rate payers. The actual premium expected in each province was determined using the carbon intensity of electricity generation in that province, as published in Canada's National Inventory Report.[2]

Table 3: Effective premiums on electricity prices associated with carbon pricing of fuels, by province

Year	Premium by province ($/GJ)								
	BC	AB	SK	MB	ON	QC	NB	NS	NF
2020	0.11	6.58	5.50	0.03	0.33	0.01	2.33	5.00	0.27
2021	0.14	8.78	7.33	0.04	0.44	0.01	3.11	6.67	0.36
2022	0.18	10.97	9.17	0.05	0.56	0.02	3.89	8.33	0.44

[2] See https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html

Effective energy prices

Based on this analysis, two energy price scenarios were developed:

The **Current Price** scenario reflects prices that Canadians currently pay for electricity, gas and heating oil, as of August 2020. It includes the carbon levies in effect at that time, and reflects changes in demand associated with the ongoing COVID-19 pandemic.

The **Projected Price** scenario reflects the best estimate of where energy prices would stand in the winter of 2022-23. This scenario adds additional price premiums to all fuels to reflect increased carbon levies. It also increases the price of heating oil to reflect anticipated recovery from the ongoing COVID-19 pandemic.

Table 4: Effective energy prices used to evaluate costs of heating — Current (2020) and Projected (2022) scenarios

	Electricity ($/GJ)		Natural Gas ($/GJ)		Heating Oil ($/GJ)	
	Current	**Projected**	**Current**	**Projected**	**Current**	**Projected**
BC	38.97	39.04	10.47	11.52	35.44	49.46
AB	19.72	24.11	5.80	6.85	No Data	No Data
SK	14.23	17.90	6.82	7.87	33.58	46.97
MB	24.25	24.27	6.89	7.94	34.26	47.88
ON	— See **Table 5**—		7.65	8.70	40.33	56.01
QC	26.06	26.07	15.83	16.88	33.26	46.54
NB	31.06	32.62	19.90	20.95	34.26	47.88
NS	43.90	47.23	16.54	17.59	28.41	40.04
NF	33.90	34.07	NA	NA	28.05	39.56

Table 5: Effective time-of-use prices in Ontario (current and projected scenarios)

Charge		**Tariff with Ontario Rebate ($/GJ)**		**Tariff without rebate ($/GJ)**	
Time-of-use:	On-peak	39.40	(14.2 ¢/kWh)	57.78	(20.8 ¢/kWh)
	Mid-peak	27.28	(9.8 ¢/kWh)	40.00	(14.4 ¢/kWh)
	Off-peak	19.13	(6.9 ¢/kWh)	28.05	(10.1 ¢/kWh)
Transmission and Delivery		3.22	(1.2 ¢/kWh)	4.72	(1.7 ¢/kWh)

Monthly charges

In addition to the supply, transmission and distribution charges, electrical and natural gas customers also pay a fixed charge each month. This charge reflects connection fees, account administration and other charges that do not vary with energy consumption. Table 6 presents estimated monthly charges by province.

Table 6: Monthly charges for electricity and natural gas utilities

Province	Electric utility ($/month)	Gas utility ($/month)
BC	6.29	12.84
AB	7.10	25.06
SK	22.79	23.20
MB	8.61	14.00
ON	28.64	21.48
QC	12.35	16.73
NB	22.39	20.00
NS	10.83	21.87
NF	15.97	NA

3.5. Reference Cases

In this project, the cost-effectiveness of heat pumps was compared to three reference cases:

In the **Gas-heating reference case,** the home was heated using a new forced-air gas-furnace, with an annual fuel utilization efficiency of 95%.

In the **Electric-heating reference case**, the home was heated using an electric forced air furnace, with an effective efficiency of 100%.

In the **Oil-heating reference case**, the home was heated using a new forced-air oil-furnace with an annual fuel utilization efficiency of 78%.

3.6. Heat Pump Deployment Scenarios

In this study, it was assumed that a home's existing furnace (electric, gas or oil) would be replaced with an appropriately sized CC-ASHP unit. For homes with loads that exceed the capacity of the largest unit evaluated (3 1/2 ton), it was assumed that unit would rely on back up heat in colder weather.

Two heat pump deployment scenarios were examined:

- **Electric HP:** The electric-HP scenario assumed that the CC-ASHP systems were deployed in a manner consistent with current product specifications. Existing furnaces were replaced with an indoor air handling unit, which included an indoor heat exchange coil and electrical resistance heater to ensure the load would always be met.
- **Gas-Hybrid:** In the gas-hybrid scenario, the CC-ASHP's outdoor unit was connected to an indoor heat exchange coil. This specification does not incorporate an indoor air-handler or back-up plenum heater; instead the indoor coil is mounted above a conventional gas furnace, which serves as an air handler for the coil. This furnace could be the existing furnace in the building, a new furnace from a third-party supplier, or possibly an OEM-supplied unit designed to complement the CC-ASHP.

These two systems differ in their operation and control. In the all-electric scenario, the heat pump can operate in tandem with the back-up resistance heater. As loads begin to exceed capacity, the temperature of air leaving the indoor coil would drop below the threshold where it can comfortably heat the building. At these times, the back-up heater would operate as required to boost the supply air temperatures and ensure comfort.

Conversely, the gas hybrid scenario assumes that the heat pump and furnace cannot operate at the same time. Once the load exceeds the heat pump capacity, the furnace must operate to ensure adequate supply air temperature. This increases the temperatures entering the indoor coil well above the heat pump's operation range, and the heat pump must be deactivated to conserve energy.

Relative to gas-furnace heating, two utility service scenarios were also considered:

- **All-electric service**: In the all-electric scenario, it was assumed that homeowners would replace all gas appliances (including heating, hot water, cooking and decorative appliances) with electric equivalents. In this scenario, the household would no longer use any natural gas, and the homeowner could save additional money by suspending their gas utility service agreement.
- **Split gas/electric service**: in the split gas/electric scenario, it was assumed that homeowners would opt to retain gas service to the home for use in other appliances. In this scenario, the household would not take advantage of additional savings associated with suspending gas service.

Table 7 summarizes the heat pump scenarios used in this study.

Table 7: Summary of heat pump deployment scenarios, by reference case and utility service scenarios

Reference case	All-Electric Service	Split Gas/Electric Service
Gas	Electric HP	Electric HP & Gas Hybrid
Electric	Electric HP	—
Oil	Electric HP	—

3.7. Uncertainty

CanmetENERGY researchers undertook this study using the best-available information on housing characteristics, heating loads and utility prices. Even so, there are numerous sources of uncertainty associated with these inputs. This uncertainty may affect the energy and cost savings described.

Key sources of uncertainty include:

- **Utility pricing:** Energy prices vary over time. Changes to economic activity, energy demands and government regulatory programs affect the prices that homeowners pay for electricity, natural gas and heating oil. In this study, attempts were made to estimate short-term utility price changes that reflect pending carbon tariffs and economic recovery. The forecasted 2022 energy prices presented must be regarded as estimates — actual prices payed by customers may vary. Moreover, energy prices will continue to evolve beyond 2022, as will the economics of electric heat pumps.

- **Housing characteristics:** The scope of this study was limited to four archetype homes, varying from pre-1980 construction to modern Net-Zero Energy Ready standards. These archetypes are useful for understanding housing trends in Canada, and they resemble large segments of the housing stock. Even so, there are many Canadian homes that are not represented by these archetypes. Some, like multi-unit residential buildings and mobile homes, clearly do not conform to the four archetypes used here. Others may fall into the segments described by one of the archetypes, but still exhibit very different energy performance because they have been previously renovated or differ from the archetypes used in some other way.
- **Homeowner activity:** Building loads were estimated using the EnerGuide Rating system's standard operating conditions. These conditions put forward assumptions about how many people live in each house and how they use their appliances and lighting, as well as the temperature they set their thermostat to. These assumptions affect heating loads and energy use, and they vary from household to household. Depending on the activities within their households, some homeowners will realize greater savings than presented in this report; others may realize less.

4. Findings

4.1. Cost-Effectiveness of all-Electric CC-ASHP

Energy and emission impacts

The current CC-ASHP systems assessed are much more efficient than any of the reference systems. Figure 6 plots the energy savings achieved by the CC-ASHP system relative to the electric, gas and oil heating references. This plot considers only Archetype B, the post-1980 two-story house.

Savings are generally proportional to the efficiency of the equipment —savings are highest compared to oil heating equipment (AFUE 78%) and lowest compared to electric furnaces (efficiency of 100%). The amount of savings that CC-ASHP systems afford also varies by climate: warmer regions exhibit higher savings because heat pump COPs improve in warmer weather. For this reason, the predicted savings are highest in Victoria BC, and lowest in Winnipeg, Manitoba.

Note that the energy savings quoted here reflect point-of-use. These estimates differ from primary energy savings. Primary energy savings would also account for the efficiency of the electricity generating source used to power the CC-ASHP, among other transmission and distribution losses. In regions with primarily fossil-fuel fired electricity generation, this could have a substantial impact on energy savings from CC-ASHPs (decreasing energy savings by more than 60% of the percentage savings shown here).

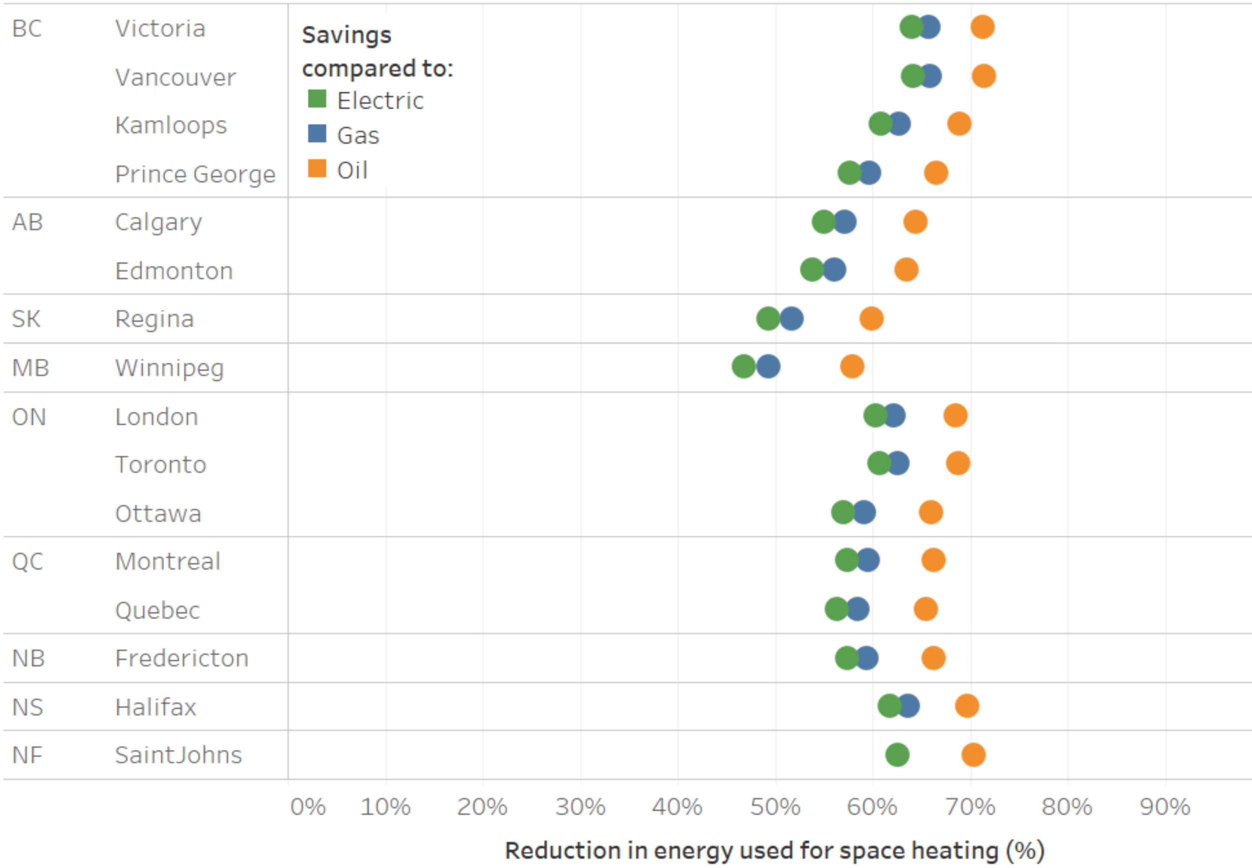

Figure 6: Reduction in annual energy used for heating in Archetype B (Post 1980s 2-story home), CC-ASHP vs electric, gas and oil furnaces

Figure 7 plots the reduction in annual greenhouse gas (GHG) emissions when the CC-ASHP system is compared to the reference heating systems. These results show that the emission impacts are much more sensitive to location than the site energy use. While the emissions associated with the gas and oil reference cases remain relatively constant between regions, the emissions associated with electricity vary province to province according to the carbon intensity of the generation infrastructure.

British Columbia, Manitoba, Quebec and Newfoundland generate the bulk of their electricity using hydro resources; Ontario also produces about 80-90% of its electricity from non or low emitting sources. In these regions, switching to heat pumps from gas or oil significantly reduces GHG emissions. But when compared to electric resistance, heat pumps offer negligible savings. In these provinces, electric resistance heating is nearly carbon free.

The opposite is true in Alberta, Saskatchewan, New Brunswick and Nova Scotia. These provinces use coal and gas-fired power plants to varying degree for the majority of electricity generation. In these locations, CC-ASHP technology delivers carbon savings relative to oil furnaces and electrical baseboards. When compared to gas furnaces, CC-ASHP systems lower emissions in New Brunswick, and increase emissions in Alberta and Saskatchewan. In Nova Scotia, gas furnaces and CC-ASHP systems produce similar emissions.

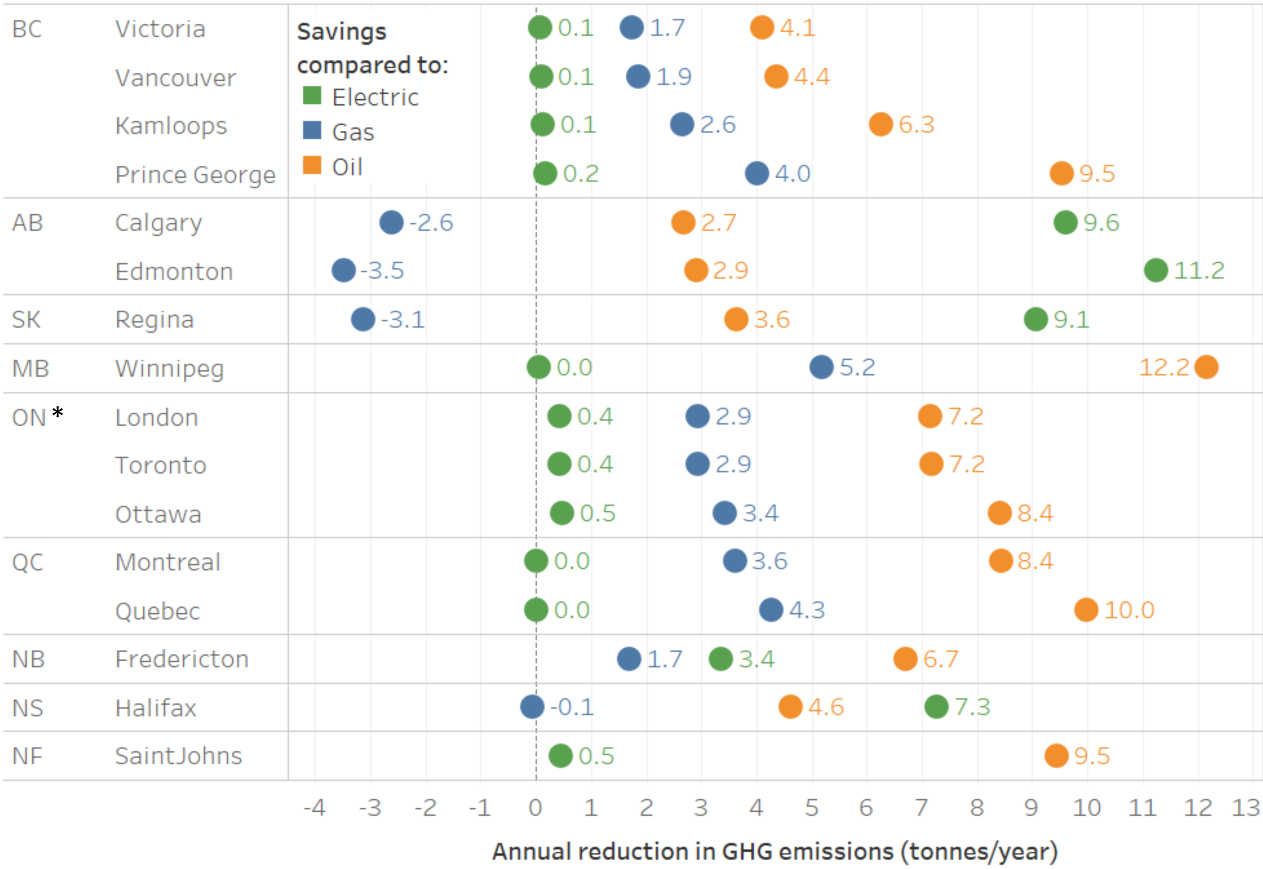

Figure 7: Reduction in annual GHG emissions associated with heating in Archetype B (Post 1980s 2-story home), CC-ASHP vs electric, gas and oil furnaces

* Note that GHG emissions were calculated based on average annual emissions factors from the electricity generation mix for that jurisdiction. It should be noted that actual GHG emissions associated with hourly electricity generation depend on a complex array of factors. For example, in cases where load is added to the grid (e.g., fuel switching from natural gas to electricity), the additional electricity needed to power CC-ASHPs may be generated by the marginal source of electricity generation. In some cases, this marginal source of electricity generation may have higher or lower GHG emissions associated with it than the average used in this analysis. In Ontario, the marginal source of electricity generation may be natural gas and/or hydroelectric. The degree to which marginal electricity generation is provided by natural gas electricity generation has an impact on GHG reductions. Refer to [13] for more details. Previous research into the impacts of seasonal hourly marginal emissions on hybrid systems (which combine natural gas furnaces with ASHPs) has shown that basing GHG reductions on seasonal hourly marginal emissions factors in Ontario may reduce the GHG reductions by about 5%. Refer to [14] for further details.

Energy costs compared to electric heating

The impact of CC-ASHP systems on utility bills also varies by region, according to the price of electricity. Figure 3 illustrates just how much the price of electricity varies from region to region. The economic savings that CC-ASHP systems can achieve depends on the local price of electricity.

Figure 8 plots the estimated annual reduction in electric utility bills for Archetype B (post-1980 two-story home), when compared to electric resistance heating. The utility savings evaluated are substantial. In regions where electric resistance heating predominates (Quebec and Atlantic Canada), replacing an electric furnace with a CC-ASHP will save homeowners an estimated $1,000-2,000 on utility bills every year.

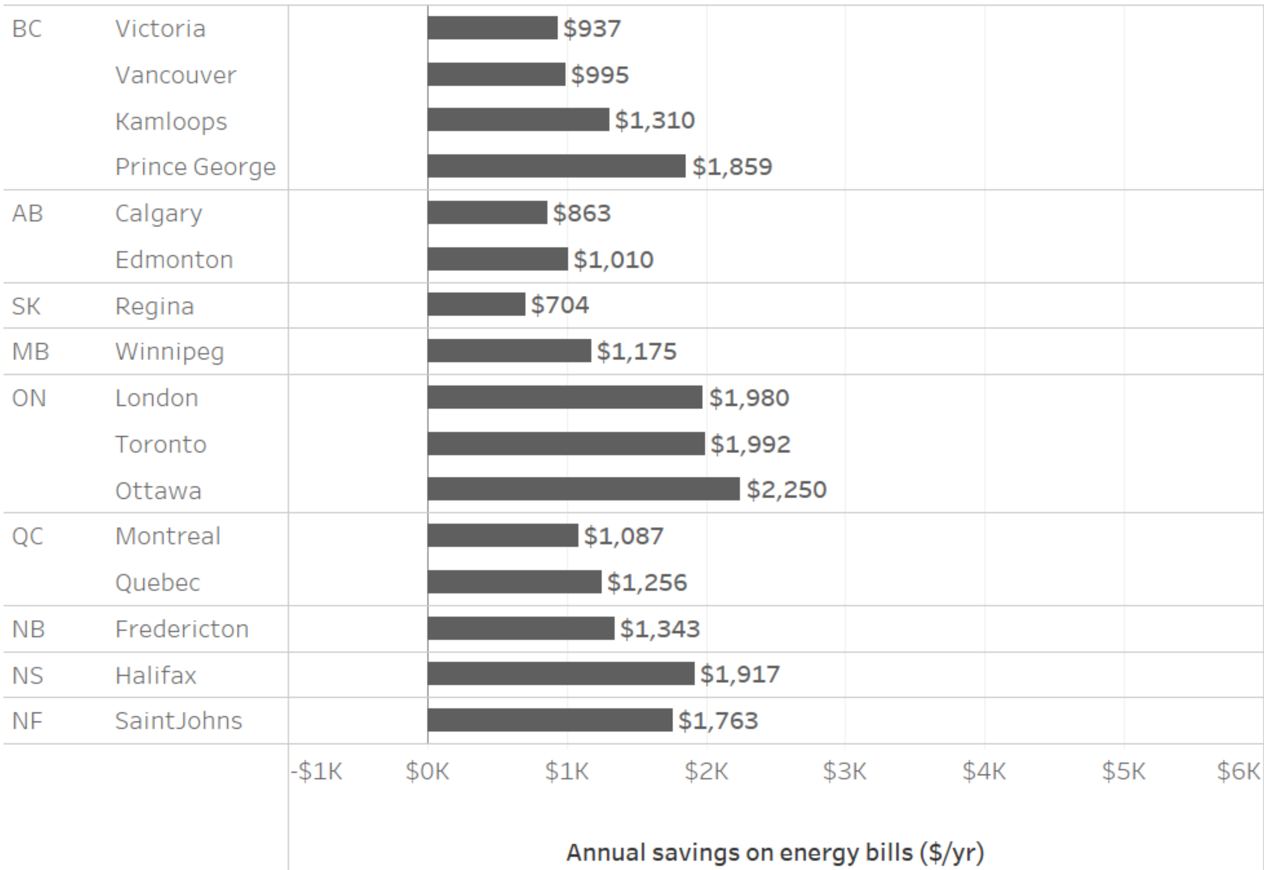

Figure 8: Estimated annual savings on energy bills by province for Archetype B, CC-ASHP vs electric furnace with current (2020) energy pricing

Energy costs compared to gas heating

Relative to Canadian electricity prices, natural gas is much cheaper when measured by unit of energy delivered to the household. While the superior efficiency of CC-ASHP technology means that heat pumps use much less energy than gas furnaces, the lower cost of natural gas means that the operating costs of CC-ASHPs and gas furnaces may be similar in many parts of Canada.

Figure 9 plots the estimated annual reduction in utility bills for Archetype B (post-1980 two-story home), when compared to a natural gas furnace. The savings offered by the heat pump are highest in Quebec, New Brunswick and Nova Scotia — provinces where current gas prices are considerably higher than in the rest of Canada.

West of Quebec, the estimated costs of operating heat pumps and gas furnaces are approximately equal. In most regions, the CC-ASHP scenario saves homeowners between $50-150/year compared to gas heating. The exceptions are Winnipeg MB and Prince George BC, where colder weather reduces the seasonal efficiency heat pumps. In these locations, the CC-ASHP systems evaluated may cost more to operate than a comparable gas furnace.

A significant part of the utility bill savings depicted in Figure 9 is found in the fixed charges associated with natural gas supply. For the all-electric service scenario, the analysis assumed that new homes constructed with a CC-ASHP would not also be connected to the gas distribution grid, and that home owners replacing gas furnaces with heat pumps would suspend gas service to their property. In this scenario, homeowners can forgo monthly fixed charges associated with natural gas service, amounting to $150-300/year in savings.

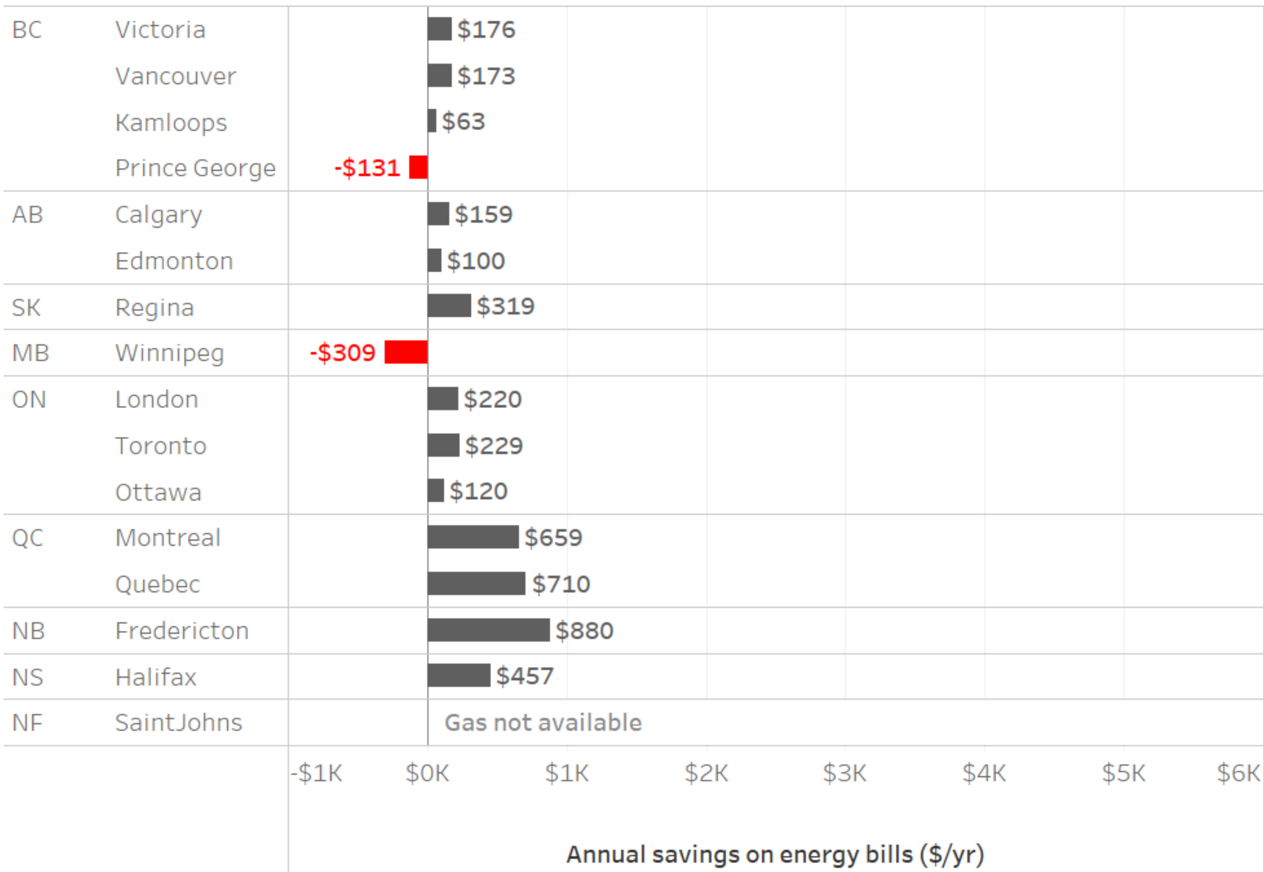

Figure 9: Estimated annual savings on energy bills by province for Archetype B, CC-ASHP vs gas furnace with current (2020) energy pricing

This scenario may not apply to all households. Some homeowners may choose to retain their gas connection for use in cooking appliances, decorative fireplaces and other end-uses. These homeowners will be obliged to continue to pay monthly fixed charges, even if they replace their furnace with a CC-ASHP.

Figure 10 quantifies the impact of this assumption. The left hand column plots the annual savings attributed to the fixed monthly charges; the right hand column plots the annual savings attributed to the variable charge (that is, the amount of gas actually consumed by the furnace). For instance, it was estimated that CC-ASHP would cost $176/year less to operate than a gas furnace in Victoria, BC. Of these savings, $154/year would be achieved by suspending gas service to the house. The remainder ($22) reflects the difference between the variable cost of the energy used by the CC-ASHP and gas furnace.

West of Quebec, the reduction on fixed charges amounts to the largest fraction of savings offered by CC-ASHP systems. And in some of these regions, the cost of electricity consumed by the heat pump is greater than the cost of gas used by a furnace. In these locations, homeowners who would replace gas furnaces with heat pumps but do not also suspend natural gas service may anticipate an overall increase in household utility costs.

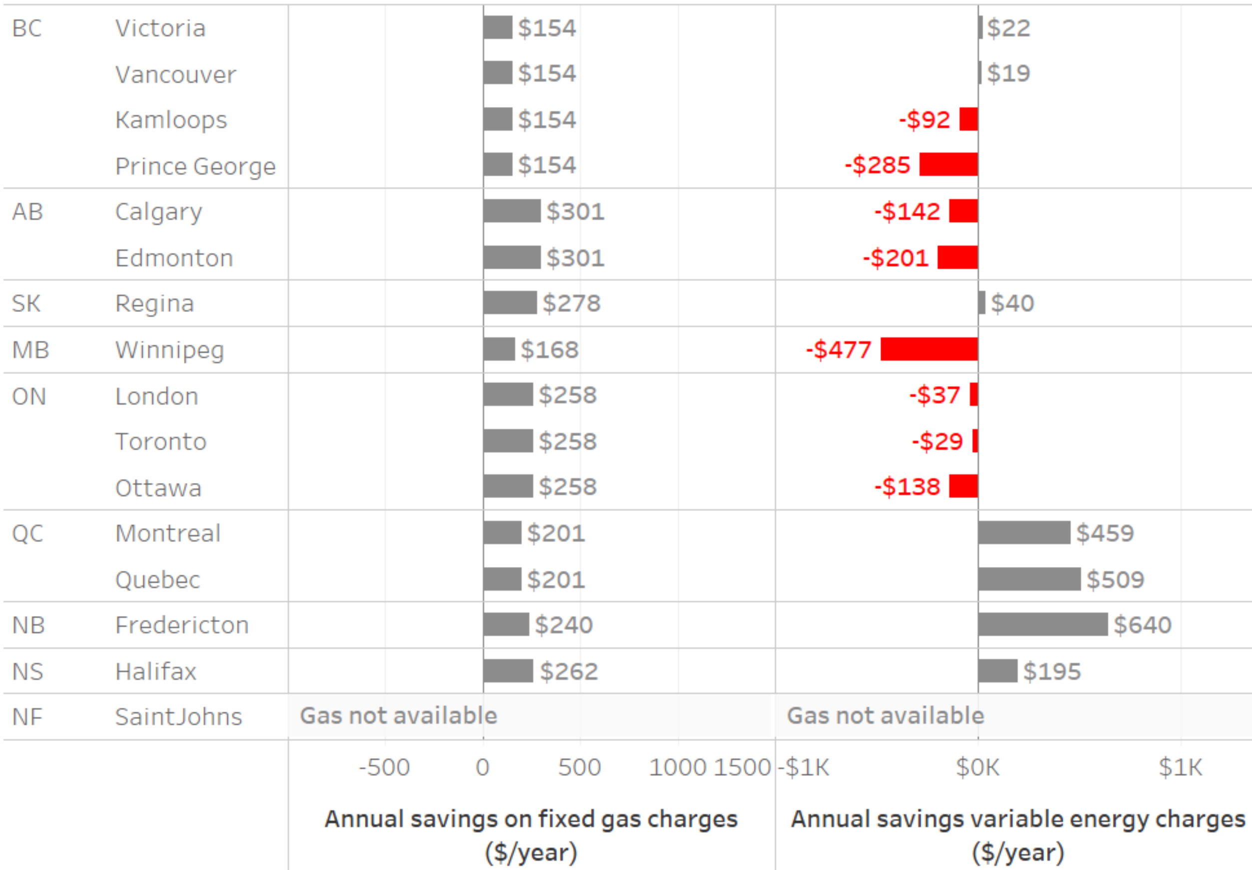

Figure 10: Estimated savings on fixed and variable energy charges, CC-ASHP vs gas furnace, assuming current (2020) energy pricing and all-electric service (suspension of gas service agreement)

Energy costs compared to oil heating

Figure 11 plots the estimated annual reduction in utility bills for Archetype B (post-1980 two-story home), when compared to an oil furnace. The results suggest that CC-ASHP systems are very attractive relative to oil heating in all parts of Canada. Two factors contribute to this finding:

- The price of electricity is generally comparable to heating oil when measured by units of energy delivered to the home, and
- Oil heating equipment is generally less efficient than both heat pump and gas furnace technology.

The 2020 energy prices used in this study reflected a significant decline in petroleum commodity prices due to the ongoing COVID-19 pandemic. Even so, the results suggest that homeowners replacing oil furnaces with heat pumps could expect to save between $1,000-3,000 annually under this price scenario.

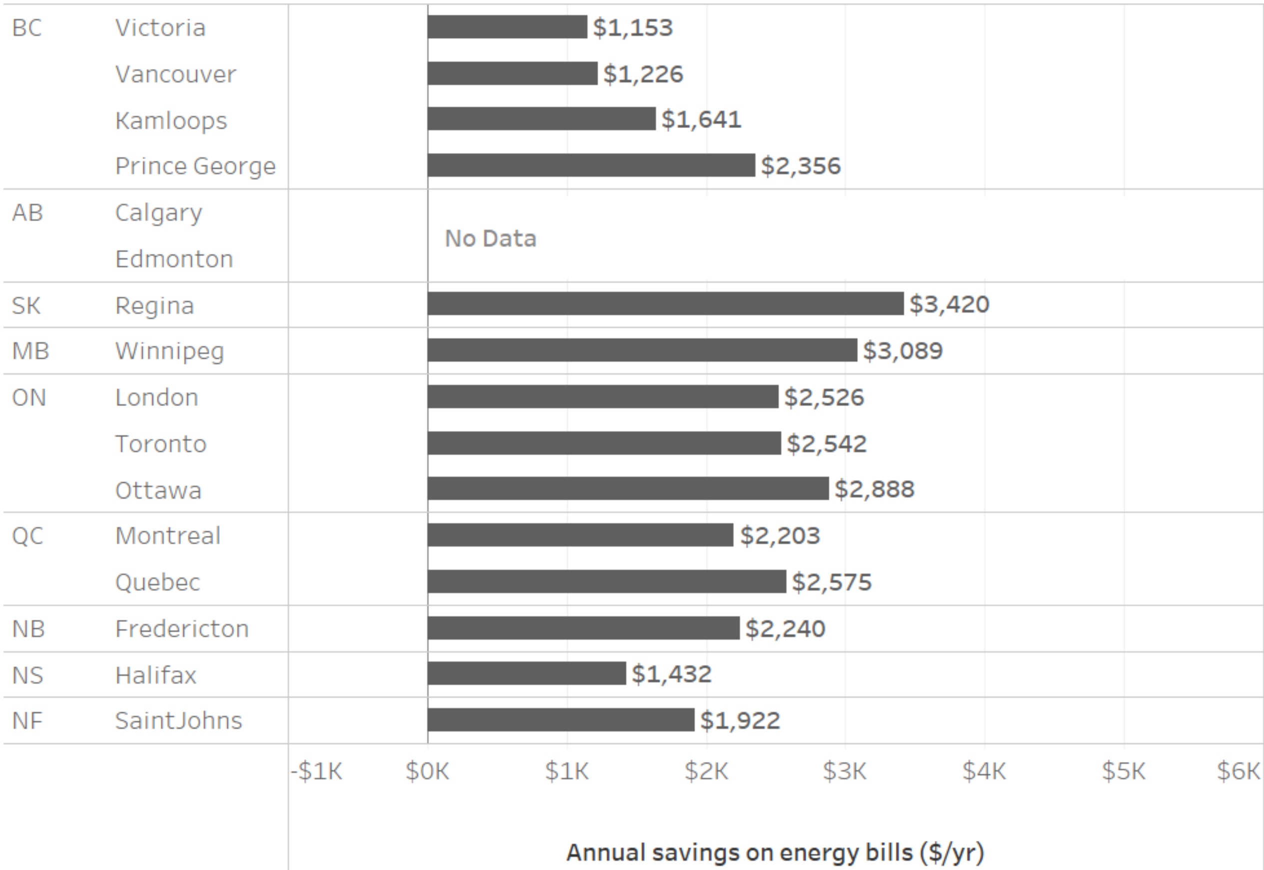

Figure 11: Estimated annual savings on energy bills by province for Archetype B, CC-ASHP vs oil furnace with current (2020) energy pricing

Energy cost savings by archetype

The results presented thus far reflect estimated savings for Archetype B — a two-story detached home built after 1980. While Archetype B represents many homes in Canada, the national housing stock is diverse in both size and insulation levels. As part of this study, the impact across three other archetypes that represented a range of heating loads was also examined. Refer to Section 4.1 for further discussion on relative numbers of homes in Canada represented by each Archetype.

Figure 12 presents the estimated savings on utility bills for the four archetypes. Each dot corresponds to one of the 16 different locations across the country. The black lines depict the average savings observed across all locations.

When compared to electric resistance and oil furnaces, savings from CC-ASHP equipment is generally proportional to a home's heating load. Archetype A (pre-1980) has higher air leakage and lower insulation levels than archetype B. These characteristics increase its space heating load, and generally, the amount of savings more-efficient heating equipment can deliver. For this reason, older homes will benefit more from CC-ASHP technology. On average, savings in Archetype A are $350 higher than in archetype B for a CC-ASHP when compared to electric resistance, and $550 higher when compared to oil furnaces.

Conversely, Archetypes C (Post-1980 one-story) and D (NZE-Ready) have lower heating loads than archetype B. When compared to electric resistance and oil furnaces, the savings that CC-ASHP technology can deliver in archetype C is about half that of archetype

B. And in the net-zero-ready archetype, the loads are so small that the CC-ASHP delivers modest savings of $100-200/year.

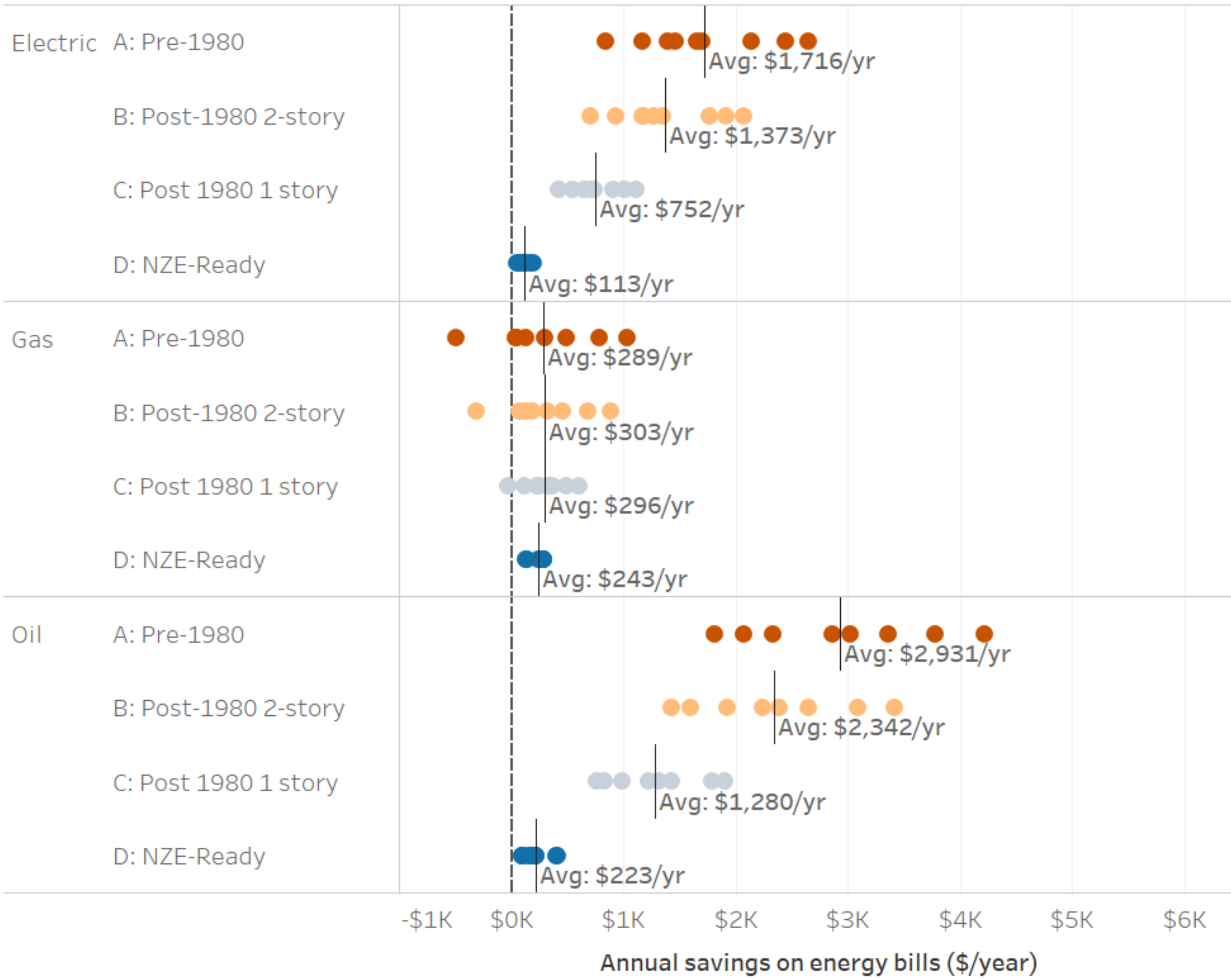

Figure 12: Estimated annual savings on energy bills by archetype, CC-ASHP vs electric resistance, gas and oil furnaces, with current (2020) energy pricing

When compared to gas furnaces, the economic impact of CC-ASHP technology is more variable. The analysis for archetype B showed that the annual savings on utility bills were affected by the relative prices of gas and electricity. In regions where CC-ASHP systems save on utility bills relative to gas furnaces, the results for archetype A suggest that they would save even more in older homes. However, the results for archetype B identified one location (Winnipeg) in which CC-ASHPs might significantly increase costs of heating relative to gas furnaces. Results for archetype A show that that the increase in heating costs will be even larger in this location.

Results for archetypes C & D are also notable. Whereas results for archetypes A & B included outcomes where the CC-ASHP scenario increased costs relative to gas furnaces, the CC-ASHP consistently delivers utility savings in the smaller, lower-load homes. This outcome reflects the importance of fixed utility charges in more-efficient housing. Smaller homes, and well insulated, well-sealed homes require less energy to heat. In these homes, the fixed energy charges comprise a larger portion of total energy costs. Installing CC-ASHP systems in lieu of gas furnaces allows homeowners to forgo those expenses.

Projected changes: 2020→2022

The results presented above reflect current energy pricing (at the time of writing), using data sourced in August 2020. It is anticipated that these prices will change, in part due to increased carbon taxes that are scheduled to take effect in the next two years. Federal and provincial carbon levies will increase the price of heating with natural gas and oil; they will also affect the price of electricity.

In addition to the carbon tax, it is anticipated that the price of heating oil will recover from the downturn observed in the first half of 2020, as the global economy begins to recover from the COVIC-19 pandemic, and commercial, industrial and transport activities increase.

Figure 13 illustrates the effect these price changes could have on the utility bill savings of CC-ASHP systems relative to electric resistance, gas and oil furnaces. Arrows indicate the direction of change; the length of each arrow indicates the estimated change in utility bill savings. Regions in which no significant changes are anticipated are denoted with a circle.

The results suggest that future price changes will modestly increase the savings that CC-ASHP technology can deliver relative to gas furnaces. In all locations except for Alberta and Saskatchewan, a $50-$100 annual increase in the savings delivered by CC-ASHP equipment is estimated — making CC-ASHPs more attractive to homeowners.

A modest increase in savings relative to electric resistance in provinces that still use significant amounts of fossil-fueled electricity generation (AB, SK, NB, NS) is also anticipated. As higher carbon taxes are passed on to rate payers, CC-ASHP will save electrically heated households more money.

However, the biggest change in savings is anticipated to be relative to oil heated homes. Two factors will contribute to a significant increase in the cost of heating with oil:

- Heating oil is more carbon intense than natural gas. Carbon taxes disproportionally affect the price of oil to cleaner fuels.
- Economic recovery will likely increase demand for petroleum fuels, causing heating oil prices to return to pre-pandemic levels.

Based on these trends, CC-ASHP technology is expected to become even more financially attractive relative to oil furnaces in all locations across Canada.

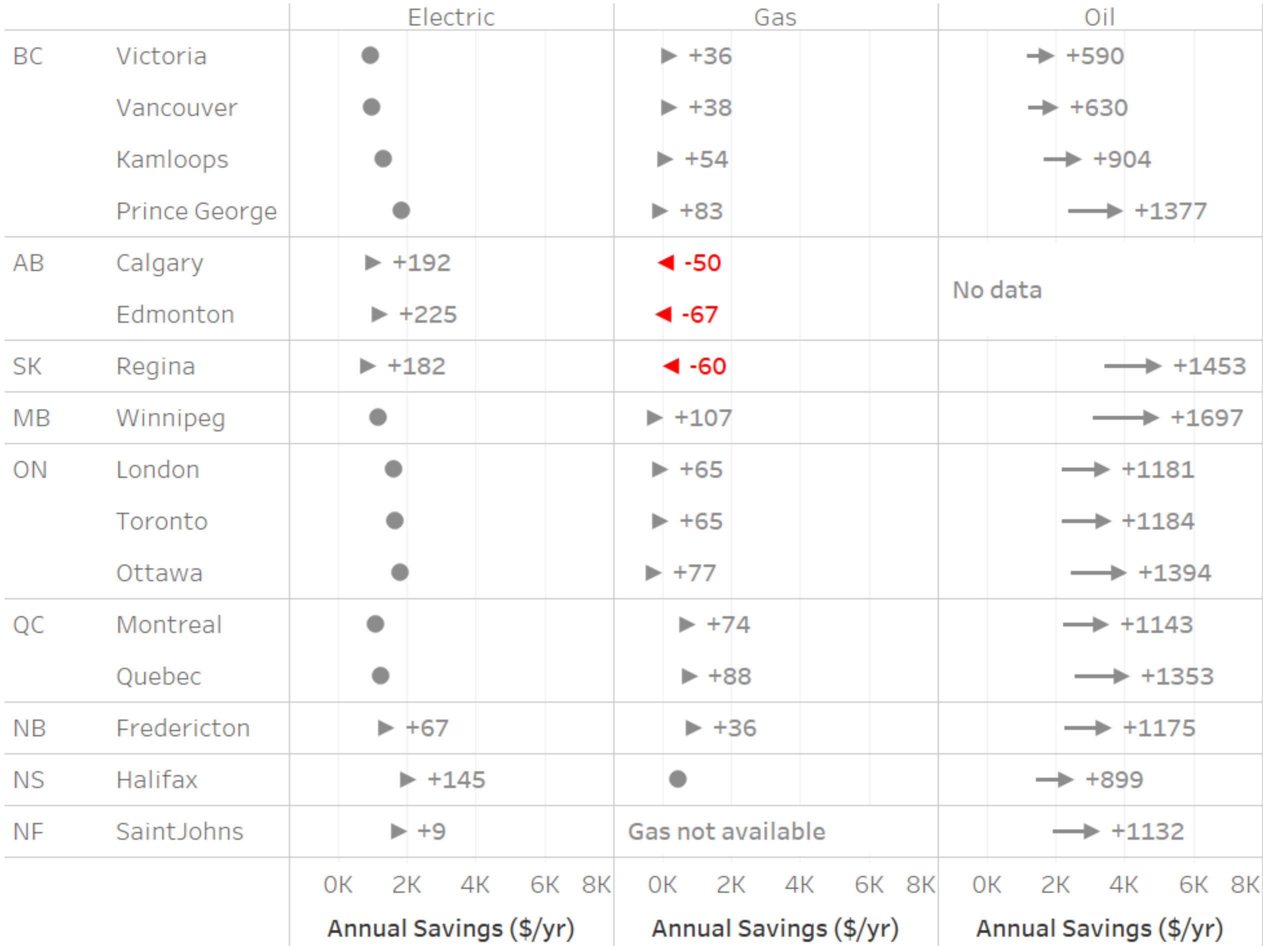

Figure 13: Projected change in savings on energy bills for Archetype B, CC-ASHP vs electric resistance, gas and oil furnaces

Impact of Ontario Electricity Rebate

Finally, the effect of Ontario's Electricity Rebate on the utility bill savings achieved by CC-ASHP technology was considered. While Ontario's electricity prices reflect the cost of supplying the province with electricity, rate payers at the time of writing benefitted from a provincial program that discounted their electricity bill by 31.8%.

The rebate was funded by government revenues, and it could be suspended by an act of legislature. Figure 14 illustrates how the rebate affects the cost savings delivered by CC-ASHP technologies.

Relative to homes heated with electric resistance, savings from CC-ASHP systems would be $500/year higher without the rebate. Without the rebate, electricity would be more expensive, and technologies that reduce the consumption of electrically heated homes would become more attractive.

For gas furnace and oil heated homes, savings from CC-ASHP systems would be about $200/year lower without the rebate. This has a modest impact on the savings relative to oil furnaces. Relative to gas furnaces, CC-ASHP systems deliver modest savings with the rebate in effect; these same systems would become slightly more expensive than gas furnaces if the rebate were not available.

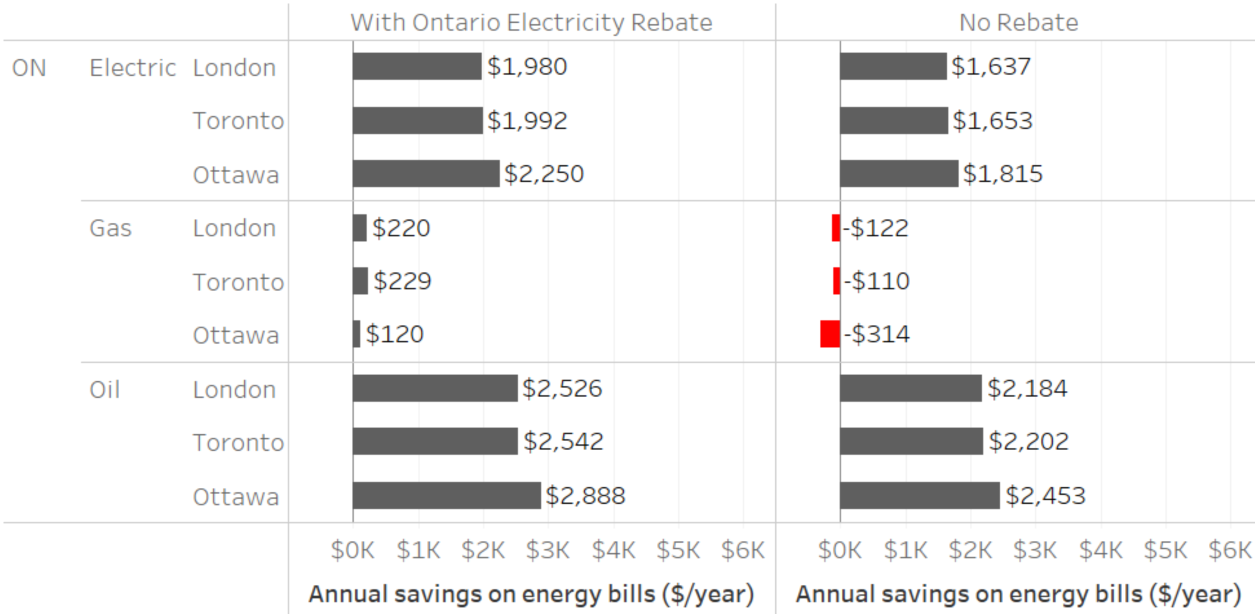

Figure 14: Comparison of savings for Archetype B in Ontario, with and without Ontario Electricity Rebate.

4.2. Cost-Effectiveness of Gas Hybrid CC-ASHP

For gas heated households, gas hybrid heat pump technology may provide an attractive alternative to all electric heat pumps. Some homeowners may wish to retain gas service for cooking, decorative fireplaces or other end-uses. In these circumstances, replacing a gas furnace with an all-electric heat pump would create a net-increase in operating costs (recall Figure 10, which quantifies the amount of savings that are attributable to the gas supply charge).

Gas hybrid heat pumps can use smart controls to decide whether it is more economical to heat with gas or electricity, depending on the price of energy, the time of use (if applicable) and outdoor conditions. These smart switching controls allow gas hybrids to deliver economic and emission savings relative to gas furnaces.

Energy impacts of gas hybrids

Figure 15 compares energy savings achieved by gas-hybrid and all electric CC-ASHP systems. The smaller blue dots indicate the savings achieved by the all-electric heat pump, while the larger red circles denote the savings achieved by the gas hybrids.

The gas hybrid's energy savings approach those of the all-electric heat pumps in warmer climates (Victoria and Vancouver), and regions where gas prices are higher (Quebec, New Brunswick and Nova Scotia). In those regions, the smart controller determines that the heat pump is more economical than the gas furnace in all but the coldest weather.

In other regions, the hybrid delivers less energy savings. The controller only operates the heat pump when the outdoor conditions are mild enough to allow for lower operating costs than the gas furnace back-up. As a result, the hybrid delivers approximately 15% savings in Alberta and Manitoba, and approximately 30% savings in Ontario, Saskatchewan and colder regions in British Columbia.

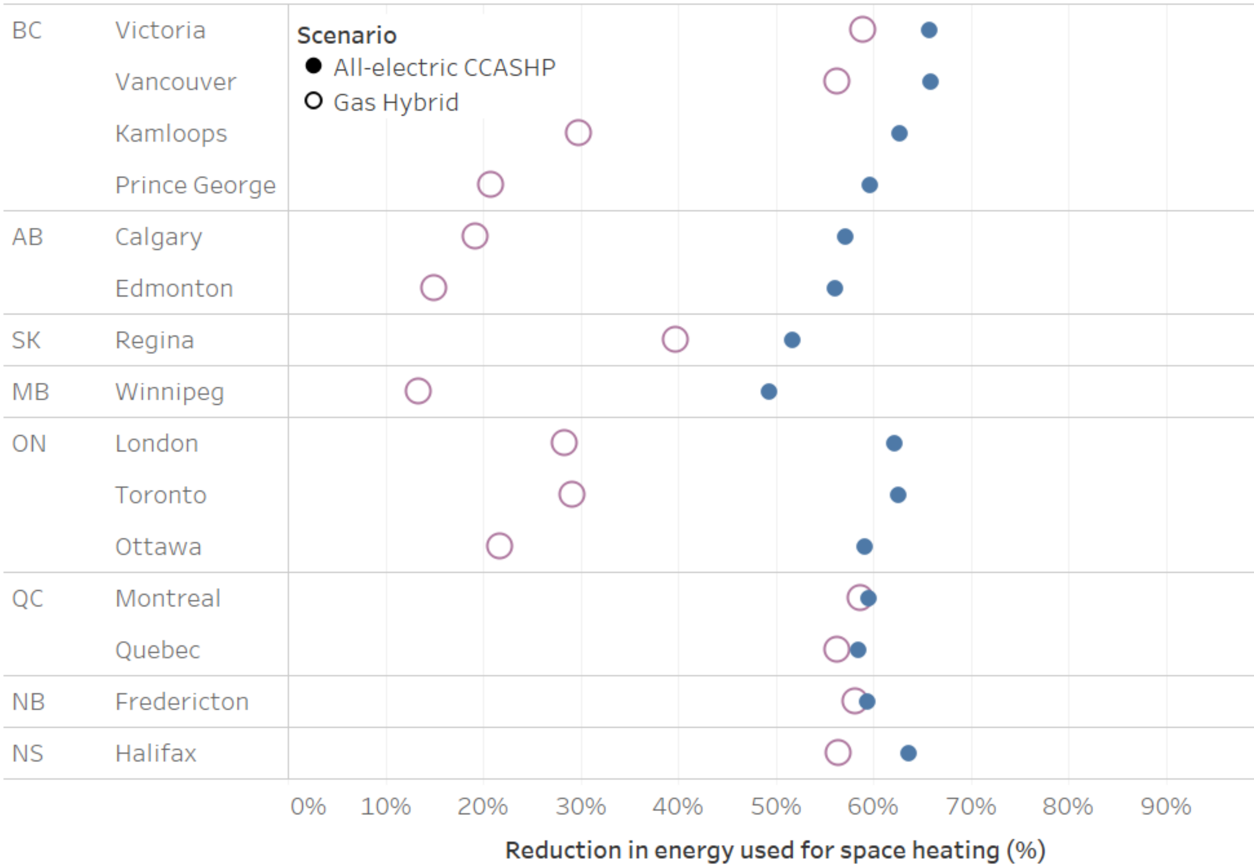

Figure 15: Comparison between energy savings achieved by all-electric CC-ASHP and gas-hybrid in Archetype B (Post 1980s 2-story home), relative to a gas-furnace

Energy savings compared to all-electric heat pumps

In Section 5.1, it was discussed how gas heated households that opt to install a heat pump can achieve significant economic savings by suspending gas service to the house (Recall Figure 10, which quantifies the savings from fixed and variable energy charges.)

The all-electric service scenario may not be realistic for many homeowners, who wish to retain gas service for cooking, decorative fireplaces or other heating end-uses. Homeowners who install CC-ASHP systems but elect to continue both gas and electric services can expect to pay $150-$300 more each year in fixed monthly charges. In Ontario, Manitoba, Alberta and colder regions of British Columbia, the result will be a net increase in annual operating costs.

Figure 16 compares the annual savings on utility bills that an all-electric CC-ASHP and gas hybrid system can achieve when installed in place of a gas furnace. In this comparison, it was assumed that households would continue to pay for gas service for cooking or other purposes. With this assumption, the all-electric CC-ASHP does not benefit from the $150-300 savings in fixed monthly charges from the gas utility.

The analysis shows that these homes would always save more money with a gas hybrid. The difference is minor in regions with moderate climates and/or higher gas prices, where the hybrid achieves savings of approximately $10-15 more than all-electric option.

But they are significant in colder regions and regions with lower gas prices. Here, the gas-hybrid equipment evaluated was shown to deliver economic savings relative to the all-electric CC-ASHP, because the smart controller can choose to operate either the heat pump or the gas furnace depending on which is cheaper. It was estimated that gas heated households in these regions would pay about the same each year with a gas hybrid as they would with a conventional gas furnace, while reducing their energy consumption and GHGs by about 30%. Those same households would pay $100-500 more each year if they installed an all-electric heat pump, and also continued to pay for gas service to the household.

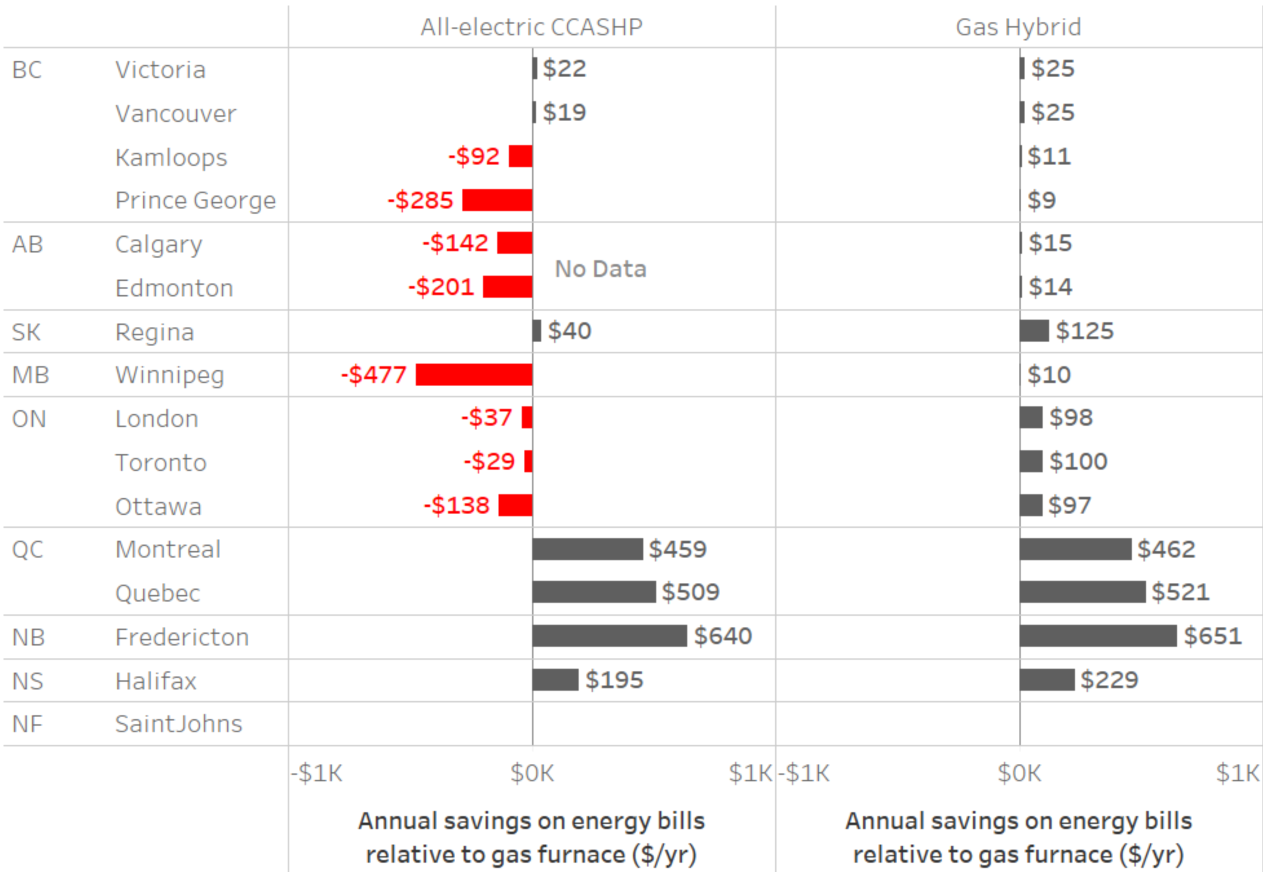

Figure 16: Comparison between all-electric CCSASHP and gas hybrid utility bill savings relative to gas furnace hybrid, assuming current (2020) energy pricing and continuation of gas service

Economic switchover temperatures

Relative to gas furnaces, the economics of heat pumps depend on four factors: the price of electricity, the price of gas, the gas furnace efficiency and the heat pump's coefficient of performance (which varies with outdoor temperature). Figure 17 illustrates the relationship of energy prices on the "break-even COP" — that is, the COP that a heat pump must achieve to be cheaper to operate than a gas furnace. The price of electricity is plotted on the horizontal axis, while the price of natural gas is plotted on the vertical axis. The green lines indicate different heat pump COPs; points along these lines correspond to combinations of electricity and gas prices where running a heat pump with specific COP is comparable to natural gas.

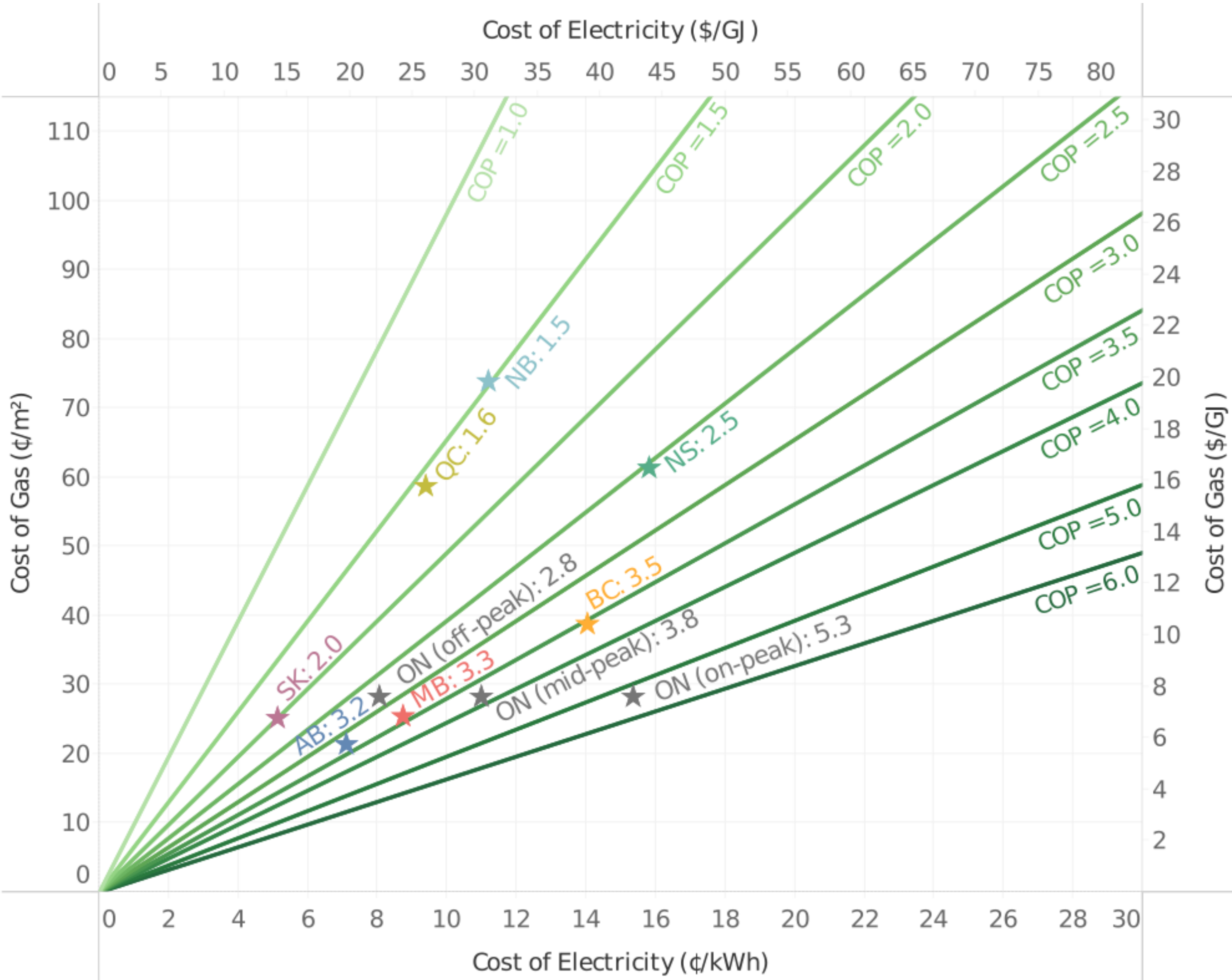

Figure 17: "Break-even COP" as a function of electricity and gas prices.

The stars indicate the current electricity and gas prices in each of the provinces that were examined. For Ontario, the plot includes separate stars for off-peak, mid-peak and on-peak periods.

Saskatchewan, Quebec, New Brunswick, and Nova Scotia have the lowest break-even COPs. This agrees with the findings described in Figure 9 (Section 5.1), in which the all electric CC-ASHPs save on utility bills in these jurisdictions regardless of whether the fixed charges associated with gas service are included or not.

Ontario, Alberta, Manitoba and BC all have break-even COPs of 2.8 or greater. In many Canadian climates, current CC-ASHP technology cannot achieve these COPs when performance is averaged over the entire season. For this reason, all-electric CC-ASHP systems may be more expensive to operate than gas furnaces in some regions in these provinces. Even so, homeowners opting for all-electric utility services may see net savings on utility bills (refer to Figure 10).

Those savings notwithstanding, CC-ASHP technology may still be financially attractive relative to gas in Ontario, Alberta, Manitoba and BC when homeowners chose to retain split gas and electric utility services. While an all-electric heat pump can not achieve the break-even COP over the entire heating season, there are portions of the heating season where temperatures are mild enough to exceed those COPs. This is a key idea behind gas-hybrid technology: homes should use heat pumps when they are more efficient and more economical to operate than gas. But when temperatures drop and heat pump efficiency declines, they switch to a lower-cost heating fuel.

5. Conclusions

This study examined the cost-effectiveness, energy savings and GHG reductions associated with the use of cold-climate air source heat pump systems in Canadian homes. CanmetENERGY researchers compared the operating costs of these systems to those of electric resistance, gas and oil furnaces for different parts of Canada, and for different types of housing.

Utility prices

Findings from this study largely depend on assumptions about utility rates. While energy prices are always subject to change over time, the ongoing COVID-19 pandemic contributes even more uncertainty because the downturn in economic activity has lowered energy demand.

To quantify the effect on utility prices, current prices that residential customers pay for electricity, natural gas and heating oil were first surveyed. Statistics Canada's Consumer Price Index was examined to understand how these costs have fluctuated over the last six months. From this investigation, it was concluded that current gas and electricity prices approximate pre-pandemic levels, but the price of heating oil had fallen by approximately 25%. Accordingly, a set of projected 2022 utility prices that reflect a) recovery in the price of heating oil and b) pending increases to federal and provincial carbon tariffs were developed.

Next, HOT2000 was used to estimate the heating loads associated with four Canadian housing archetypes varying from less efficient, pre-1980's construction to modern, Net-Zero Energy Ready (NZE-R) standards. From this data, a CC-ASHP sized to meet the design heating load (where possible) was selected from the range of capacities considered, and its energy consumption at every hour of the year was computed.

Savings from CC-ASHP technology

As expected, it was found that the CC-ASHP systems were much more efficient than comparable electric, gas and oil furnaces. Greenhouse gas emissions impacts varied according to the regional energy sources that are used to generate electricity. Even so, it was found that CC-ASHP technology delivers GHG reductions when replacing oil furnaces in all parts of Canada. CC-ASHPs also generate lower GHG emissions than gas furnaces in BC, MB, ON, QC and NB (refer to earlier notes with respect to seasonal marginal emissions factors, particularly in the case of Ontario).

Due to their higher efficiency, CC-ASHPs are more economical than electric resistance or oil furnaces to operate for space heating. Homeowners replacing electric furnaces with CC-ASHP systems could expect to save between $700-1900 each year on utility costs for the archetype homes evaluated. Homeowners choosing CC-ASHP systems over oil furnaces could expect to save between $1000 and $3500 annually based on current pricing and the archetype homes evaluated. If oil prices rise as economic activity resumes, those savings could exceed $5500/year in some cases.

The low cost of natural gas in many regions in Canada means that the cost of operating CC-ASHPs are more comparable to those of a conventional gas furnace. Two specific scenarios were considered when comparing CC-ASHPs to gas furnaces:

- the all-electric service scenario, in which the homeowner replaces all gas appliances in the home with electric equivalents, and suspends their natural gas service, and
- the split gas/electric scenario, in which the homeowner replaces the gas furnace with a CC-ASHP but retains their gas service for use by other appliances.

For the all-electric service scenario, results show that the CC-ASHP system is cheaper to operate than the gas furnace in most regions of Canada. Even though the gas consumed by the furnace costs less than the electricity used by the heat pump, the additional savings associated with forgoing the gas service (and avoiding fixed administration charges) are sufficient to make the CC-ASHP cheaper to operate.

However, homeowners who replace gas furnaces with all electric heat pumps but also elect to retain gas service would find that their utility bills increase by $100-$500/year in Ontario, Manitoba, Alberta and colder regions of British Columbia. Homeowners in other parts of Canada would still realize savings on utility bills.

Potential of gas hybrids

As part of this study, an alternate scenarios where CC-ASHP technology was combined with gas furnaces in a hybrid (or dual-fuel) configuration was examined. In this scenario, smart switching controls could choose from the lowest-cost heating source depending on the climate, equipment performance, building loads and energy prices.

Results suggest that the gas-hybrid configuration may be more attractive to homeowners who opt for split gas/electric service. In these scenarios, the hybrid technology costs less to operate than the gas-furnace and delivers 15-35 % reduction in energy use and GHG emissions.

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Appendix A: Heat Pump Performance

HP Performance data: 2 1/2 ton

Ambient	Capacity Factor		COP	
Temp.(°C)	Low	High	Low	High
-25.0	0.32	0.74	1.90	1.40
-15.0	0.41	0.94	2.24	1.76
-8.3	0.47	0.94	2.43	1.90
0.0	0.53	0.94	3.00	2.52
8.3	0.53	1.00	4.39	3.07
12.8	0.55	1.14	4.84	3.27
18.0	0.58	1.32	5.46	3.48

HP Performance data: 3 ton

Ambient	Capacity Factor		COP	
Temp.(°C)	Low	High	Low	High
-25.0	0.33	0.73	2.15	1.38
-15.0	0.38	0.95	2.54	1.82
-8.3	0.48	0.95	2.74	2.06
0.0	0.52	0.95	3.40	2.99
8.3	0.45	1.00	4.63	3.49
12.8	0.47	1.11	5.08	3.61
18.0	0.49	1.24	5.72	3.74

HP Performance data: 3 1/2 ton

Ambient	Capacity Factor		COP	
Temp.(°C)	Low	High	Low	High
-25.0	0.39	0.67	1.79	1.46
-15.0	0.39	0.89	2.25	1.91
-8.3	0.48	0.89	2.44	2.09
0.0	0.53	0.90	3.02	2.43
8.3	0.35	1.00	4.28	3.25
12.8	0.39	1.11	4.71	3.35
18.0	0.44	1.24	5.22	3.45