Energy and Economic Performance of Cold-Climate Air-Source Heat Pumps for Three Commercial Building Archetype Models

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Abstract

Three National Energy Code for Buildings (NECB) 2017 archetypes models (small office, full-service restaurant, and 4-storey multi-unit residential buildings) are modified to use cold-climate air-source heat pump (CCASHP) air systems. The predicted energy consumptions using the Building Technology Assessment Platform (BTAP) of the three archetypes is lower for CCASHP systems compared to the NECB 2017 baseline. However the cost of electricity is higher than natural gas, therefore heating ventilation with a CCASHP compared to a gas-fired unit, was not cost effective. The high capital cost of CCASHP systems makes it difficult to achieve a reasonable payback period for most locations. Payback years are more attractive for locations such as Halifax where the price difference between natural gas and electricity is reduced. Net-Present Values for CCASHP systems are relatively close to the baseline for many cases, which could make these systems attractive if they can help reduce Green-House Gas (GHG) emissions.

Introductions

The use of air-source heat pumps in cold-climates for space heating has been limited due in large part to the fact that this technology does not operate below a certain cut-off temperatures. In addition, the capacity and COP of the heat pump decreases significantly as the temperature decreases. Recent advances in heat pump technology, using variable speed compressors, have adjusted the cut-off outdoor temperature to -25 °C and below. According to the National Energy Regulator of Canada (2018), the number of installed heat pumps has been steadily increasing since the year 2000 and most of these installations are air-source heat pumps. The advances in cold-climate heat pump technology will help further increase the adoption of air-source heat pumps in the built environment of cold climates.

Tamasauskas et al. (2018) studied the energy and cost performance of a cold-climate air-source heat pump based system relative to an NECB 2011 small office archetype building. The baseline NECB 2011 building had a roof-top unit with DX coil for cooling (rated COP = 3.9) along with a natural gas furnace (rated efficiency = 80%). The performance of the CCASHP DX coils was based on data reported by Mitsubishi Electric for their City Multi Variable-Refrigerant Flow heat pump. The CCASHP unit had a backup electric heater sized to 100% of the peak load, and the DX heating coil was sized for 60% of the peak load. The minimum temperature for the DX heating coil operation was -25 °C. The authors reported energy and economic performance data for five different Canadian locations (Halifax, Montreal, Toronto, Vancouver, and Whitehorse). The savings for the HVAC related end-use energy relative to NECB2011 ranged from 25% to 34%. The economic analysis is showed that CCASHP technology in this case was not economical when compared to the baseline due to the low cost of natural gas. The increased cost of CCASHP technology was smallest in places such as Montreal where the unit price difference between electricity and natural gas was smallest. The cost difference increased in areas such as Whitehorse, which had higher electric demand charges.

This study deals with energy and economic performance of small office, full-service restaurant (FSR), and 4-storey multi-unit residential (MURB) building archetypes with CCASHP systems for nine Canadian locations. The archetypes are compliant with the performance path of the Canadian National Energy Code for Buildings 2017.

National Energy Code for Buildings of Canada Archetype Models

The Canadian commercial building archetypes are based on the USDOE commercial building archetypes (National Renewable Energy Laboratory 2011). The USDOE archetypes are modified in accordance with the performance path of the NECB 2017. The energy code specifies rules for assigning HVAC systems for each space type and number of stories. A default fuel source is assumed for each of the locations based on the predominant fuel in the province. The creation of the archetypes based on the initial geometry files is automated using BTAP.

Three of the commercial building archetypes small office, full-service restaurant, and 4-storey MURB are used in the current study. The small office has a floor area of 511.1 m^2 and has one storey with four perimeter zones and one core zone with an NECB 2017 "office-enclosed" space type. Each of the zones is served by a roof-top unit. Table 1 shows the source of heating and cooling for this building for the various locations. The cases with hot-water heating have baseboards connected to a plant loop with one or two boilers and a pump. Zone electric heating is provided by electric baseboards.

Table 1: Air-system and zone heating and cooling sources for Small Office and Full-Service Restaurant archetypes

City	Sys Htg	Sys Clg	Zone Htg	Zone Clg
Calgary	Gas	DX	HW	none
Halifax	Gas	DX	HW	none
Montreal	Electric	DX	Electric	none
Ottawa	Gas	DX	HW	none
Saskatoon	Gas	DX	HW	none
Toronto	Gas	DX	HW	none
Vancouver	Electric	DX	Electric	none
Winnipeg	Electric	DX	Electric	none
Yellowknife	Electric	DX	HW	none

"Sys Htg": System Heating; "Sys Clg": System Cooling; "HW": Hot-Water; "DX": Direct-Expansions

The full-service restaurant archetype with a floor area of 511.1 m^2 is one storey with one zone for a dining area and another zone for food preparation. The HVAC system and the source of heating and cooling is the same as that for small office archetype shown in Table *1*.

The 3rd archetype considered is a 4-storey MURB with a floor area of 3134.6 m^2. The 1st storey of the building has 7 apartment suites, a corridor, and an office. The three other storeys each has a corridor and eight apartment suites. The corridors and the office are served each by a single roof-top unit with DX cooling with either hot-water or electric baseboards in the zones. A single dedicated-outside air system (DOAS) serves all the apartment suites on the three floors. The DOAS delivers air at 20 °C to the suites. The HVAC and source of heating and cooling are shown in Table 2.

All of the HVAC components are autosized by OpenStudio/EnergyPlus. The only exceptions are boilers and chillers where NECB stipulates the use of two units of equal size above a certain autosized capacity requirement.

A total of 9 locations across Canada are selected to present the data for the impact of cold-climate heat pump air systems on the NECB 2017 baseline end-use HVAC energy consumption. The dominant fuel source is electricity in Montreal, Winnipeg, Vancouver and Yellowknife. Natural gas is the dominant fuel source in Calgary, Halifax, Ottawa, Toronto, and Saskatoon.

Table 2: Air-system and zone heating and cooling sources for the MURB archetype

City	Sys Htg	Sys Clg	Zone Htg	Zone Clg
Calgary	Gas	DX	HW	PTAC
Halifax	Gas	DX	HW	PTAC
Montreal	Electric	DX	Electric	PTAC
Ottawa	Gas	DX	HW	PTAC
Saskatoon	Gas	DX	HW	PTAC
Toronto	Gas	DX	HW	PTAC
Vancouver	Electric	DX	Electric	PTAC
Winnipeg	Electric	DX	Electric	PTAC
Yellowknife	Electric	DX	HW	PTAC

"Sys Htg": System Heating; "Sys Clg": System Cooling; "HW": Hot-Water; "PTAC": Packaged-Terminal-Air Conditioner

Modelling CCASHP Air-System in EnergyPlus/OpenStudio

The heating mode of the CCASHP is modelled in EnergyPlus/OpenStudio using the HVAC component 'Coil:Heating:DX:VariableSpeed'. According to the Engineering Reference of the EnergyPlus engine (US sss Department of Energy 2018), this component represents the heating capacity at certain operating conditions *HCAP* with the equation:

$$HCAP = HCAPFT \times HCAPFF \times HCAP_{rated} \quad [1]$$

where the temperature and airflow modifier functions are given by:

$$HCAPFT = a_0 + a_1 T_{idb} + a_2\, T_{idb}^2 + a_3 T_{odb} + a_4 T_{odb}^2 + a_5 T_{idb} T_{odb} \quad [2]$$

$$HCAPFF = a_0 + a_1 FR + a_2 FR^2 \quad [3]$$

T_{idb} is the inside inlet air dry-bulb temperature, T_{odb} is the outdoor air dry-bulb temperature, and FR is the actual to design air flow ratio.

The Heating Energy-Input Ratio is given by:

$$HEIR = HEIRFT \times HEIRFF \times HEIRFPLR \times HEIR_{rated} \quad [4]$$

where the temperature, airflow, and part-load modifier functions are given by:

$$HEIRFT = a_0 + a_1 T_{idb} + a_2\, T_{idb}^2 + a_3 T_{odb} + a_4 T_{odb}^2 + a_5 T_{idb} T_{odb} \quad [5]$$

$$HEIRFF = a_0 + a_1 FR + a_2 FR^2 \quad [6]$$

$$HEIRFPLR = a_0 + a_1 PLR + a_2 PLR^2 \quad [7]$$

The cooling mode of the heat pump is modelled with component 'Coil:Cooling:DX:VariableSpeed' in

OpenStudio/EnergyPlus. In this case the total cooling capacity is:

$$CCAP = CCAPFT \times CCAPFF \times CCAP_{rated} \quad [8]$$

where,

$$CCAPFT = a_0 + a_1 T_{iwb} + a_2 T_{iwb}^2 + a_3 T_{odb} + a_4 T_{odb}^2 + a_5 T_{iwb} T_{odb} \quad [9]$$

$$CCAPFF = a_0 + a_1 FR + a_2 FR^2 \quad [10]$$

T_{iwb} is the inside inlet air wet-bulb temperature.

The Cooling Energy-Input Ratio is given by:

$$CEIR = CEIRFT \times CEIRFF \times CEIRFPLR \times CEIR_{rated} \quad [11]$$

where,

$$CEIRFT = a_0 + a_1 T_{iwb} + a_2 T_{iwb}^2 + a_3 T_{odb} + a_4 T_{odb}^2 + a_5 T_{iwb} T_{odb} \quad [12]$$

$$CEIRFF = a_0 + a_1 FR + a_2 FR^2 \quad [13]$$

$$CEIRFPLR = a_0 + a_1 PLR + a_2 PLR^2 \quad [14]$$

PLR is the Part-Load Ratio of the unit.

The heating and cooling performance data for the Mitsubishi Citi Multi VRF Hyper-Heating outdoor unit, sample shown in Figure 1 and Figure 2 is used to generate the correlation coefficients (a_i) for *HCAPFT*, *HEIRFT*, *CCAPFT*, and *CEIRFT*. In these figures the Coefficient-Of-Performance Ratio *COPR* is shown instead of the Energy-Input Ratio *EIR*. Correlation coefficients for *HEIRFPLR* and *CEIRFPLR* equations are from Technical Note from Mitsubishi Electric USA (Brackett and Vaughan 2017). EnergyPlus/OpenStudio defaults are used for the remaining performance curves to account for the effect of airflow.

The EnergyPlus model requires as input the minimum outdoor temperature for compressor operation in heating mode. The Mitsubishi City Multi VRF technology used to generate the performance curves can operate down to -25 °C, which is used to generate the results in this study.

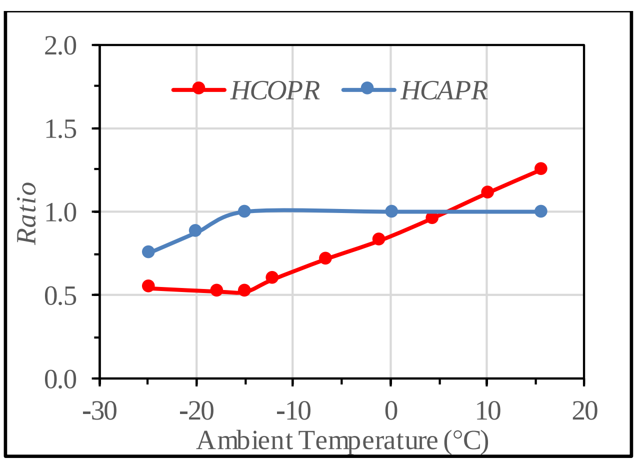

Figure 1: Variation of capacity and COP ratios in heating mode for Mitsubishi City Multi VRF outdoor unit (T_{idb} = 21.1 °C)

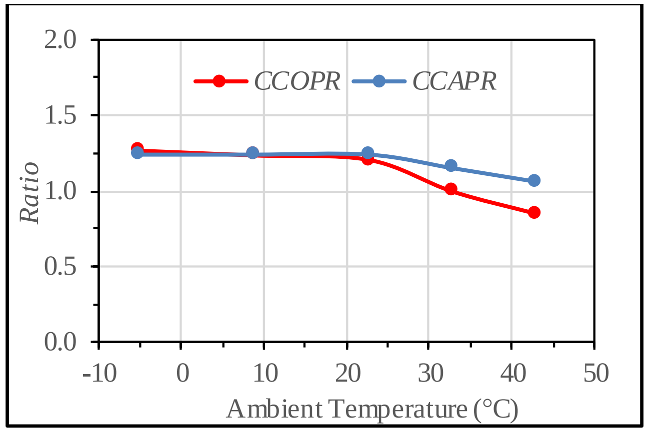

Figure 2: Variation of capacity and COP ratios in cooling mode for Mitsubishi City Multi VRF outdoor unit (T_{iwb} = 23.9 °C)

Performance Data for CCASHP

As indicated previously the EnergyPlus models for the components used to represent the heat pump use correlations for capacity and Energy-Input Ratio *EIR*. In this section the performance data used in the analysis of the cold-climate air-source heat pump is presented. The data for *EIR* is presented using the Coefficient-Of-Performance Ratio *COPR*, which is the inverse of *EIR*.

Air-handling units (AHU) with cold-climate heat pump technology don't seem to be available on the North American market as off-the-shelf products (Tamasauskas et al. 2018). However, it is possible to fit an AHU with a direct expansion coil connected to a separate Variable-Refrigerant Flow (VRF) outdoor unit. A supplemental electric heater is also included in the AHU. Warm or cold air from the AHU is then delivered to each of the zones served by the air system.

The ratios of the capacity to the rated capacity (*HCAPR*) and the *COP* to the rated *COP* (*HCOPR*) in the heating mode of the CCASHP are a function of indoor and outdoor dry-bulb temperatures as shown in Figure *1*. The figure shows that the heating capacity remains constant down to an outdoor temperature of -15 °C and the minimum temperature for operation is -25 °C. Figure 2 shows the variation of capacity and *COP* ratios for the cooling mode. The capacity and *COP* ratios temperature dependence data used is for a Mitsubishi City Multi VRF Hyper-Heating unit (*CCAP* = 21.1 kW; *HCAP* = 21.1 kW). The cooling and heating capacities of the units range from 5.3 to 56.3 kW and from 6.4 to 63.3 kW, respectively. While the cooling and heating *COP* range from 3.1 to 4.1 and from 3.4 to 4.1, respectively. The *COP* generally decrease as the size of the units increases.

It is possible that a building archetype requires heat pump capacities greater than those of the largest sized Mitsubishi model available on the market. In this case the performance of the largest unit is used in the analysis. Outdoor VRF units vary the speed of the compressor depending on the load with a minimum turn down ratio. Figure 3 shows the variation of the COP of the outdoor VRF unit with the part-load ratios.

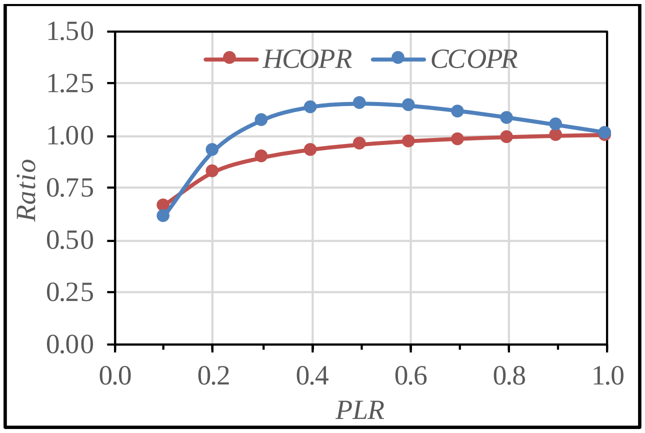

Figure 3: COP ratio variation with Part-Load Ratio

OpenStudio Measure for CCASHP Air-Systems

The OpenStudio measure developed modifies the NECB 2017 office building archetype models to use an air system with CCASHP with electric backup, reheat coils, and baseboards. The measure scans the model and removes the existing heating and cooling coils from the air system. Then new DX heating and cooling coils and a backup electric heater are added to the air loop. Mixed air enters the cooling coil first, then the heating coil, then the backup coil, and finally the fan. In addition, the user can select to change any terminal reheat coils and baseboards to electric. The measure then performs a sizing run and then the estimated capacities of the DX coils are used to set the *COP* based on performance data for the Mitsubishi VRF units. The measure also assigns the proper performance curves.

The arrangement of the heating coils in the CCASHP air system results in the use of the DX heating coil first and then the backup electric coil to meet the remaining heating load of the air system. The DX coil does not operate when the outdoor temperature falls below -25 °C and the back-up electric heater meets the full load.

EnergyPlus by default sets the size of the system DX heating coil capacity to the cooling capacity. The measure overrides this default approach by setting the DX coil heating capacity to the maximum of the cooling capacity and 50% of the supplemental heater capacity. The effect of defrost cycle is neglected in this study.

The NECB archetypes have zonal baseboards as stipulated by the energy code performance path. Zonal electric baseboards are then used with the CCASHP air system. Usually baseboards are used to help maintain comfortable conditions inside the space by warming colder surfaces in the building envelope especially next to the windows.

Energy Costing Methodology

The energy costing uses 2020 average consumption pricing for natural gas, oil and electricity as published by the National Energy Regulator of Canada per province. Block and schedule rates, time of use rates, fixed charges, and demand charges are not included in this analysis. The NEB average Canadian 2020 rates were: $33.76/GJ for electricity, $7.11/GJ for natural gas and $35.53/GJ for oil.

BTAP provides the equipment sizing information for each system in the building. The simulation also determines the heating size capacity required for each thermal zone. For costing BTAP uses a 935 watt electric baseboard reference to determine the number of baseboards in each zone. BTAP costs hydronic heating using the zone heating capacity and determines the length of fin-tubed hot water convectors (425 watts per linear foot using a hot water supply temperature of 82 °C and a copper tube diameter of 31.5 mm) to a maximum of 2.43 meters.

Other aspects of the baseline HVAC, such as boilers, chillers, heat rejection, pumps, piping, pipe insulation, pipe connections and valves and gas utility services were also costed.

To assess the effectiveness of the CCASHP air system, the ventilation system's heating device and cooling device was replaced with a DX heating/cooling coil connected to the outdoor VRF unit. The balance of the ventilation system (fan, controls, enclosure, ducting and distribution) remained unchanged and matched the baseline. The CCASHP option did require a backup electric heater in the ventilation system, sized for heating design conditions, as the CCASHP has a -25 °C cut-off temperature. The CCASHP option still requires zone heating when the ventilation system is scheduled off, similar to the baseline.

The comparable capital cost for the baseline is the cost of the DX or chilled water coil, the electric, gas/oil furnace or hot water coil for each air handler plus the cost of the boiler, chiller cooling tower, pumps, flues, boiler/chiller/tower piping, wiring and utility connection plus the cost of the zone heating devices (electric baseboards, convectors, piping, accessories). The comparable capital cost for the CCASHP option is the cost of the DX heating/cooling coil and outdoor VRF unit plus the cost of the electric backup heater for each air handler and the cost of the electric baseboards in each zone. The method followed to cost the CCASHP system is similar to the approach adopted by Tamasauskas et al. (2018).

The difference between the two previous costs is the estimated net incremental capital construction cost for the CCASHP system option.

Results and Discussion

Energy Consumption

Error! Reference source not found. shows the percentage reduction relative to the NECB 2017 base case in the total

HVAC energy consumption for the three building types when CCASHP air system is used. The HVAC energy accounts for site energy for heating, cooling, fans, pumps, heat recovery, and heat rejection end-uses.

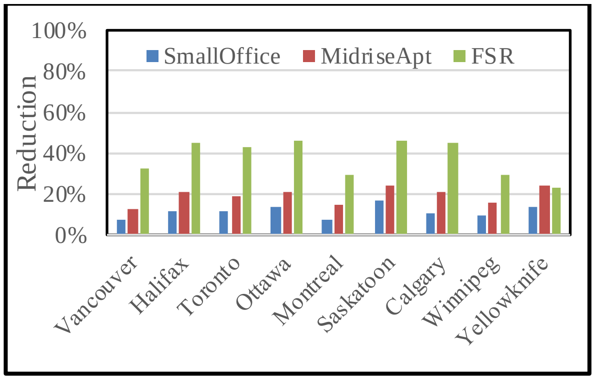

Figure 4: Percentage reduction in total HVAC energy with the use of CCASHP air system for three archetypes

The relative savings in energy consumption are largest for full-service restaurant ranging from 22.7% in Yellowknife to 45.7% in Ottawa and Saskatoon. This archetype has a dining area with a very high outdoor air fraction in the air system, which increases the energy reduction in this case when a CCASHP is used. Yellowknife has the coldest weather among the nine locations which increases the portion of the heating demand provided by the backup electric heater of the air system.

The 4-storey MURB has the next highest relative savings ranging from 12.7% in Vancouver to 24.3% in Yellowknife. In this case the cooling demand is a larger portion of the total end-use. The CCASHP has a lower cooling COP than NECB 2017 DX cooling. As a result Yellowknife with the lowest fraction of cooling demand is associated with the greatest relative savings in energy. The small office has the lowest savings from 7.1% in Montreal to 16.9% in Saskatoon. This archetype has the lowest outdoor air fraction among the three building types considered.

The percentage reductions in **Error! Reference source not found.** are lower for locations where the base case uses electricity for heating. This happens to be the case in Montreal, Vancouver, and Winnipeg as shown in Table 1 and Table 2. The NECB efficiency for gas boilers and furnaces is of the order of 80% compared to 100% for electric heating. In addition, the longer the heat pump operates instead of the backup coil the larger the savings will be.

The reductions in HVAC energy use with CCASHP reported in **Error! Reference source not found.** can be further increased by using the CCASHP air system to also provide the heating energy provided currently by the zonal baseboards. However, there is increased potential in this case for cold drafts next to the windows in the zones.

The HVAC energy consumption for the baseline and the CCASHP buildings for all locations considered are shown in **Error! Reference source not found.** through **Error! Reference source not found.**. As expected higher energy consumption are predicted in general for colder climates.

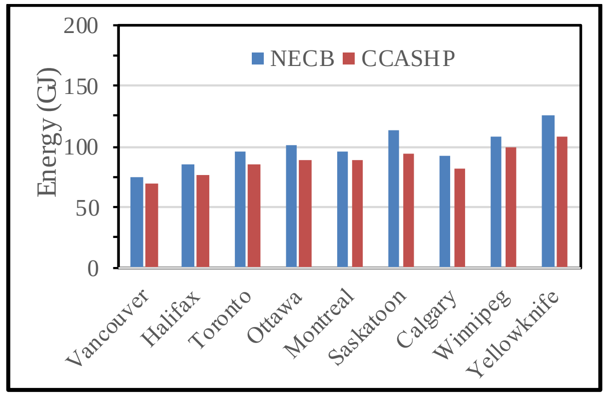

Figure 5: Small Office total HVAC energy consumption for various locations

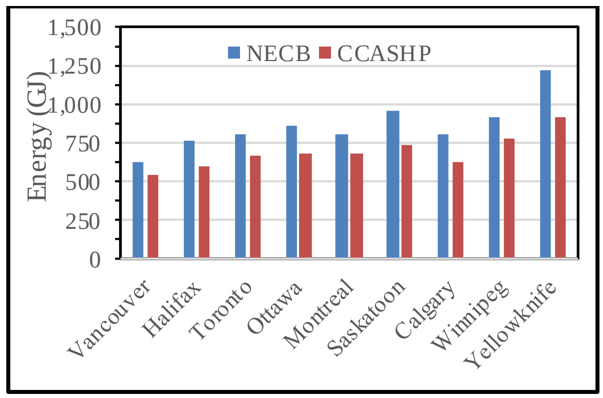

Figure 6: 4-storey MURB total HVAC energy consumption for various locations

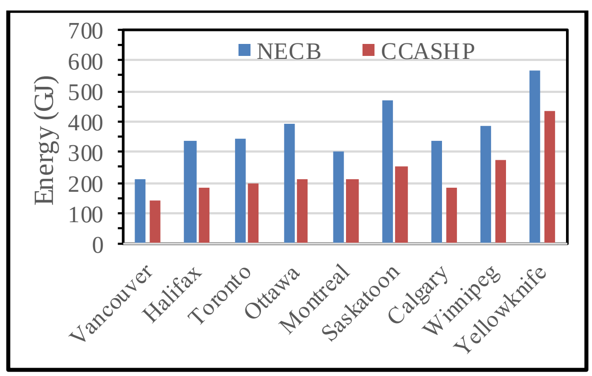

Figure 7: Full-Service Restaurant total HVAC energy consumption for various locations

Economic Analysis

Energy Cost**:** The energy costs are for end-use energy for heating, cooling, fans, pumps, heat recovery, and heat rejection. The three office building archetypes energy costing results are shown in **Error! Reference source not found.** through **Error! Reference source not found.**.

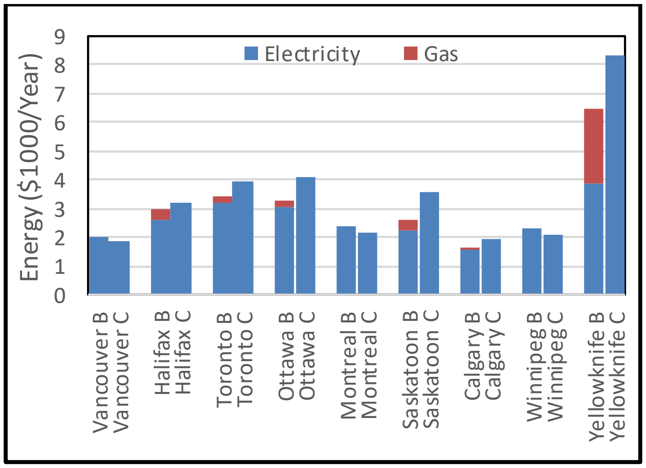

Figure 8: Small Office annual HVAC energy cost (B: Baseline; C: CCASHP)

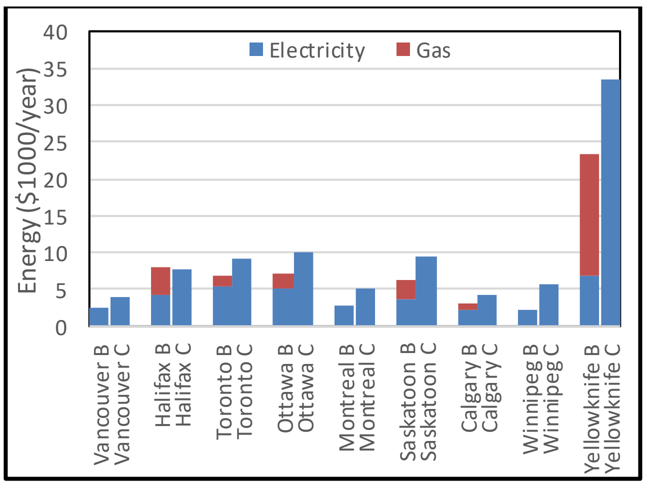

Figure 9: Full Service Restaurant annual HVAC energy cost (B: Baseline; C: CCASHP)

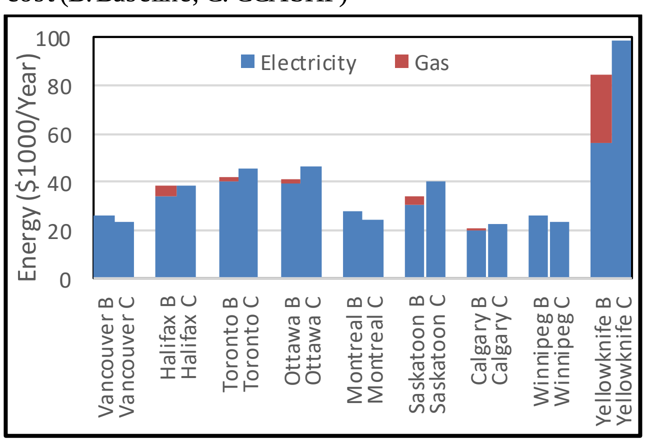

Figure 10: 4-storey MURB annual HVAC energy cost (B: Baseline; C: CCASHP)

Given that natural gas is significantly less expensive compared to electricity in most of Canada, the CCASHP option has higher utility costs than a gas heated building, even with 20-30% annual energy savings. Small single storey offices in Vancouver, Winnipeg and Montreal exhibited energy cost savings, but this is mainly due to the CCASHP outperforming an all-electric HVAC system. Halifax was the only city where a CCASHP offered utility cost savings compared to natural gas in full service restaurants. This is due to the large ventilation load of restaurants and fairly high natural gas prices in Halifax. Again in the 4-storey MURB, CCASHP offered cost savings in Vancouver, Winnipeg and Montreal due to an all-electric comparison. The energy cost differences between gas heating/DX cooling and CCASHP heating/cooling was reduced in the MURB archetype due to the continuous operation of the ventilation systems.

Capital Cost: As described in the methodology, the construction costs are net incremental capital costs of the CCASHP system compared to the NECB 2017 baseline system for only the heating and cooling system. The system includes the distribution piping and hydronic convectors for the NECB hot water baselines. Gas and oil heated archetypes will include hot water perimeter heating, whereas electric heated archetypes will include electric baseboard perimeter heating. The CCASHP option always uses electric baseboard perimeter heating.

The installed capital cost of the CCASHP averages about $13.5K for a 14 kW unit. This cost include the condenser, low temperature kit, VRF controller, condenser remote control, EV valve and balancing. It is assumed that the refrigerant line from the condenser to the air handling unit for both the baseline and CCASHP option is identical. The capital costs for the 3 archetypes are shown in Figure 11 through Figure 13.

In the small office case (Figure 11), the 5 baseline rooftop system DX unit/gas-fired furnaces or DX unit/electric coil were replaced with 5 CCASHP with a backup electric heater and a refrigerant coil. CCASHP systems are cost prohibitive for small offices due to a large back-up electric heater and due to the operating schedule of offices.

The full service restaurant reference system is a make-up air unit for the dining area and a packaged roof-top unit for the dining area. The capital cost of the CCASHP and back-up electric heating device is too expensive compared to the make-up air unit or packaged roof-top unit with DX cooling and gas/electric heating. The high ventilation requirements of restaurants required high capacity ventilation equipment and CCASHPs. The costs of this system was 50 to 100% greater than the reference.

The MURB capital cost differences were not as great. The ventilation loads were smaller per occupant than the other archetypes, thereby requiring the smallest ventilation systems and corresponding CCASHP. If, the MURB was heated with gas/oil, the cost of the boiler, pumps, piping was almost identical to the cost of the CCASHP. When the cost of the ventilation cooling is added, there is a capital cost balance with the CCASHP.

In all cases the cost of a gas line to the boiler and to the roof-top units has been included in the baseline, which is a cost saving for the CCASHP option. Certain items such as electrical service cost differences between the baseline and the CCASHP option have not been included. The costs presented in Figure 11 through Figure 13 represent the major HVAC capital cost item differences between the baseline and CCASHP option.

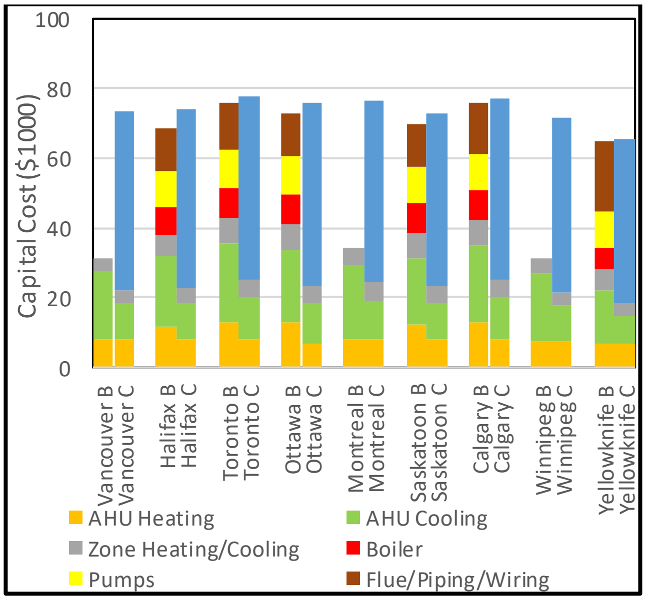

Figure 11: Small Office HVAC system capital costs (B: Baseline; C: CCASHP)

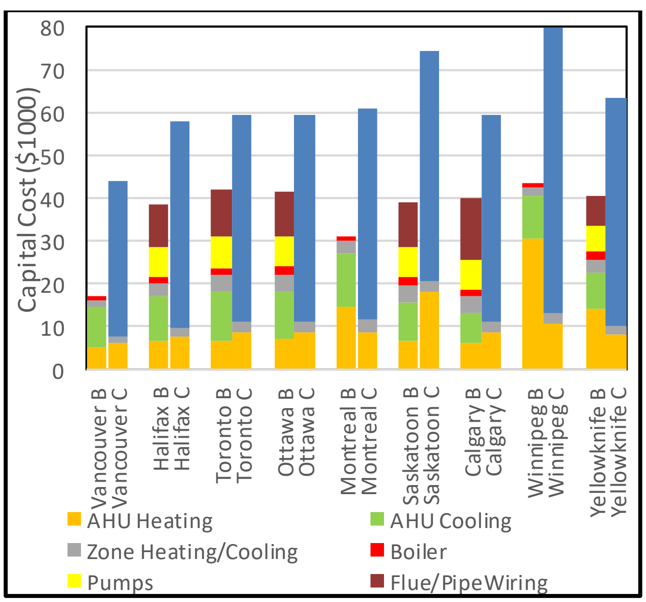

Figure 12: Full-Service Restaurant HVAC system capital cost (B: Baseline; C: CCASHP)

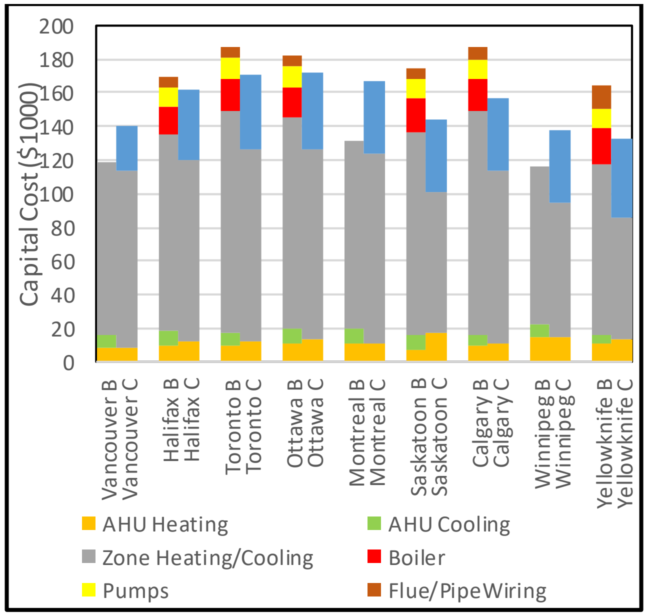

Figure 13: 4-storey MURB HVAC system capital costs (B: Baseline; C: CCASHP)

The economic assessment uses the annual energy cost savings and the incremental capital cost of the CCASHP option to determine a simple payback period. This is presented in **Error! Reference source not found.**.

A "null" value means a payback is not possible as the annual energy cost savings of the CCASHP option is negative. This occurs in cities with low natural gas or oil pricing compared to electricity. For example, 2020 rates in Ontario were $7/GJ for gas and $46.31/GJ for electricity, or 6 times higher. Given that the CCASHP option also has a capital cost greater than the baseline, in addition to costing more to operate, a payback is not possible. A CCASHP option is possible only in Nova Scotia, as the price gap between natural gas and electricity is reduced. The electric baselines have high payback periods due to the capital cost of the CCASHP compared to the baseline. An "instant" payback occurs when the capital costs of the CCASHP is less than the capital cost of a boiler hydronic system and roof-top gas/DX systems, which occurred in the MURB archetype.

Table 3: Payback Period (years) for CCASHP

	Small Office	Full Service Restaurant	4-Storey MURB
Vancouver	266.9	null	9.5
Halifax	14.5	4.9	instant
Toronto	null	null	instant
Ottawa	null	null	instant
Montreal	251.3	null	11.8
Saskatoon	null	null	instant
Calgary	null	null	instant

Winnipeg	185.5	null	6.8
Yellowknife	null	null	instant

Another method to compare involves a Net-Present Value (NPV) calculation. This is presented in Table 4. This approach projects the annual utility costs into the future using the National Energy Regulator utility pricing escalation per province and then using a discount rate (3.22%) converts this cost stream to a value today and then subtracts the incremental capital cost to hopefully attain a positive value. The annual utility costs were projected 15 years using NER escalations. A ratio of less than 1 indicates a positive return beyond 15 years. This was only possible in the MURB comparison against gas-fired hydronic systems. In all other cases, the NER electricity yearly escalations were usually higher than natural gas resulting in a poor NPV for the all electric CCASHP option. While a CCASHP saves energy (GJ), the price difference between natural gas and electricity, and the high capital cost of a CCASHP results in a difficult economic case. Other non-price factors, such as greenhouse gas emission reduction or electrification of new construction would have to be considered. Also, the capital cost of CCASHP could be reduced as this technology gains market acceptance.

Table 4: CCASHP NPV to baseline NPV ratio results

	Small Office	Full Service Restaurant	4-Storey MURB
Vancouver	2.32	2.58	1.16
Halifax	1.08	1.43	0.96
Toronto	1.02	1.38	0.93
Ottawa	1.04	1.40	0.95
Montreal	2.21	1.99	1.24
Saskatoon	1.05	1.62	0.83
Calgary	1.02	1.45	0.85
Winnipeg	2.26	1.87	1.16
Yellowknife	1.02	1.5	0.86

Conclusions

Three NECB 2017 archetype OpenStudio models for small office, full-service restaurant, and midrise MURB are modified to use a cold-climate heat pump in the air system. Energy consumptions and costs are then estimated for 9 Canadian locations.

The relative savings in energy using CCASHP compared to NECB baseline are greatest for the full-service restaurant and lowest for Small Office. These two building types have the highest and lowest outdoor air fractions, respectively.

The cost estimates show that the CCASHP system, as considered, offers an attractive payback for MURBs. Halifax is the outlier, as it offer a reasonable payback for all archetypes due to a reduced price difference between electricity and natural gas.

Net-Present Value for the CCASHP system are consistently higher than the baseline for small office and full-service restaurant. In the cases where the baseline has a boiler plant, the two values are relatively close which could make the CCASHP system attractive if it is also associated with lower GHG emissions. For the MURB the NPV is actually lower than the baseline for locations requiring a boiler plant in the NECB building.

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