Air Source Heat Pump Systems – A CO_2 Emissions Analysis

April 24, 2017
Revision: 2

Prepared for:
Enbridge Gas Distribution and Sustainable Buildings Canada

Contents

Executive Summary

A study was conducted to evaluate the carbon emission impact of air-source heat pump based HVAC systems in comparison to traditional natural gas furnace HVAC systems in single-family homes in Ontario. To do this, twelve hourly energy models were created to evaluate three different home types, each with four different HVAC systems.

The three homes types were a large 2-story detached home, a medium 2-story detached home, and 3-storey interior row house as part of a 6-unit building. Each house model assumed typical construction building standards. The following four HVAC and DHW system types were then applied:

1. Conventional HVAC System (Gas furnace, Gas DHW, and DX air conditioning)
2. Air-Source Heat Pump [ASHP] (Electric back-up, Electric DHW)
3. Air-Source Heat Pump [ASHP] (Gas back-up, Gas DHW)
4. Variable Refrigerant Flow Air Source Heat Pump [VRF ASHP] (Gas back-up, Gas DHW)

For all ASHP systems, the ASHP capacity was selected based on the cooling load, ensuring that that capital costs of the ASHP system would be relatively comparable to a conventional gas furnace HVAC system. It is noted that ASHP system sizing directly influences the amount of back up heating required when the heat pump is not capable of meeting the full heating load.

The annual hourly energy use developed by each model was then used to calculate operating costs(based on current electricity and natural gas utility rates), and carbon emissions, based on both specific hourly generation source energy data (provided from the IESO), and assuming a marginal energy generation source of natural gas only.

The results and highlights of the study:

- From a site energy use perspective, all the models using ASHP systems (2, 3, and 4) consumed less energy than the model using the conventional natural gas furnace HVAC system (1). This is as expected as the energy efficiency of an ASHP, the COP, is by definition greater than that of natural gas based system efficiency. The lowest energy use scenario in all cases was for system 4, Variable Refrigerant Flow Air Source Heat Pump [VRF ASHP] (Gas back-up, Gas DHW).

- From an annual operating cost perspective, System 1, the Conventional HVAC System (Gas furnace, Gas DHW, and DX air conditioning) was the lowest in all cases. This is due to the significantly higher cost for electrical energy as compared to natural gas energy. HVAC system 2 had the highest operating cost. The operating cost differential however was less significant where back-up systems for the ASHP HVAC were natural gas. In this case, the model was able to combine the advantage of the ASHP efficiency and the lower natural gas costs.

- Using the specific hourly generation mix provided by the IESO resulted in lower CO_2 emissions for all the ASHP based HVAC systems. The current mix of electricity generation in the province is primarily from zero-carbon sources, primarily nuclear, and hydro, with some renewables (wind and solar). Only about 10% of the recent electricity mix in Ontario was provided by fossil fuel (natural gas) generation. Essentially, as the use of electricity increases, the CO_2 emissions decreases. As result, HVAC system 2, the all-electric system showed the lowest CO_2 emissions.

- Emission calculations were also conducted using a marginal natural gas generation. This is consistent with the Ontario Building Code's Supplementary Standard SB-10 for carbon emission compliance. This approach is used to recognize that while the majority of today's generation mix is nuclear and large hydro (over 80%); much of the new electrical load will require new supply essentially assumed natural gas dominated. Under this approach, HVAC system 2 goes from best to worst in CO_2 emissions, and there is minimal difference between the conventional system (1) and the ASHP systems with natural gas back-up (3 and 4).

The study's results highlight the significant impact that generation mix assumptions have on the forecasted CO_2 emissions. In the study, two electricity generation mix assumptions were used; one that represents the current specific hourly generation mix, and one that represents an all-natural gas generation mix for new load. Neither represent the true situation and further discussion and study is necessary to better quantify the CO_2 emission impacts of ASHP in new housing. In particular, projections of emissions factors that accommodate the expected use of the natural gas as a generation fuel should be more fully investigated as it is understood that other generation sources may also provide peak power in the future.

Additional study is also recommended to better understand the impact and optimum ASHP sizing in relation to the heating load from both a cost/benefit and C02 emission perspective.

Background

Ontario has recently announced the Climate Action Plan, which includes a variety of strategies and targets to reduce the carbon emissions in the province. As outlined in the Climate Change Action Plan, "Buildings, and the energy they consume, account for almost one quarter of Ontario's total greenhouse gas pollution,". Ontario has committed to encouraging housing to take advantage of both new and existing technologies to help reduce emissions. One existing home HVAC technology identified to potentially reduce carbon emissions and help in meeting these targets, is air-source heat pumps.

Conventional single-family and row house HVAC design in southern Ontario utilizes a gas furnace forced air system for heating with an electric direct expansion (DX) air conditioning unit. With an air-source heat pump system (ASHP), the basic DX central air conditioning system is replaced by the ASHP system that would meet the home's cooling load as well as provide for some or the entire heating requirement.

Both the DX central air conditioning system and the ASHP operate on the basic vapor compression cycle, which uses the refrigerant in the system to extract heat from one environment and transfer it to another. In cooling, both the DX system and the ASHP extract heat from indoor air and transfer it to the outdoors. If heating is required, the ASHP can reverse this cycle, extracting heat from the outdoor air and transferring it to the indoor space. In heating with an ASHP, the heating source is converted from natural gas to electricity.

In regards to carbon, the current mix of electricity generation in the province is primarily from zero-carbon sources, mainly nuclear and hydro, with some renewables (wind and solar). Nuclear and hydropower often provide over 80% of the Province's electricity operating as the base load generation. Wind, solar, and biofuel provide power when available and the remaining load is provided by natural gas generation. As power demand peaks in the Province, the percentage of power provided by natural gas typically increases, subsequently increasing the carbon intensity of the electricity supply.

Sustainable Buildings Canada has retained EQ Building Perfoemance Inc. to evaluate the net source carbon emissions and energy costs of both conventional (natural gas furnace) and air-source heat pump systems using hourly energy-use models of archetype low-rise houses. The hourly electricity and gas demand predicted by the energy models is then matched to recent hourly generation source grid data, provided by the IESO (Independent Electricity System Operator) under various scenarios, to calculate carbon emissions.

Air Source Heat Pumps

For space heating, ASHPs operate more efficiently than standard electric resistance heating as the heat that they deliver to the indoor space is a combination of the purchased source energy and the energy transferred from the outdoor air. This efficiency is referred to as the Coefficient of Performance (COP). A COP of 3 for example, means that for every single unit of energy purchased, 3 units of energy is transferred from the outdoor space to the indoor space. For example:

$$COP = \frac{\text{Delivered Energy}}{\text{Purchased Energy}} = \frac{\text{(2 units of transferred energy + 1 unit of purchased energy)}}{\text{1 unit of purchased energy}} = 3$$

Both the heating efficiency and capacity of an ASHP are reduced in colder outdoor temperatures, as it becomes more difficult for the systems to extract heat from the cooler air. In very cold temperatures, the COP is typically only marginally better that standard electric resistance (COP=1). In climates like Ontario, home HVAC designs utilizing ASHP usually limit the amount of heat pump capacity to meet only a portion of heating load. The remaining heating capacity is provided by either natural gas or electric resistance sources, as additional heat pump costs are not justifiable based on system efficiency savings (especially where natural gas is available).

In this analysis, the ASHP capacity was selected to be just slightly higher than the cooling load requirement for the home. The sizing criteria was chosen as it is only a marginal increase in the overall HVAC system costs. Essentially the ASHP replaces a “similar” sized central air conditioning system. Both systems utilize the same furnace system and costs with the only difference being that the ASHP offsets some of the base case natural gas heating.

Methodology

To complete this study, EQ analyzed three archetype case study buildings: a large 2-story detached home, a medium 2-story detached home, and 3-storey interior row house as part of a 6-unit building. EnergyPlus with OpenStudio was used to create the hourly energy models of each case study building. Each building was modeled with the following HVAC and DHW system types:

1. Conventional HVAC Systems (Gas furnace, Gas DHW, and DX air conditioning)
2. Air-Source Heat Pump [ASHP] (Electric back-up, Electric DHW)
3. Air-Source Heat Pump [ASHP] (Gas back-up, Gas DHW)
4. Variable Refrigerant Flow Air Source Heat Pump [VRF ASHP] (Gas back-up, Gas DHW)

Each model produces an annual hourly energy use profile by major end use. Operating costs are then determined by applying local utility rates to the aggregate hourly natural gas and electricity usage profiles.

The primary focus of the analysis was on the carbon emissions results from each model. These emissions are calculated for each case by mapping the hourly energy profiles against the specific hourly generation source energy data that was provided from the IESO. By using hourly generation source data rather than an annual blended average, the emissions calculated represent the impact of the Ontario generation mix while accounting for the impact of the specific energy usage profile of the homes, including peak electricity usage.

In addition to this approach, carbon emissions were also calculated assuming generation source energy mix based solely on natural gas. This is consistent with the Ontario Building Code's Supplementary Standard SB-10 for carbon emission compliance. The marginal natural gas rate is higher than the annual blended carbon rate and represents a more conservative representation of potential carbon emissions.

Detailed Modeling Assumptions

The following modeling inputs are common to all cases considered in this study:

Exterior Wall Construction:	Wood Framed – Effective R-14.8
Roof Construction:	Effective R-20
Window Construction:	Effective U-0.50, SHGC-40
Window to Wall Ratio:	7.6 %

Outdoor Air:	76 cfm (150 cfm) (Per ASHRAE 62.2-2010 requirements)
Lighting & Equipment Power:	24 kWh/day/unit (based on previous HOT2000 modeling for each project)

The weather file used for this study was the Toronto CWEC weather file from the EnergyPlus Weather Data database. This weather file is based on historic data, but it is expected that our climate is trending towards warmer levels. Forecast hourly weather data could influence the results of this study.

The details of the HVAC inputs and detailed efficiencies modeled for each case are as follows:

System 1: Furnace Heating, Gas DHW → Current existing stock

Gas Furnace Efficiency:	AFUE – 96%
Domestic Hot Water Heater Efficiency:	EF = 0.67
Air Conditioner SEER:	13

System 2: ASHP, Electric Back-up, Electric DHW → All Electric system

ASHP Heating COP:	3
ASHP Cooling EER:	10.2
Domestic Hot Water Heater Efficiency:	EF=0.96
Backup Heating Source:	Electric
OA Temp for Backup Use:	0°C

System 3: ASHP, Gas Back-up, Gas DHW → Retrofit Scenario

ASHP Heating COP:	3
ASHP Cooling EER:	10.2
Domestic Hot Water Heater Efficiency:	EF = 0.67
Backup Heating Source:	AFUE – 96% Gas furnace
OA Temp for Backup Use:	0°C

System 4: VRF ASHP, Gas Back-up, Gas DHW → High efficiency Retrofit

VRF ASHP Heating COP:	6.6
VRF ASHP Cooling EER:	22.8
Domestic Hot Water Heater Efficiency:	EF = 0.67
Backup Heating Source:	AFUE – 96% Gas furnace
OA Temp for Backup Use:	-8°C

Energy Costs

Historical utility rates from 2015-2016 were used for this study. The three case studies are located within the greater Toronto area, which is served by Toronto Hydro for electricity and Enbridge Gas for natural gas.

Electricity Rates:

Residential homes with Toronto Hydro are subject to a tiered electricity rate consisting of Off-Peak, Mid-Peak and On-Peak rates to encourage energy conservation during peak demand. On-peak hours are between 11 am and 5pm, off-peak is between 7pm and 7am, with all remaining hours considered mid-peak. The Ontario Energy Board shows that the Toronto Hydro tiered electricity rates for 2015/16 were as follows:

Table 1 – OEB 2015/16 Historical Toronto Hydro Tiered Electricity Rates

	Off-Peak (¢/kWh)	Mid-Peak (¢/kWh)	On-Peak (¢/kWh)
Nov 1 2015 – April 30 2016	8.3	12.8	17.5
May 1 – Oct 13 2016	8.7	13.2	18.0

The rates from the OEB do not include additional fees such as delivery or transmission fees as these can vary depending on where the house is located. As a conservative estimate, EQ assumed that these fees account for an additional 4¢/kWh. With this adjustment, the following electricity rates were used:

Table 2 – Modeled Tiered Electricity Rates

	Off-Peak (¢/kWh)	Mid-Peak (¢/kWh)	On-Peak (¢/kWh)
January 1 – April 30	12.3	16.8	21.5
May 1 – October 31	12.7	17.2	22.0
November 1 – December 31	12.3	16.8	21.5

Natural Gas (Rate 1)

Residential homes with Enbridge Gas are subject to Rate 1. The historical commodity prices in 2015/16 from the OEB are as follows:

Table 3 – OEB 2015/16 Historical Enbridge Gas Rates

	Commodity Price (¢/m^3)	Gas Cost Adjustment (¢/m^3)	Effective Price (¢/m^3)
July 1 – Sept 31	12.1794	2.5730	11.7524
Oct 1 – Dec 31 2015	12.2443	0.8524	13.0967
Jan 1 2016 – March 31	10.5327	1.2158	11.7485
April 1 – June 30	9.1760	2.2088	11.3848

In addition to these commodity prices, natural gas is subject to regulatory charges. These regulatory charges are also controlled by the OEB. For 2015/16 the rates were as follows:

Table 4 - Enbridge Gas 2015/16 Regulatory Charges

	Transportation Charge (¢/m^3)	System Sales Gas Supply Charge (¢/m^3)
July 1 – Sept 31	6.2367	12.1794
Oct 1 – Dec 31 2015	6.3318	12.2443
Jan 1 2016 – March 31	5.0725	10.5327
April 1 – June 30	5.3338	9.1760

Totaling the commodity and regulatory charges provides the total rate per cubic meter. The rates used in this study are as shown in the table below.

Table 5 – Modeled Natural Gas Rates

	Effective Rate (¢/m^3)
January 1 – March 31	27.3537
April 1 – June 30	25.8946
July 1 – September 30	30.1685
October 1 – December 31	31.6728

IESO Hourly Electricity Breakdown

The raw electricity source generation data for both 2014 and 2015 is shown in the Figures below:

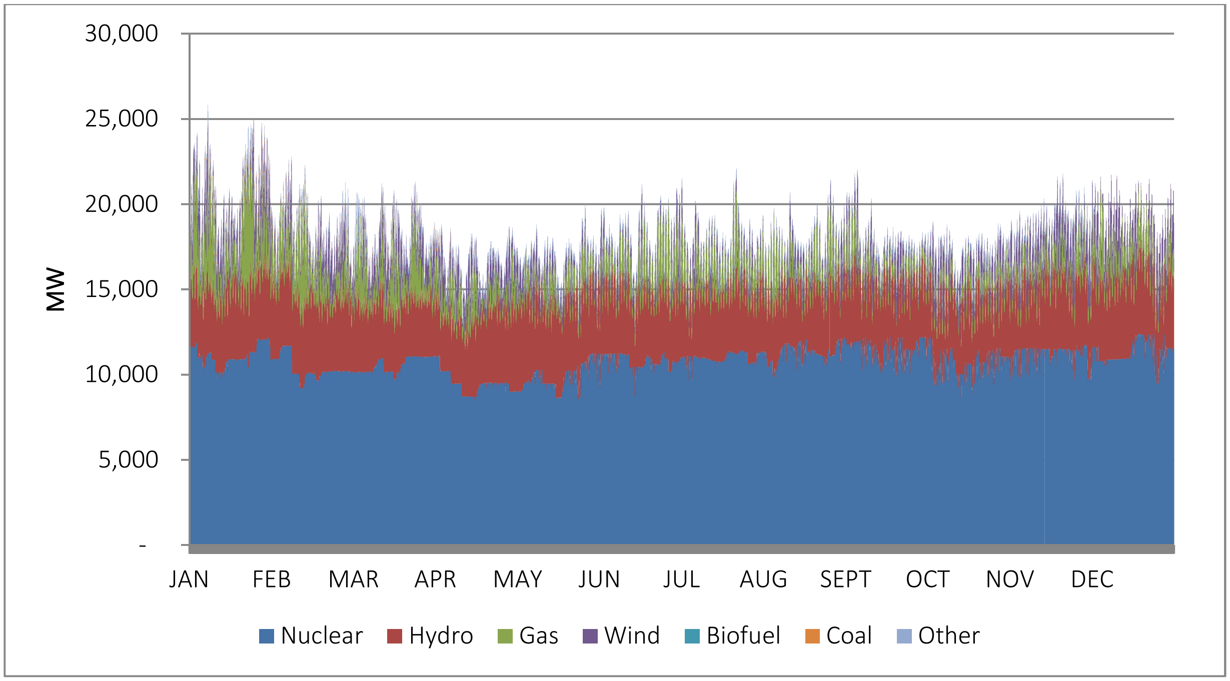


Figure 1 - 2014 IESO Electricity Source Data

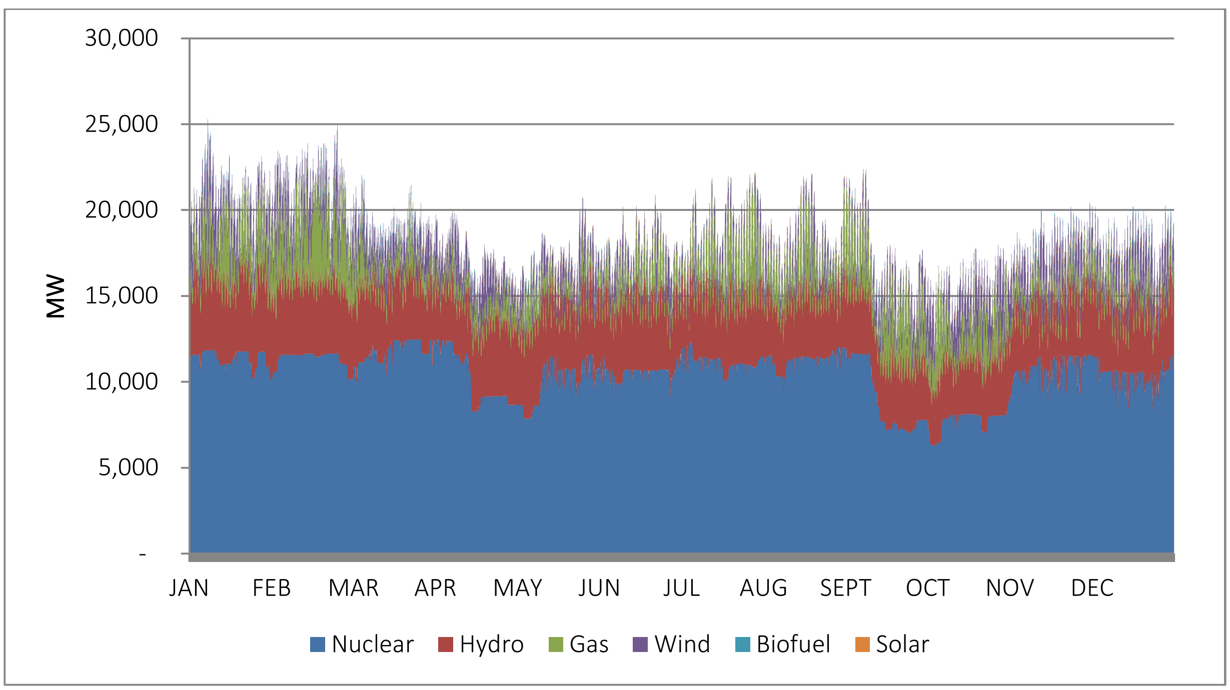


Figure 2 - 2015 IESO Electricity Source Data

The nuclear and hydro loads remain fairly constant throughout the year (as expected). While the nuclear and hydro meet the base of the load, variability on the grid is met through the use of renewables, gas, and biofuel sources.

There appear to be anomalies in both the 2014 and 2015 IESO data. In 2014, coal plants contributed to Ontario's electrical mix for about half the year, but these plants have subsequently been closed and coal is not planned to be used in the future. In 2015, the electricity production in the latter part of the year was quite a bit lower than in 2014 or early 2015, possibly due to unseasonably mild weather. In addition, in 2015 it is apparent that some of the nuclear capacity was shut down (likely for maintenance) in April-May and again in September-November.

For the purposes of this study, the 2014 IESO hourly grid mix was used, with a slight modification that all coal energy use has been considered as natural gas-sourced. While gas plants will operate at a higher thermal efficiency than coal plants will, this has not been taken into account when adjusting the 2014 coal load to gas for this study.

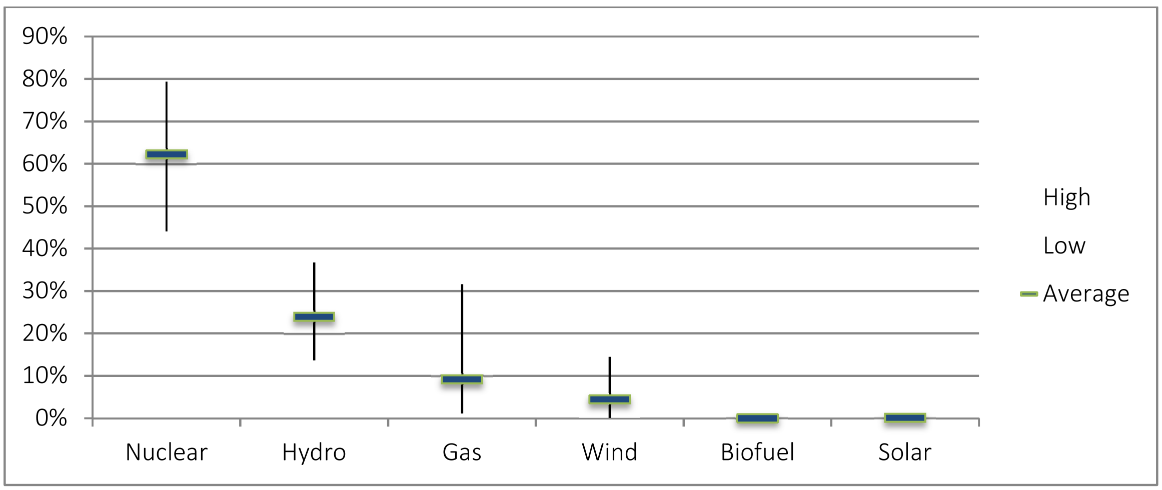


Figure 3 - Range of Hourly Electric Grid Mix

The mix of energy use varies throughout the year. Figure 3 above shows that nuclear and hydro are the clear majority, making up an average of 62% and 24% respectively of the grid mix. Comparatively, carbon-intense natural gas-sourced electricity only represents 9% of the total annual grid energy but can reach up to 32% of the grid generation mix on an hourly basis. It is also noted that natural gas is used for both ramping and peak requirements, with the ramping requirement relating to the instability of the wind and solar generation.

Carbon Equivalents

The choice of carbon emission factors used in this study has an impact on the conclusions. For this reason, two different sets of carbon emissions factors have been selected for comparison.

Firstly, hourly IESO data detailing the electricity-grid sources was used so that hourly carbon factors can be applied to the hourly energy modeling results. The carbon factors for each electricity source was applied based on the hourly demand from each case study modeled allowing peak demand to be reflected with increased carbon usage.

Secondly, an overall marginal (based on gas) carbon factor was used. A marginal gas rate is referenced in the Ontario Building Code's Supplementary Standard SB-10 for carbon emission compliance. The marginal gas rate is higher than a blended carbon rate and is a more conservative representation of potential carbon usage.

For this study, EQ has chosen to use the CO_2 emission factors listed in MMAH Supplementary Standard SB-10 (September 14, 2012 edition) Table 1.1.2.2. as the basis for the analysis:

Table 6 - OBC SB-10 2012 CO_2e Emission Factors

Building Energy Source	CO_2e (kg/kWh)
Grid Delivered Electricity (marginal based on natural gas)	0.400
Natural Gas	0.191

Based on this, the equivalent carbon emission factors used for this study are as follows:

Table 7 - CO2e Emission Factors

Building Energy Source	CO_2e (kg/kWh)
Natural Gas	0.191
Electricity (Marginal)	0.400
Electricity (Hourly Project-Specific Carbon Use)	
Nuclear	0
Hydro	0
Gas	0.400
Wind	0
Biofuel	0.800 (estimated)
Solar	0
Other	0

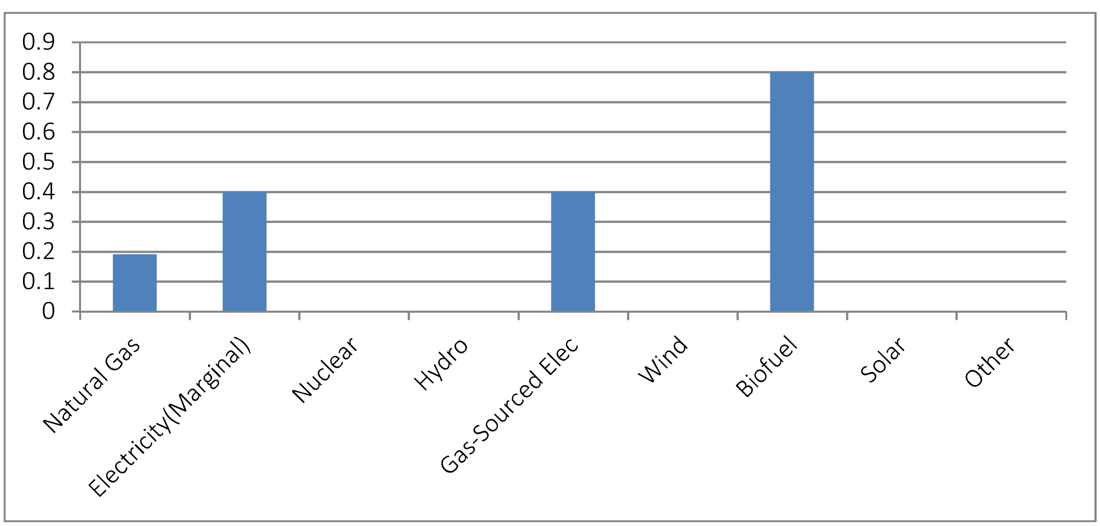


Figure 4 – OBC SB-10 2012 CO2e Emission Factors

This study does not intend to suggest that either the marginal carbon factor or hourly project-specific carbon factor is a more accurate representation of actual carbon usage, but instead uses both in order to show both a high and low carbon estimate, with the actual usage likely falling somewhere in between.

Results

Twelve energy models were created using EnergyPlus with OpenStudio. Each of the three case study homes were modeled with the four different HVAC system scenarios. To simplify each case name, the following legend has been used:

<u>Legend</u>
A – Detached House 1
B – Detached House 2
C – Row House

1 – All Gas - Base case, gas furnace, gas DHW
2 – All Electric - ASHP, electric back-up, electric DHW
3 – Hybrid 1 - ASHP (sized for cooling), gas furnace back-up, gas DHW
4 – Hybrid 2 – VRF ASHP, gas furnace back-up, gas DHW

The energy usage of each building can be seen in the chart below. The energy use within each building has been broken out by end use to give greater clarity for analysis.

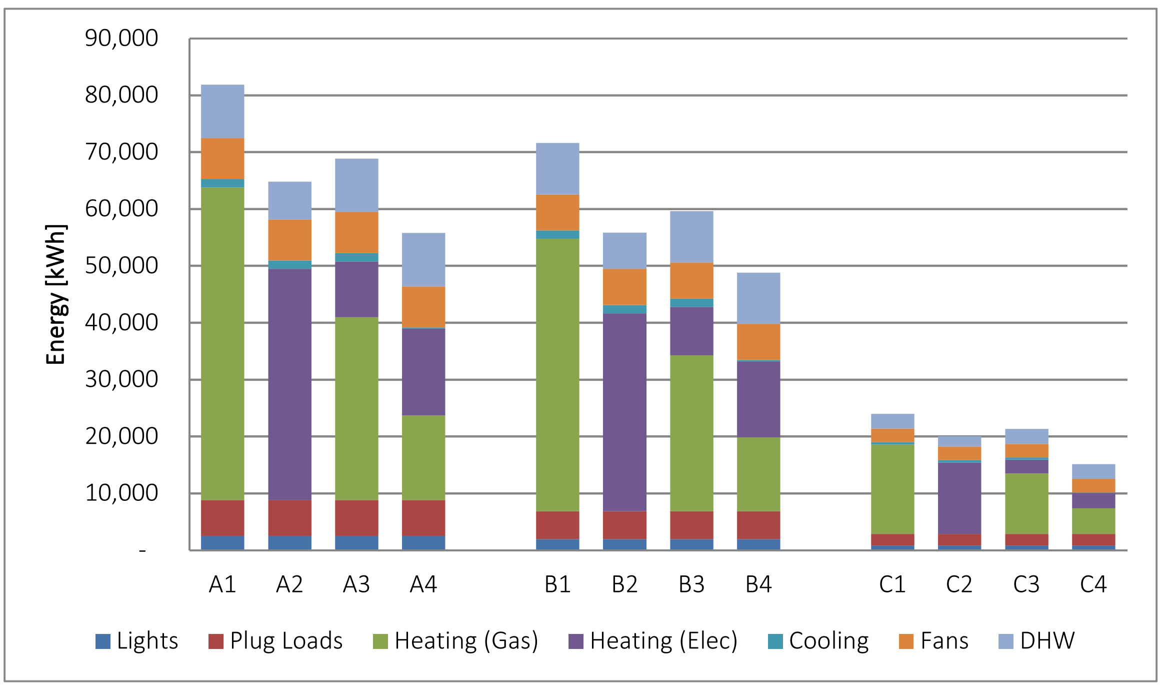


Figure 5 - Annual Energy Use By End Use Per Household

As seen above, heating is by far the greatest energy end-use. In both the gas and electrically heated cases, the heating makes up at least half of the energy use. The heat pumps result in an overall increase in heating and cooling efficiency resulting in approximately 20% savings over the base (1) case. With an air-source heat pump nominal COP of 3.0 compared with an AFUE of 0.96, a 20% reduction in overall energy savings may seem low. Switching system types in each case study only directly affects the heating and cooling loads with all other loads remaining fairly even, causing the savings to appear less effective. Figure 6 below shows only the heating portion of each of the case studies:

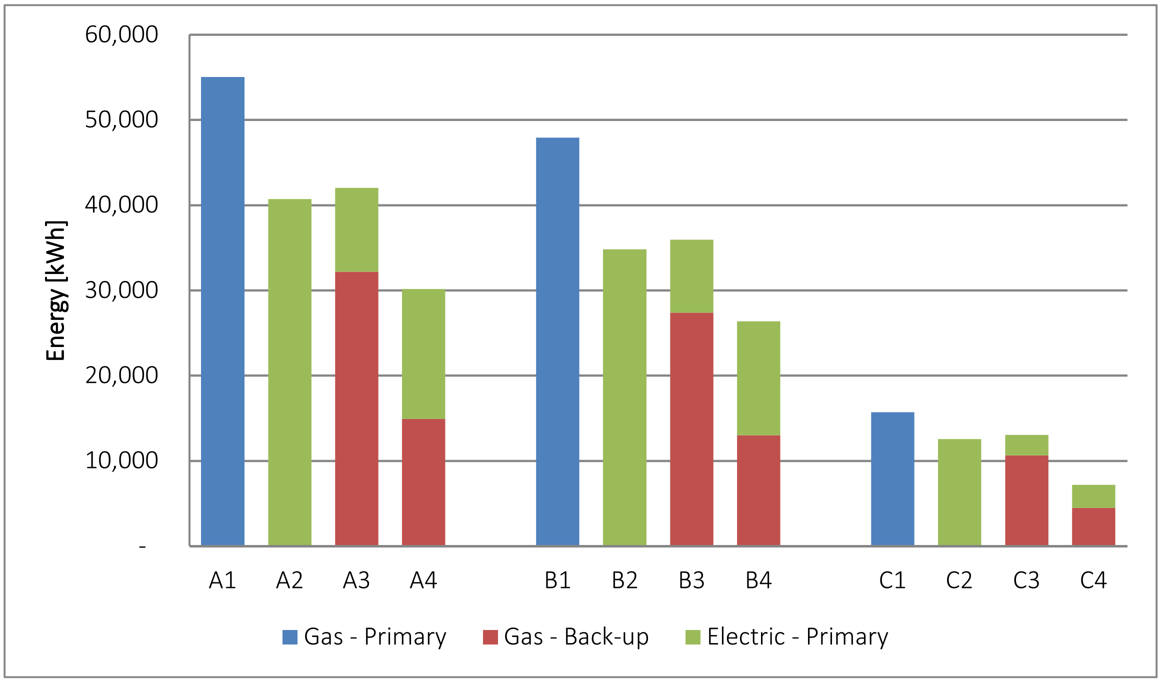


Figure 6 - Annual Heating Energy Use by Source per Household

When looking at heating savings in isolation, we can see up to 27% savings between the air source heat pump and baseline cases. By design, heat pump systems can only operate effectively down to a certain temperature. For HVAC system 3, 0°C was assumed while the more efficient HVAC system 4 can operate down to -8°C. When the outdoor air temperature was below this limit, the back-up heating source with standard efficiencies would kick in to meet the heating load. With HVAC system 4, the high efficiency VRF ASHPs were able to operate to lower temperatures.

While the heat pump systems are able to operate down to low temperatures, they unfortunately have decreasing efficiencies. As explained earlier, as the outdoor temperatures reduce, it becomes increasingly difficult to extract heat out of the air. While the air source heat pumps are rated with a COP of 3 for heating, at very low temperatures their true efficiency may be only marginally better than standard electric resistance (COP=1). Further, when there is only little heat to extract from the air, the air source heat pump may only be able to provide a portion of the heating load relying on the electric (COP=1) or gas back-up (AFUE=0.96) sources to provide the remainder. Given Toronto’s cold climate, these conditions can be frequent and explain why in both case (2) and (3) there is still significant back up fuel source used with air source heat pumps.

Case study A3 was considered in additional detail to further explain these results. Figure 7 below shows a breakdown of what heating source is used when there is an hourly demand in the building. While the ASHP is used in whole or in part for 73% of hours where there is a demand for heating, the back-up source is also used in whole or in part for 40% of the hours.

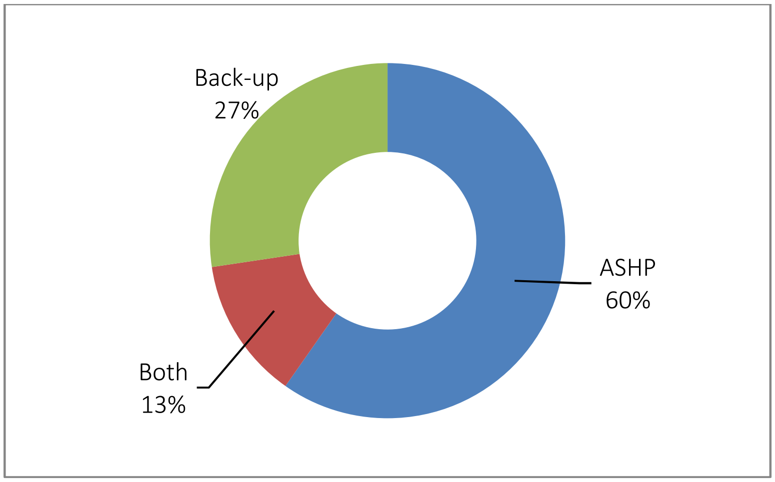


Figure 7 – Case Study A3 Heating Source

Figure 8 below shows a breakdown of how much of the heating load is being met when each heating source is used. When operating, heat pumps on average meet 88-100% of the heating load. The highest heating loads are found at the coldest temperatures when back-up heating must be used. On an hourly average basis, back-up heating sources provide 70% of the heating load when used, though most hours when back-up is needed, it is providing 100% of heating.

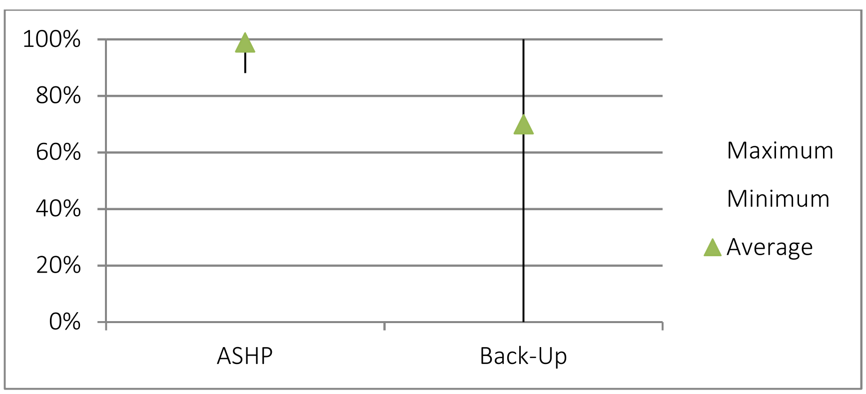
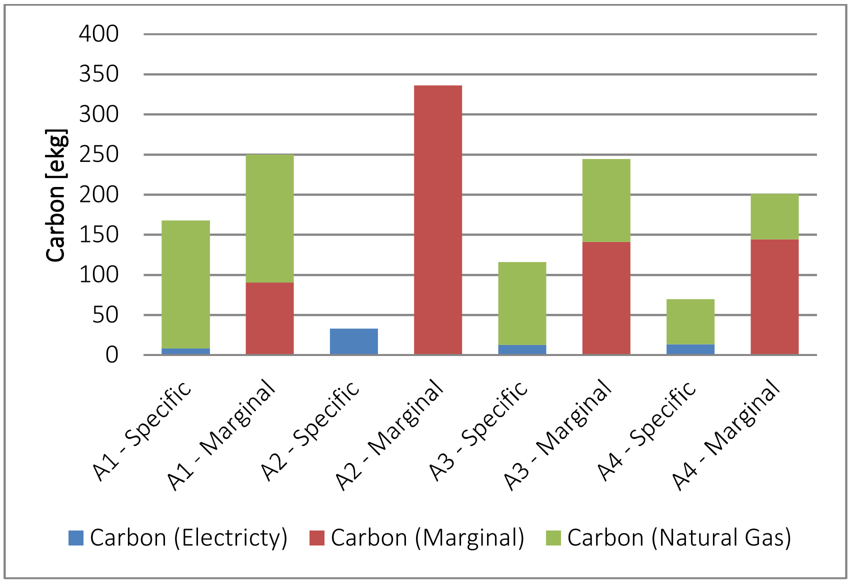


Figure 8 – Case Study A3 Amount of Heating Demand Met by Heating Source When Operating

Fuel switching in these hybrid cases could influence a home's carbon footprint, though this depends on what carbon factors are used. Figures 9-11 and Tables 8-10 below show a breakdown of each building's case study annual carbon footprint with both specific and marginal natural gas rates.



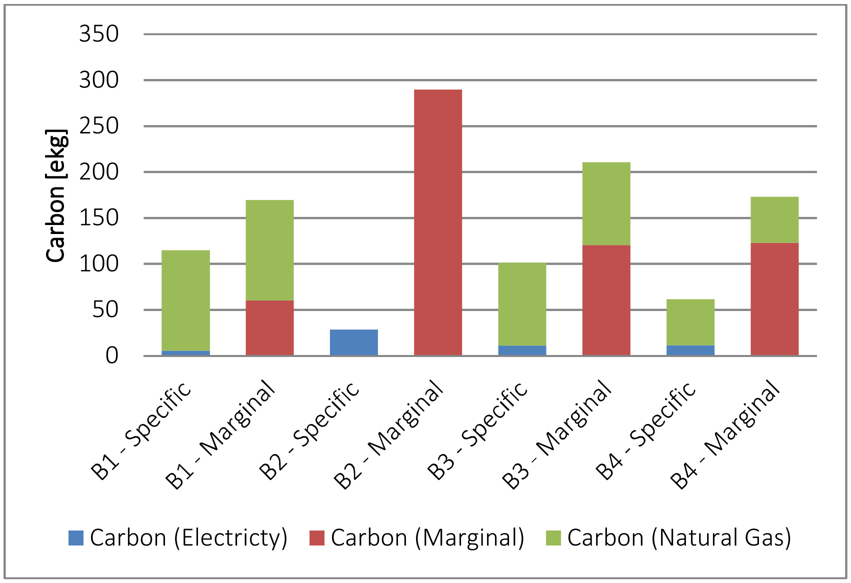
<u>Legend</u>
A – Detached House 1
B – Detached House 2
C – Row House

1 – All Gas - Base case, gas furnace back-up, gas DHW
2 – All Electric - ASHP, electric back-up, electric DHW
3 – Hybrid 1 - ASHP (sized for cooling), gas furnace back-up, gas DHW
4 – Hybrid 2 – VRF ASHP, gas furnace back-up, gas DHW

Figure 9 - Annual Carbon Use per Household (A)

Table 8 - Annual Carbon Use per Household (A)

	Carbon (Electricity)	Carbon (Marginal)	Carbon (Natural Gas)	Total Carbon
A1 – Specific	8	0	159	**168**
A1 - Marginal	0	90	159	**250**
A2 – Specific	33	0	0	**33**
A2 - Marginal	0	336	0	**336**
A3 – Specific	13	0	103	**116**
A3 - Marginal	0	141	103	**244**
A4 – Specific	13	0	56	**70**
A4 - Marginal	0	144	56	**201**



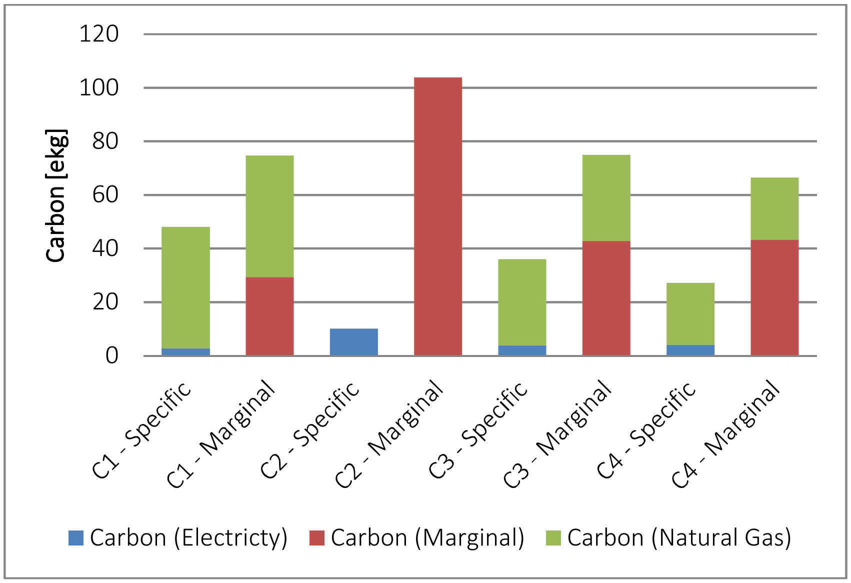
Legend
A – Detached House 1
B – Detached House 2
C – Row House

1 – All Gas - Base case, gas furnace back-up, gas DHW
2 – All Electric - ASHP, electric back-up, electric DHW
3 – Hybrid 1 - ASHP (sized for cooling), gas furnace back-up, gas DHW
4 – Hybrid 2 – VRF ASHP, gas furnace back-up, gas DHW

Figure 10 - Annual Carbon Use per Household (B)

Table 9 - Annual Carbon Use per Household (B)

	Carbon (Electricity)	Carbon (Marginal)	Carbon (Natural Gas)	Total Carbon
B1 – Specific	6	0	109	**115**
B1 - Marginal	0	60	109	**169**
B2 – Specific	28	0	0	**28**
B2 - Marginal	0	290	0	**290**
B3 – Specific	11	0	90	**101**
B3 - Marginal	0	120	90	**210**
B4 – Specific	11	0	50	**62**
B4 - Marginal	0	123	50	**173**



<u>Legend</u>
A – Detached House 1
B – Detached House 2
C – Row House

1 – All Gas - Base case, gas furnace back-up, gas DHW
2 – All Electric - ASHP, electric back-up, electric DHW
3 – Hybrid 1 - ASHP (sized for cooling), gas furnace back-up, gas DHW
4 – Hybrid 2 – VRF ASHP, gas furnace back-up, gas DHW

Figure 11 - Annual Carbon Use per Household (C)

Table 10 - Annual Carbon Use per Household (C)

	Carbon (Electricity)	Carbon (Marginal)	Carbon (Natural Gas)	Total Carbon
C1 – Specific	3	0	45	**48**
C1 - Marginal	0	29	45	**75**
C2 – Specific	10	0	0	**10**
C2 - Marginal	0	104	0	**104**
C3 – Specific	4	0	32	**36**
C3 - Marginal	0	43	32	**75**
C4 – Specific	4	0	23	**27**
C4 - Marginal	0	43	23	**66**

When using an hourly project-specific carbon rate, the carbon emissions of HVAC system 2 (air-source heat pump with electric back-up heating and electric DHW) is significantly lower than all of the other cases. This makes sense given that electricity use in Ontario is largely supplied by zero-carbon sources of nuclear and hydro. When the carbon for electricity is at the margin and uses natural gas however, the electric driven HVAC system 2 has significantly higher CO_2 emissions.

Comparing HVAC system 1 (traditional, gas furnace heating with DX cooling) and HVAC systems 3 and 4 (air-source heat pumps with gas back-up heating and gas DHW), the CO_2 footprints show some improvement for both the marginal and specific generation mixes form models houses A and C, and minor increases for house B. When using a mixed-fuel system, the case study was able to take advantage of the increased ASHP efficiencies without the increased marginal carbon use associated with an electric back-up heating source.

It should be noted that the VRF ASHP in HVAC system 4, can operate at lower outdoor air temperatures and with higher efficiencies that a basic ASHP. In addition, at colder temperature, electricity demand rises in the province and the natural gas percentage of the specific hourly generation mix increases. As a result, this system will provide the better energy efficiency and lowest CO_2 emissions as compared to HVAC system 3.

A final relevant factor that for the analysis is the annual operating costs. Figure 12 below uses historical 2014 rates to estimate the annual operating cost in each case analyzed.

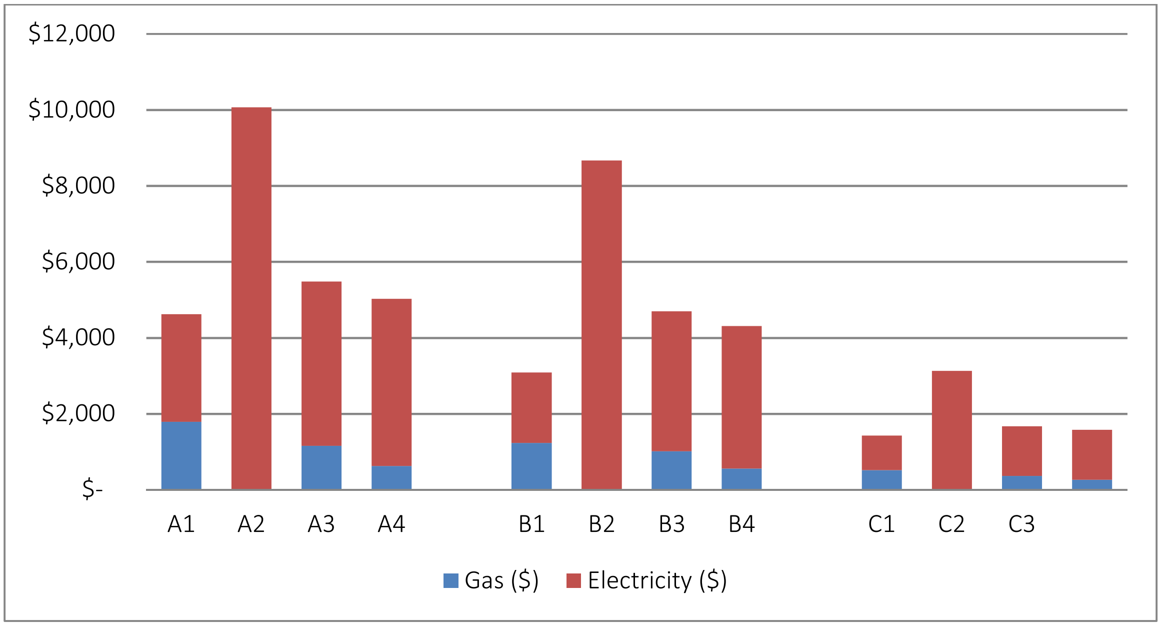


Figure 12 - Annual Utility Bill Per Household

<u>Legend</u>
A – Detached House 1
B – Detached House 2
C – Row House

1 – All Gas - Base case, gas furnace back-up, gas DHW
2 – All Electric - ASHP, electric back-up, electric DHW
3 – Hybrid 1 - ASHP (sized for cooling), gas furnace back-up, gas DHW
4 – Hybrid 2 – VRF ASHP, gas furnace back-up, gas DHW

The annual energy costs of HVAC system 2 are approximately twice as high as the traditional or hybrid systems. This relates to the significant price difference between gas and electricity on a per unit basis so that homes that are "all electric" will experience significantly higher utility bills. The homes that use gas for space heating will have the lowest utility bills for all cases. The hybrid homes are more cost effective than the all electric home, particularly if the home is smaller.

Discussion

The Climate Change Action Plan strives to decrease the amount of carbon emissions generated in Ontario. While reducing carbon use is important, it is also important to consider the impacts of these goals in terms of individual homeowners. Examining energy use in isolation, the heat pump systems have a better performance in comparison with traditional gas systems. This makes sense, as the heat pumps are able to provide higher efficiencies than the traditional natural gas systems.

Examining carbon in isolation and using the current grid-mix of electricity sources, increasing the use of electricity to meet HVAC demands is an obvious solution that also ties in well with decreasing energy use. HVAC System 2 (ASHP with electric back-up), the only system evaluated with 100% electricity usage uses significantly lower carbon than any other case evaluated. With zero-carbon nuclear and hydropower supporting the majority of the electric grid, fuel switching appears to be a simple solution for addressing climate change. Different conclusions result however when marginal emissions rates, or utility costs are considered.

With marginal rates, the carbon use for HVAC System 2 (100% electric) was the most carbon intense system type considered in this study. When using marginal rates, the carbon intensity of the electricity is roughly double the natural gas rate. The use of marginal (natural gas) electricity rates results in a heavy carbon penalty for each GJ of energy that switches from natural gas to electricity, a key factor in using ASHP systems. When using marginal rates, the traditional system and hybrid heat-pumps with gas back up had comparable carbon use. This suggests that, using marginal rates, both traditional and hybrid systems are preferred over 100% electric systems.

When considering costs, 100% electric systems can have annual utility bills almost twice as high as the traditional natural gas heated systems. When hybrid air-source heat pump systems are used, utility costs are only increased marginally. Utility rates in Ontario are largely driven by a high electricity cost so any increase in electricity use is largely influential on utility bills. Natural gas prices in Ontario have been significantly lower in the past few years than they were even ten years ago. The commodity and gas adjustment rate in July 2016 was 9.7246 ¢/m3 while in July of 2006 it was 35.0086 ¢/m3; a decrease of 360%.

While the current grid mix of electricity does promote the use of air-source heat pumps with electric back up for energy and carbon reductions, a sharp increase in utility bills will occur. Hybrid solutions of air-source heat pumps with natural gas back up give an appealing solution to this problem. Factoring in energy, carbon and costs, hybrid solutions using high efficiency air-source heat pumps (or VRFs) with natural gas secondary heating sources could be a good compromise between the traditional and all-electric systems.

Future Work

While the analysis presented in this report is representative of the current grid mix, forecast data would be ideal for predicting the effects of air-source heat pumps on future carbon emissions.

With changing utility prices, the option to use both electricity (air-source heat pumps) and natural gas could provide homeowners the ability to take advantage of fuel switching to lower their utility bills. Forecast energy prices and a more detailed hourly analysis of the annual energy use would be necessary to study how big of an impact this could have on utility bills and fuel switching is effect on Ontario’s carbon goals.

References

1. https://www.ontario.ca/page/climate-change-action-plan

2. http://www.ontarioenergyboard.ca/OEB/Consumers/Electricity/Electricity+Prices/Historical+Electricity+Prices

3. http://www.ontarioenergyboard.ca/OEB/Consumers/Natural+Gas/Natural+Gas+Rates/Natural+Gas+Rates+-+Historical

4. http://www.ontarioenergyboard.ca/oeb/Industry/Regulatory%20Proceedings/Decisions/2015%20Decisions

5. http://daikincomfort.com/media/pdfs/extras/PF-VRV4.pdf

6. ftp://ftp.panasonic.com/heatairconditioner/brochure/ahri-certified_brochure.pdf