Analysis of the Residential Electrification Potential for the Waterloo Region

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Executive Summary

The Waterloo region and all associated municipalities have committed to reducing greenhouse gas emissions (GHGe) by 80% below 2010 levels by 2050. For the residential sector, which accounts for 18% of total emissions, achieving this target will ultimately require homes to decarbonize their energy needs. In most cases, this will likely require homes to switch to electrified space and water heating using energy efficient heat pump technology, particularly cold climate air source heat pumps (ASHPs) and heat pump water heaters (HPWH). This study examines the economic and climate impacts of switching space and water heaters to heat pumps and uses modeled and measured NRCan (Natural Resources Canada) home energy data from local home energy audits carried out between 1999 and 2020.

The majority of homes in the Waterloo region use natural gas (NG) for space and water heating (92% and 84% respectively). At current (July 2020) utility prices, our models suggest that ASHPs are significantly more expensive to operate than NG furnaces (average $432/yr), but if a home can disconnect from the gas supply and save the connection fee, the average price premium for using an ASHP is only an average of $166/yr. The cost difference varies by home but in 22% of local homes, ASHPs are already cost equivalent or better than NG furnaces if the home can disconnect the gas supply. These homes are newer, smaller and often have shared walls (semi-detached or row housing). For water heaters, HPWHs are already operationally cost-competitive with natural gas systems due largely to the significant difference in energy efficiency of the two technologies.

The economic conditions under which ASHPs are cost-competitive to NG systems were examined. Cost parity would be achieved if NG prices were to increase by 56%, or electricity prices decrease by 37%. If the NG supply is disconnected the respective values become 20% and 14%: fluctuations that are within historical ranges. A carbon tax of $127/t ($68/t with disconnection) would also achieve price parity.

The capital cost of buying and installing heat pumps, both for space and water heating, is greater than that of conventional heating systems. However, the lifetime costs of heat pumps are significantly lower than oil, propane and other forms of electric heat. Government incentives will therefore be required if heat pump technology is to achieve widespread adoption.

The real benefit of switching to heat pump technology is in reducing the climate altering GHGe. ASHPs can reduce whole home emissions by 60-71% and improve energy efficiency by 42-45%. If HPWH are also used, whole home emissions would decrease by 70-82% and energy efficiency would increase by 58-61%: our municipal climate targets can be nearly met with just these two measures. In fact, if our electricity supply were also decarbonized, emissions would drop by nearly 100%: installing heat pumps for space and water heating must be a priority if climate targets are to be met.

This report characterizes five priority housing categories for promoting electrification of local space and water heating using heat pumps. Firstly, new builds, which are already energy efficient should be the first to decarbonize to avoid locking the homes in to new fossil fuel infrastructure. Secondly, priority should be given to the existing homes in which heat pump technology is already operationally cost effective. In addition, HPWH should be promoted in homes that are replacing their existing hot water systems. Homes that are replacing their air conditioning systems or installing new AC are another priority. Finally, heat pump systems must be promoted in all homes, especially if retrofits can be performed first to reduce the overall heating needs.

Introduction

Our homes are a significant source of the greenhouse gas emissions (GHGe) that contribute to climate change and threaten our current and future well-being. The Waterloo region has therefore committed to reducing emissions by 80% below 2010 levels by 2050, with residential buildings being a major target for climate action as they account for 18% of our community's emissions[1]. While adding insulation and air sealing are essential steps in improving the energy efficiency of our homes, reaching these ambitious targets will require most homes to shift from using fossil fuels for heat and hot water to using carbon-free alternatives. Alternatives could include hydrogen generated with carbon captures and storage, hydrogen generated from excess electricity, or carbon-free electricity. Use of hydrogen as a fuel source is still in its infancy and may not be widely available in the timeframe needed to meet our climate targets. This report therefore focusses on the electrification of home heating needs.

There are many options for heating with electricity, but one option stands out from the others: the heat pump. Heat pumps move heat, rather than generating heat and are therefore capable of being far more efficient than other heating equipment (average 300% vs 60-95% efficiency), and can also move heat out of a home to provide air conditioning services in the summer months. Heat pump water heaters can also efficiently provide a home's hot water needs. Although this may sound surprising, it is the same reliable technology that powers your fridge.

Planning for electrification of home energy systems requires an understanding of the existing local conditions. An analysis of local NRCan (Natural Resources Canada) data collected during home energy audits between 1998 and early 2020 provided insight into these conditions. The dataset includes measurements and modeled energy use from 44,463 single-family, semi-detached, and row housing, and represents approximately 19% of such housing in the Waterloo region[2].

This study examined the electrification potential for residential buildings in the Waterloo region. Current utility rates (July 2020) were used to calculate the operational costs for different fuel types, and the upfront costs of different systems were collected. The conditions under which heat pumps can compete with natural gas (NG) for operational cost were explored, as were the GHGe impact of fuel switching. The report concludes with an analysis of how to prioritize a switch to electric systems based on cost-effectiveness, how easy the switch is to engineer, and other climate considerations. Ultimately, the move to heat pump-based heating and hot water is essential and this report shows that it is also possible. But it is a change that must be planned for, incentivized, and promoted.

Heat pumps

There are three common types of heat pumps that can be used for space heating: ground source heat pumps, dual fuel air source heat pumps and cold climate heat pumps. Heat pump water heaters are also available.

Ground source heat pumps (GSHP) move heat into and out of the ground. They require extensive piping underground: in horizontal trenches below the frost line or in deep bored holes. They can meet a home's heating and cooling needs through the entire year and can sometimes be used to help with water heating[3]. These are the most efficient systems because the ground experiences only small seasonal shifts in temperature, but these are also the most expensive to install due to the underground piping and are not always feasible in urban settings. They are best suited to rural areas that have the space for the underground piping.

Dual fuel air source heat pumps (DFHP) have been in use for many decades. They can provide all of the summer cooling needs and they can provide heat in the spring and fall months. Dual fuel systems are not designed for most local winter temperatures and therefore a conventional heating system is required for colder days and nights. DFHPs can be programmed to switch between heating sources under milder temperatures based on outside temperature and utility prices. They are promoted by some as a way to transition homes toward electrified heat and to build consumer confidence in the technology. Others view this approach as a strategy that locks in fossil fuel infrastructure and reinforces misconceptions about the effectiveness of heat pumps in cold weather. Regardless of philosophy, the economic and environmental impact of these systems is hard to evaluate as it depends on homeowner preferences and weather patterns. Furthermore, since most heating fuel is used in the winter months, the GHGe reduction potential from installing a DFHP is insufficient to meet our climate targets.

Cold climate air source heat pumps (ASHP) are a more recent improvement in the technology that allow effective, reliable, and efficient year round climate control even in colder climates, such as the Waterloo region. During very cold days and nights, a built-in electrical resistance heater provides backup heat ensuring that indoor temperatures remain within set parameters. Although some electrical upgrades may be required (see Appendix A), this technology could replace the existing equipment in all of our homes, rendering them nearly emissions-free. Consequently, this is the technology that is the focus of this report.

Heat pump water heaters (HPWH) move heat from the surrounding air to water for domestic use. They are capable of generating all of the hot water needs of a residential home many times more efficiently than a conventional electric water heater. Because it draws heat from the surrounding air, it will tend to cool the surrounding space: a benefit in the summer months, the impact of which is unlikely to be noticed in the winter months as the heat pump is rarely found in common living spaces.

Economic analysis

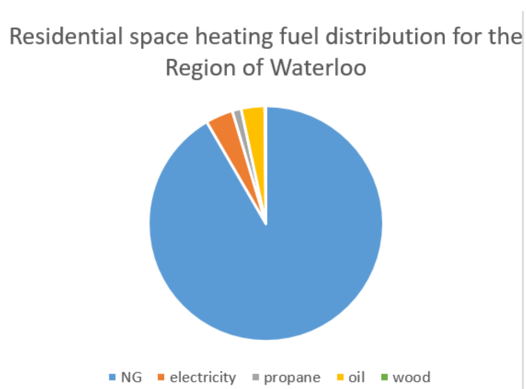
The results outlined below used the NRCan dataset for local home energy audits plus census data for the Region of Waterloo. Sample calculations are shown in Appendix B.

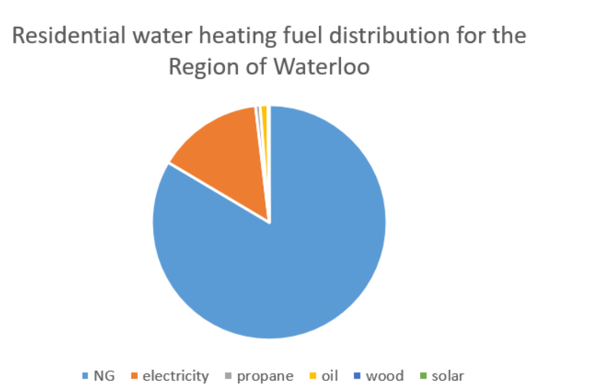
Residential fuel mix in WR

The majority of homes in the Waterloo region use natural gas for space and water heating: 92% and 84% of homes respectively (see Table 1). Achieving large reductions in GHGe from the residential sector is therefore primarily a matter of switching furnaces and water heaters to heat pumps that are powered with low carbon electricity.

Table 1 Space heating and water heating fuel sources for homes in the Waterloo Region

	Space heating		**Water heating**	
Fuel type	# homes	% homes	# homes	% homes
Natural gas	40730	92%	37140	84%
Electricity	1678	4%	6488	15%
Oil	1444	3%	474	1%
Propane	545	1%	281	1%
Other	63	0.1%	78	0.2%





It is noteworthy that there were no houses in the NRCan dataset that listed a heat pump as the primary space heating source. A total of 379 homes reportedly had heat pumps for space heating (90 water- which might be HPWH, 78 ground, 191 air). All heat pumps are required to have backup heating systems and it would appear that in the NRCan dataset, heat pumps are always considered to be the secondary heating source regardless of their climate rating.

Operational cost for electrification of space heating in WR

On a per unit of energy basis, natural gas is currently much cheaper than electricity. Indeed, at the time of writing this report (July 2020), natural gas was 5.5 times cheaper than electricity per unit of energy in the Waterloo region[4,5].

But there are two factors that narrow the price gap considerably. Firstly, natural gas systems are far less efficient than heat pumps. For space heating, natural gas furnaces are typically 78-97% efficient while ASHP can average 300% efficiency: one unit of electrical energy can move an average three units of heat energy into a home. Secondly, when a home electrifies all of its appliances, it can disconnect from the gas supply and save the fixed delivery charge currently set at $266/yr[6].

Table 2 below shows the average annual cost of space heating in Waterloo region with natural gas using the total space energy and furnace efficiency values for homes in the NRCan database. Also shown is the cost of meeting those same heating requirements using an ASHP with an average efficiency of 300%, and the difference in the two costs.

Table 2 Average annual cost comparison for heating with natural gas vs an ASHP[a]

Cost to heat with NG	Cost to heat with ASHP	Price premium for an ASHP	Price premium for an ASHP if NG is disconnected
$638	$1070	$432	$166

[a] based on July 2020 rates: $0.26/m3 for NG, $0.13/kWh for electricity and a fixed rate for NG connection of $266/yr.

Heating costs for a home are correlated with age: successive building codes have required increasing levels of insulation and air sealing measures that leave newer homes better able to retain their heat. Figure 1 shows the price premium for heating with an ASHP by age of construction of the home. Table 3 shows these same values alongside the number of homes in each dataset plus the total number of homes by era from the 2016 Statistics Canada census[7].

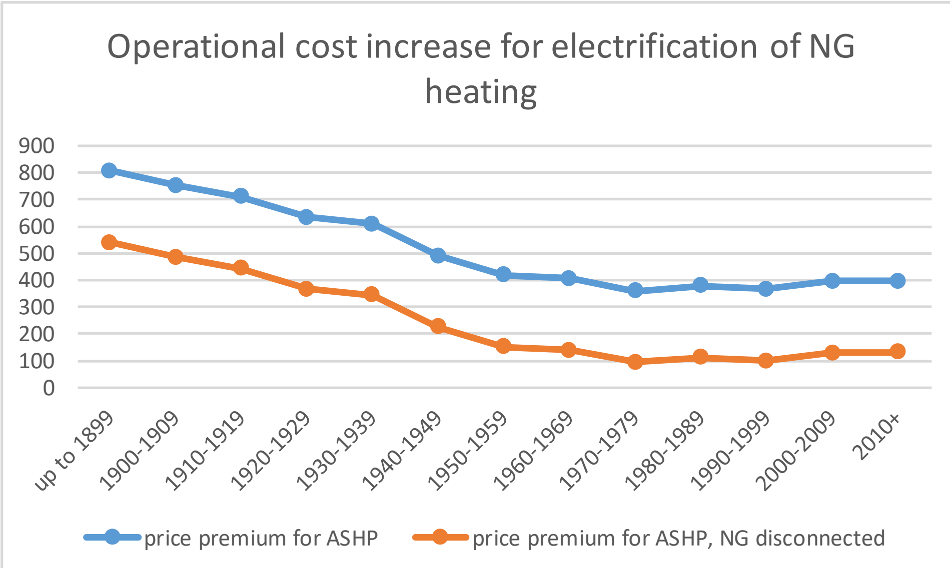


Figure 1 Annual operational cost increase for electrification of NG heating by date of construction

Table 3 Average annual cost comparison for heating with natural gas vs ASHP by date of construction.

Date of construction	Price premium for ASHP ($)	Price premium for ASHP, NG disconnected ($)	# homes (NRCan dataset)	NRCan % total homes	# homes (StatsCan)*	StatsCan housing eras[8]
Up to 1899	807	541	1363	27%	41,590	Up to 1960
1900-1909	752	485	1126			
1910-1919	711	444	919			
1920-1929	634	367	1353			
1930-1939	610	343	863			
1940-1949	491	225	1625			
1950-1959	417	151	3936			
1960-1969	406	140	5376	22%	57,615	1961-1980
1970-1979	360	94	7554			
1980-1989	379	113	8622	29%	29,885	1981-1990
1990-1999	366	100	5502	20%	27,670	1991-2000
2000-2009	397	130	2463	7%	34,335	2001-2010
2010+	397	131	28	0.2%	12,735	2011+

The operational cost of heating with an ASHP can be expected to correlate with other factors, such as total floor area, and size of the home's envelope (the surface area of the foundation, attic and exposed walls). A larger home, for example, is expected to lose more heat than a smaller home and a sprawling bungalow is expected to lose more heat than a compact two storey home of the same floor area.

However, our dataset does not include information on the size of a home's building envelope. Furthermore, the age of a home also has an effect on total floor area: many older, less energy efficient homes are also smaller than their newer and energy efficient counterparts. Consequently, this analysis did not attempt to characterize electrification potential based on floor area.

A switch from natural gas to an ASHP is already cost effective for 22% of local homes if savings from disconnecting the gas supply is included.

Characteristics of homes where it is cost-effective to switch to an ASHP

A switch from natural gas to an ASHP is already cost effective for 22% of local homes if the switch is accompanied by disconnection of the gas supply. We attempted to characterize these homes. The homes have a similar distribution to the entire dataset in terms of age of construction. However, these homes are far more likely to be under 300 m2 (3200 sq ft) in total floor area. Furthermore, these homes are less likely to be single detached housing as opposed to housing with shared walls such as row housing and semi-detached housing.

Operational cost for electrification of water heating in WR

For water heaters, the operational cost difference is smaller than for space heaters. This is due to the larger difference in energy efficiency, with natural gas tank systems performing at 55-80% efficiency but heat pump systems performing at 350-400% efficiency.

In the NRCan dataset, the energy use field for water heaters was nearly always blank. We consequently used the values that were available to calculate a regional average for energy consumed to heat water. It was assumed that there is less variation in the household hot water use and that consumption values do not correlate with any of the variables available in the dataset. The calculation yielded an average of 13.6 GJ/yr. This value is comparable to the 15.8 GJ/yr value used on US government websites[9].

This 13.6 GJ/yr average energy use for heating water was applied to all datasets when assessing the economic impact of electrification of water heating. The cost to heat with natural gas and with a HPWH (assuming 350% efficiency) was calculated using the same method used for space heating. Table 4 shows that heating water with a heat pump is, on average, $10 cheaper than heating water with a typical natural gas system. For homes that use natural gas exclusively for heating water (373 of 444,730 homes), the cost savings increase to $276/yr: a value greater than the cost of the natural gas used.

Heating water with a HPWH may be cheaper than using natural gas.

Table 4 Average annual cost comparison for water heating with natural gas vs a HPWH

Cost to heat water with NG	Cost to heat water with HPWH	Price premium for an HPWH	Price premium for an HPWH if NG is disconnected
$99	$89	-$10	-$276

Operational cost for electrification of both space and water heating in WR

The majority (90%) of homes that use natural gas for space heating also use natural gas for water heating. To achieve near zero emissions and benefit from the cost savings from disconnecting the natural gas supply, these homes will need to switch both space heating and water heating to heat pumps. Table 5 shows the operational cost comparison for fuel switching both appliances to heat pumps.

Table 5 Average annual cost comparison for space plus space heating with natural gas vs heat pumps

Cost with NG	Cost with HPs	Price premium for full electrification with HPs	Price premium for HPs if NG is disconnected
$739	$1159	$422	$156

Price equivalence point for natural gas and heat pump equipment

Natural gas prices are volatile and difficult to forecast. Meanwhile, both NG and electricity prices can also vary as a result of policy changes which are also hard to predict. Here in Ontario, NG supply rates are set by the Ontario Energy Board four times a year and reflect supply and demand plus other market factors[10]. Electricity prices are also set by the Ontario Energy Board and these rates are generally expected to increase in Ontario as nuclear power plants are refurbished and decommissioned[11].

The price equivalence point, where the average cost for space and hot water heating with natural gas is equal to using heat pumps for both, gives us a sense of how much prices must change to make heat pumps cost effective for most homes. If electricity prices were to remain the same, natural gas prices would have to increase by 56% to reach price parity (0.413$/m3 vs 0.265$/m3), but only by 20% if the gas supply is disconnected. Conversely, if natural gas prices were to remain the same, electricity prices would have to decrease by 37% to reach price parity (0.087 $/kWh vs 0.138 $/kWh) or by 14% if the gas supply is disconnected.

Table 6 Price equivalence points for NG and ASHP systems as a function of NG and electricity prices

	NG	NG + NG connection	ASHP	ASHP – NG connection
Current price	0.265$/m3	0.265$/m3 + 266$/yr	0.138$/kWh	0.138$/kWh – 266$/yr
Equivalence point price	0.413$/m3	0.318$/m3	0.087$/kWh	0.119$/kWh
% change	56%	20%	-37%	-14%

Another way to consider the effect of price variability over time on the cost effectiveness of replacing a NG furnace with an ASHP is to look at the historical cost variation for heating an average Waterloo region home with each system. Figure 2 shows the average annual cost of operating a NG furnace at historical NG rates (note the NG variable delivery rate and federal carbon charge are not factored into this analysis as they have not been constant with time). The horizontal lines show the current cost of operating an ASHP and the cost of operating an ASHP if the gas supply is disconnected. Figure 3 shows a similar analysis using historical electricity rates (note the electricity delivery and regulatory charges are not factored into this analysis as they have not been constant). These graphs also allow the user to assess the cost of operating these systems at different price points.

Figures 2 and 3 clearly show that there have been times in the past when the average home in the Waterloo region could have heated a home with an ASHP more cost effectively than with a NG furnace: such conditions are likely to recur.

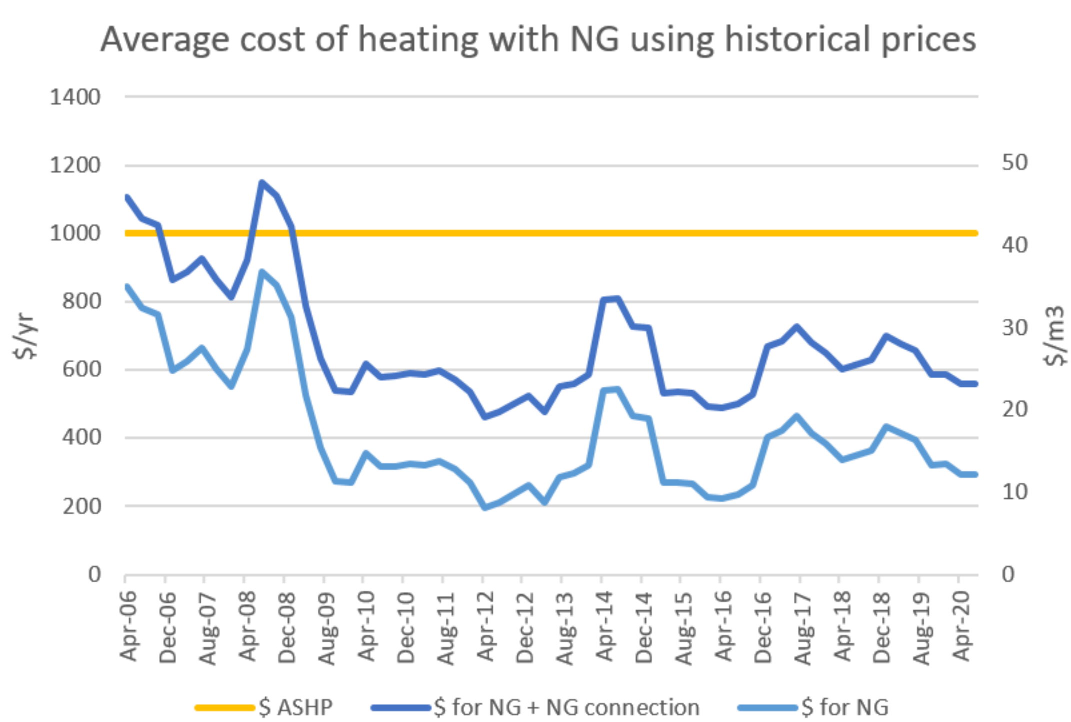


Figure 2 Average cost of heating with NG using historical prices, current ASHP cost shown for reference

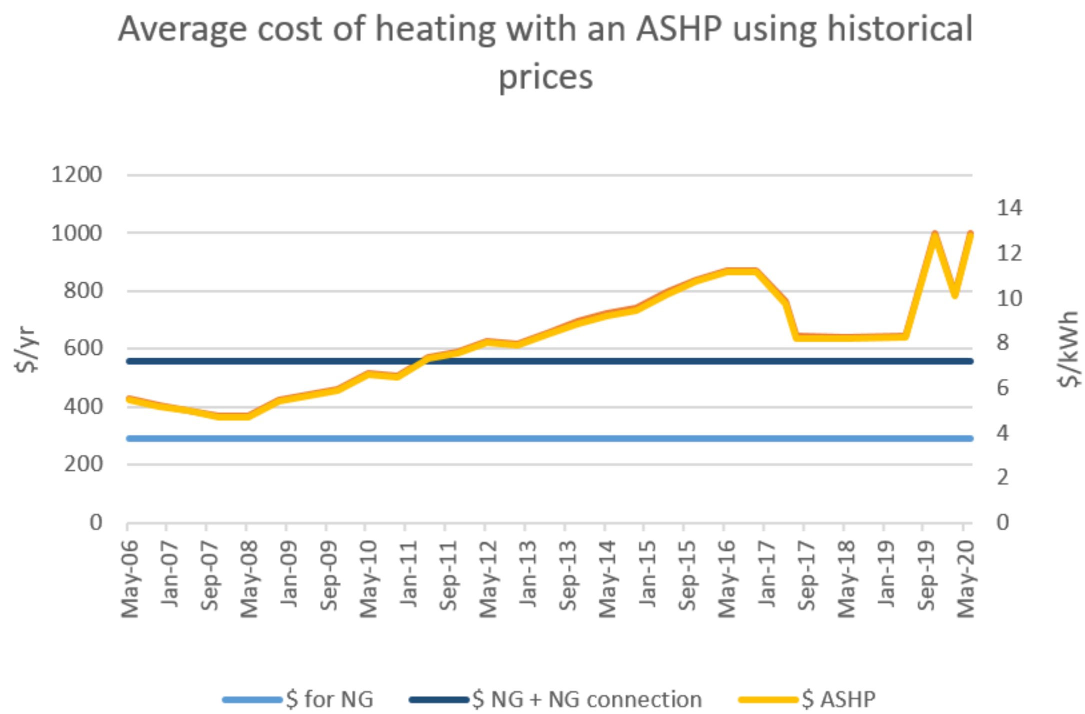


Figure 3 Average cost of heating with an ASHP using historical prices, current NG costs with and without connection fee shown for reference

Ontario has a price on carbon that currently sits at $30/tonne and is set to increase to $50/tonne by 2022[12]. For heat pumps to achieve price parity with natural gas for heating and hot water using current (July 2020) utility prices, the carbon tax would have to increase to $127/tonne. If the cost of the gas connection is factored into this equation, the carbon tax would only have to increase to $68/tonne.

Capital cost comparison

Table 6 shows the upfront purchase and installation costs of various appliances. Because heat pumps can operate in reverse, moving heat out of a home in summer, they should be considered replacements for both heating systems and air conditioning. However, the cost of a conventional heating system plus the cost of a conventional central air conditioner is still less than the cost an ASHP. Widespread adoption of this technology will likely require generous government incentives and/or government regulations. The City of Vancouver, for example, has mandated that all new and replacement heating and hot water systems by zero emissions by 2025[13].

The cost of a dual fuel heat pump system is included in Table 6. As noted above, dual DFHPs must be paired with a conventional heating source as they are not designed to operate under cold outdoor conditions. Equipment values for a ground source heat pump are also provided but do not include the costs of adding underground piping, which can be highly variable.

It should also be noted that the anticipated lifespan of older furnace equipment is reportedly much longer that that of newer equipment. Low and mid-efficiency furnaces may last for many decades due in part to thicker heat exchangers and simpler electronics[14]. In the neighbourhood where I live, many homes are approaching 30 years in age and are still operating with their original furnace.

These costs do not include additional installation costs such as the electrical supply and panel upgrades that are needed in many homes. These extra costs are outlined in Appendix A.

Table 7 Purchase costs of different heating, cooling and water heating equipment

type	fuel	Cost installed[15]	Anticipated lifespan
High efficiency furnace	Natural gas, propane	$3,000-$5,000	12-18 years
Low efficiency furnace	Natural gas, propane	No longer available	20-25 years[16]
Electric furnace	Electricity	$2,500-$4,500	20-25 years
Boiler system	Natural gas, propane or oil	$3,000-$5,000	10-20 years
Central AC	Electricity	$2,500-$5,000	10-20 years
Dual fuel air source heat pump	Electricity	$5,000-7,000[17]	12-20 years
Cold climate air source heat pump	Electricity	$10,000-$13,000[18]	15-20 years
Tank water heaters	Natural gas, propane, electricity	$1,000-$1,300	8-13 years[19], electric versions may last a few years longer
Tankless water heaters	Natural gas, propane, electricity	$2,000-$4,500	20+ years[20]
Heat pump water heater	Electricity	$2,000-$2,500 + installation[21]	13-15 years[22]

Lifecycle cost comparison

Cold climate ASHPs compare favourably to all heating fuels other than NG for operational cost and for lifecycle costs (see Table 8 and Figure 4). When it comes to hot water, HPWH compare favourably to all heating fuels operationally. The higher upfront costs of HPWH, however, leave them cost effective for all but natural gas water heaters. Not factored into this analysis is the longer average lifespan of HPWH as compared to NG tank systems (avg 17.5 vs 10.5 yrs). Furthermore, as noted below, heat pump systems generate a fraction of the GHGe during operation that other fuels do and therefore, unless conditions change significantly, government incentives will be required to drive the uptake needed to meet our climate commitments.

Table 8 Average annual cost and GHGe comparison for different space heating systems based on average heat energy requirements

fuel	oil	propane	Natural gas	Electricity (baseboard or furnace)	ASHP
Price	2,151 $/yr	3,159 $/yr	635 $/yr	3,237 $/yr	1,079 $/yr
Lifetime cost[a]	$36,269	$51,388	$13,528/ $17,525[b]	$52,057	$27,685
GHGe	8.0 t/yr	5.3 t/yr	4.5 t/yr	2.3 t/yr	0.78 t/yr
% of homes	3%	1%	92%	4%	0

[a] lifetime costs include the installed cost of the equipment and 15 years of operational costs
[b] when the natural gas fixed connection fees are included

Table 9 Average annual cost and GHGe comparison for different tank water heating systems based on average energy requirements

fuel	oil	propane	Natural gas	Electricity	HPWH
Price	307 $/yr	453 $/yr	98 $/yr	377 $/yr	89 $/yr
Lifetime cost[a]	$ 5140	$ 7042	$ 2418	$ 6051	$ 3401
GHGe	1.1 t/yr	0.76 t/yr	0.70 t/yr	0.27 t/yr	0.064 t/yr
% of homes	1%	1%	84%	15%	0%

[a] lifetime costs include the installed cost of the equipment and 13 years of operational costs

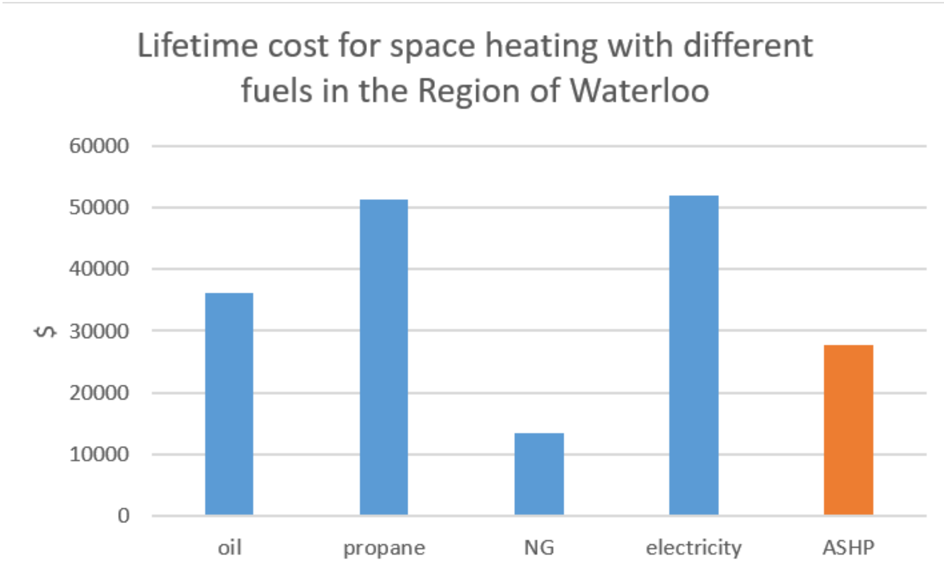


Figure 4 Lifetime cost for space heating with different fuels in the Waterloo region

Climate impact analysis

The conventional approach to cutting GHGe from residential buildings is to add insulation and seal up leaks through home energy retrofits. Yet these measures typically achieve only 20-30% energy efficiencies and GHGe reductions. We must achieve near zero emissions reductions by mid-century if we are to avert the worst climate change scenarios. Here in the Waterloo region, we aim to achieve an 80% reduction in GHGe below 2010 levels by 2050[23]. Only switching to decarbonized forms of space and water heating can realistically achieve the emissions reductions required and heat pumps are the best of the currently available technology to do so.

Tables 10 and 11 plus figures 5-7 show the potential GHGe reduction and energy efficiency gain associated with operating different heating systems in an average Waterloo region home[24]. Heat pump systems are able to achieve a whole home GHGe reduction of 70-82% and an energy efficiency gain of 58-61% if both space and water heaters are used. Just these two measures can achieve most of what is required to meet our climate targets. Furthermore, as our electricity supply is further decarbonized, the carbon footprint of heat pumps will approach zero and the GHGe reductions will approach 100%. (The province's plan to use natural gas generation to offset the nuclear power lost when the Pickering Nuclear Station is decommissioned[25] is therefore a major obstacle to reaching our climate targets.)

Table 10 Energy efficiency gain and GHGe reduction for a home that switches to an ASHP for space heating

	oil	**propane**	**Natural gas**	**Electric heat**
% efficiency gain	74%	69%	69%	67%
% whole home efficiency gain[a]	45%	42%	42%	41%
% GHGe reduction	90%	85%	83%	67%
% whole home GHGe reduction[b]	71%	64%	60%	42%

[a] assumes heating accounts for 61% of a home's energy use[26]

[b] assumes the same fuel is used for space and water heating

Table 11 Energy efficiency gain and GHGe reduction for a home that switches to a HPWH

	oil	propane	Natural gas	Electric heat
% efficiency gain	85%	82%	84%	77%
% whole home efficiency gain[a]	16%	16%	16%	15%
% GHGe reduction	94%	92%	91%	77%
% whole home GHGe reduction[b]	11%	9.8%	10%	5.7%

[a] assumes water heating accounts for 19% of the home's energy use [27]

[b] assumes the same fuel is used for space and water heating

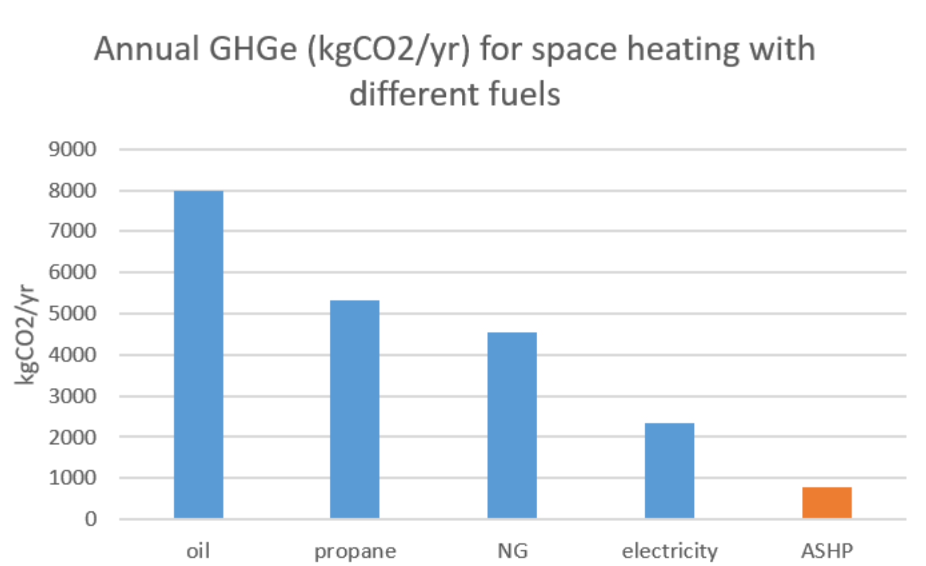


Figure 5 Annual GHGe for space heating with different fuels

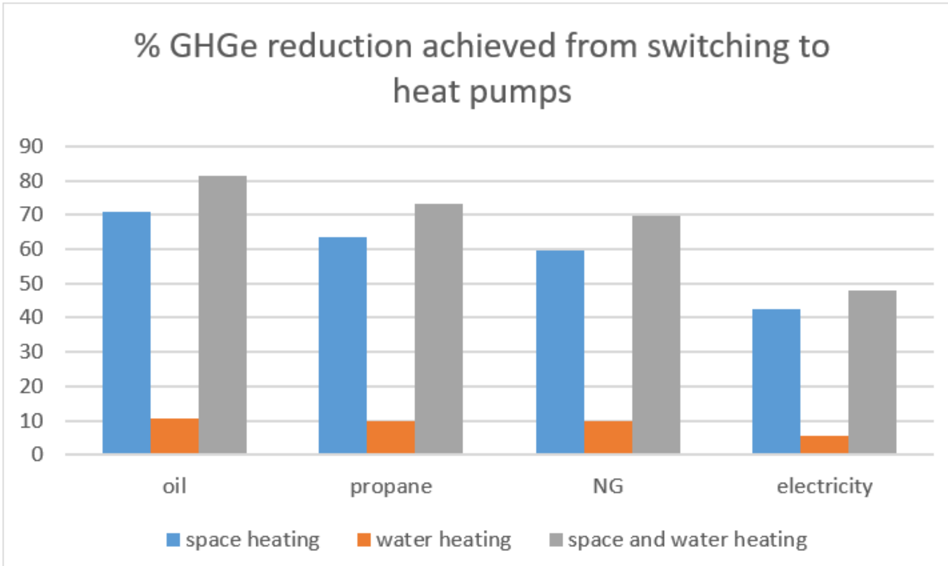


Figure 6 Potential % GHGe reduction that can be achieved from switching from various fuel sources to heat pumps for space and water heating

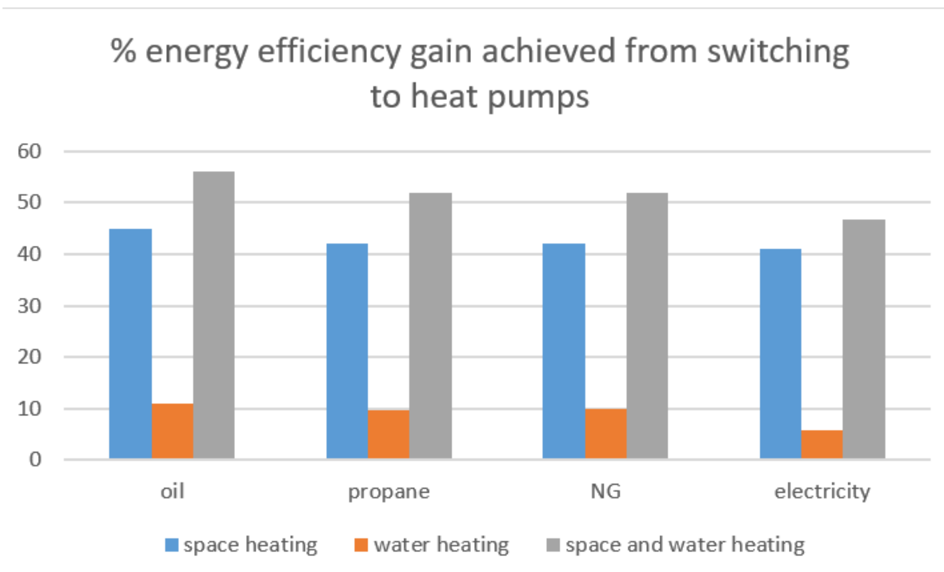


Figure 7 Potential % energy efficiency that can be achieved from switching from various fuel sources to heat pumps for space and water heating

Other considerations

A common concern about the promotion of heat pumps as a primary heat source is the increased demand that it will place on our electrical grid. Calculations based on the data available here suggest that if all low rise homes were to switch to heat pump technology for all space and water heating needs, the total annual electricity demand would rise from 1.72 TWh to 2.99TWh, a 74% increase in total demand. Much of this increased demand would occur in the winter months. Onsite electricity production, smart thermostats, and other utility-based demand management approaches could be used to shift electricity demand away from peak hours in ways that have little or no impact on the homeowner. Many North American communities are already using such program successfully[28].

The HVAC (Heating Ventilation and Air Conditioning) industry may also prove to be a barrier to electrification of space and water heating systems. I have had conversations with HVAC experts who were unaware of the existence of HPWHs. When seeking quotes for an ASHP for my home, more than one industry representative tried to convince me to consider a different system. One stated that heat pumps will never be able to compete with NG in terms of operating costs. It is clear that awareness and acceptance of electrified space and water heaters must also grow in the HVAC industry.

In the case of a power outage, switching to a fully electric heat system offers no additional risks since all conventional heating systems require electricity to operate.

Some homes use NG for cooking. Yet electric induction cooktops are more energy efficient, easier to clean, quick to heat food, better at maintaining low temperatures, and still offer the rapid changes in heat that gas stoves offer[29]. Raising awareness of the benefits of induction cookers along with the indoor air quality risks of cooking with gas[30] will be essential for residential decarbonization strategies.

Housing categories for electrification

If we are to reach our municipal, provincial and federal climate targets, all homes will have to switch to emissions-free space and water heating systems. At this time, heat pumps appear to be the best solutions. These systems are currently more expensive to install, to buy, and often to operate than NG systems. However, the technology is improving, utility prices are volatile, and carbon prices are set to increase. All of these factors could render these systems operationally cost effective in the near future. Federal and provincial incentives for low emission heating systems could also be a game changer. Below are a series of priorities for fuel switching based on the economic and climate considerations above.

1st priority: new homes

Adding NG infrastructure to new housing developments is expensive and risks generating stranded assets as electrification gains momentum. A US study put the average cost at $8,800 per household[31]: a value that exceeds the cost premium for installing an ASHP as an alternative to a natural gas furnace plus central air conditioning. Since new homes are airtight and well insulated, these homes are a good first target for electrification. Many municipalities across North America have already banned the installation of natural gas infrastructure in new developments, and many more are joining the bandwagon[32].

2nd priority: homes where electrification is already operationally cost effective now

Heat pump technology is already a cost effective alternative for homes heated with oil, propane and electricity (baseboard or electric furnace). Efforts should be made to encourage the switch to heat pumps in these homes as a climate-friendly alternative to NG. This can be done alongside retrofit measures that reduce the total energy required to heat a home. These homes represent an estimated 8% of all homes in the Waterloo region.

Furthermore, in an estimated 22% of Waterloo region homes, an ASHP is currently cheaper to operate than a natural gas furnace using current prices. These homes tend to be newer, smaller (<300 m2) and to have one or more shared walls (ie not single detached). Utility prices are volatile, however, and the upfront costs may be prohibitive: financing and incentives could go a long way toward increasing uptake in such homes.

Over 75% of homes that performed post-retrofit home energy audits between 1999 and 2019 upgraded their furnace. Since the average lifespan of a modern furnace is 10-20 years, many of these homes will be replacing their furnace again in the coming decade. Switching to heat pumps for space and hot water would represent very significant average energy efficiency gains and GHGe reductions (see Table 8).

3rd priority: homes that are replacing a hot water heater

Heat pump water heaters are currently more cost effective to operate than conventional NG tank systems as well as propane, oil and conventional electric systems. Their upfront costs are comparable to tankless systems and they can last significantly longer than conventional tank systems. The introduction of incentives could make the upfront cost and/or lifetime costs attractive for all homes.

The installation of HPWH could also be a good opportunity for a turnkey model of service where bulk purchases and efficient tradesperson scheduling could reduce the purchase cost for the consumer. For example, HeatSmart Mass is a program that aggregates homeowner buying power for clean technologies including heat pumps and resulted in the installation of 282 ASHP and GSHP systems in select communities across Massachusetts in 2019[33].

This switch would represent an average 16% energy efficiency gain and 10% GHGe reduction for most homes (see Table 9).

4th priority: homes that are installing or replacing their air conditioning

Most heat pumps perform equally well or better in terms of efficiency to standard air conditioning systems when it comes to cooling, but they offer the additional advantage of providing heat in the winter. Even cheaper dual fuel heat pumps that use a conventional furnace as a backup can be efficiently used for heating in the shoulder months or when NG prices are high.

Climate projections for the coming decades in the Waterloo region include more extreme summer heat, more intense rain and storms, and warmer winters[34]. Extreme heat events are a growing health concern for vulnerable populations, such as seniors, young children, and those with chronic illnesses[35]. The need to install cooling systems to protect these vulnerable populations is expected to grow. Ideally these cooling systems should be heat pumps that can also provide heating in cool and cold weather. Incentives could make these a cost-effective alternative to regular air conditioning units.

Of the homes where NRCan data exists about air conditioning (total 35,103 homes), 78% had central air conditioning (2,7371), 2.4% had window air conditioning (839) and 20% had no air conditioning.

5th priority: all other homes

Eventually all homes will need to switch to emissions-free space and water heating systems. Strong incentives, sustained utility price changes, and regulations may be required to motivate this change for homes where NG is currently in use. The need to upgrade the electrical wires and/or panels in many homes is an additional obstacle to fuel switching (see Appendix A) and municipalities will need to consider how best to accomplish this.

As the analysis above shows, fuel switching is more cost-effective in newer homes. Older homes should therefore be a priority for energy efficiency retrofits to reduce the overall heating load of the home first.

Conclusions

Heat pump systems that are capable of meeting all of Waterloo region's residential space and water heating needs while also cutting GHGe are available today. While they are generally more expensive to operate than the natural gas systems that fuel the majority of homes, this average price difference can be reduced to an average $166/yr if a home is disconnected from the natural gas supply. For a subset of homes, ASHPs can compete with NG systems when the gas supply is disconnected: these homes are typically newer, smaller and have shared walls. HPWHs on the other hand, are cost-comparative to operate to NG tank systems. An analysis of historical prices and show that cost parity for ASHPs could be achieved with a higher carbon tax ($127/t), a 37-56% increase in NG prices, or a 14-20% decrease in electricity prices. For other fuels, such as heating oil, propane and conventional electric appliances, heat pumps are already cost effective over their lifetime. The capital costs of these heat pump systems are still higher than conventional systems, however, and government incentives are therefore needed if heat pumps are to be widely adopted. Widespread adoption is essential if we are to meet our climate targets and the single step of switching to heat pumps for space and water heaters in all homes could achieve a 70-82% GHGe reduction: most of the way to reaching our 2050 climate targets. With only 30 years left, we need to prioritize and strategize this electrification transition. We can start with new homes where we can prevent the locking in of fossil fuel infrastructure. Add to that homes where heat pumps are already cost-effective. Next are homes that are replacing their hot water systems or adding/replacing an air conditioning system. Ultimately all homes must make the switch to heat pumps or other decarbonized heating systems. Electrification of residential heating systems is possible. It is time to develop incentives and programs to make this happen.

The electrification of residential space and water heating systems is possible. To meet our climate targets, we must start NOW to develop incentives and programs that will make this happen.

Appendix A: Electrical upgrades required

Replacing a natural gas fueled appliance with an electrical heat pump version is not always simple. An ASHP may require upgrading the home's electrical system to a 200 amp panel. Some homes already have a 200 amp panel, some homes have a 200 amp connection to the home but a lower amp panel, and some homes lack the 200 amp cable connection to the home.

Most homes built since 2000 have a 200 amp connection to the home but, depending on the builder, may or may not have a 200 amp electrical panel. An electrician is required to upgrade the panel: a service that typically costs ~$2,000[36]. There is no good way to predict whether older homes have 200 amp electrical panels or not as it depends on the builder, on upgrades since construction (eg addition of a hot tub), and on the original heating fuel used: homes built with baseboard electric heat are more likely to have a 200 amp electrical panel.

Homes that lack a 200 amp connection to the home must contact their electric utility to arrange the connection. In neighbourhoods where overhead wires are used, Kitchener-Wilmot Hydro does not charge for adding a connection but an electrician is required to upgrade the electrical panel. Other utilities have variable fees, including $900-$1100 for Waterloo North Hydro. In neighbourhoods where the wires are buried underground, the homeowner is responsible for paying the cost of upgrading the cable to the home, an endeavour that can cost several thousands of dollars[37].

An electrician may also be required to add cabling to the outside of the home to accommodate the outside unit of the heat pump and also to add a 60 amp, 205/230V breaker and wire[38].

For heat pump water heaters, the installer or an electrician may be needed to supply a new electrical connection (240V/15 or 30 amp). This may require new wiring from the electrical panel through the home to the heat pump location, the cost of which is hard to generalize: I have heard broad estimates of $300-$700.

Appendix B: Calculations

NOTES:

- unless otherwise noted, all calculations below were performed on the subset of data that included homes heated with natural gas
- the dataset includes homes that performed an initial home audit only (A and D) plus homes that performed an initial home audit and a post-retrofit audit (AB and DE)
- unless otherwise noted, the dataset used includes the most recent information about each home (from the initial audit for homes without retrofits and from the final audit for homes that had an audit post-retrofit)
- Kitchener Utility natural gas rates were used for this analysis. Enbridge Gas rates are slightly different and use a graduated rate system based on consumption.
- Kitchener Wilmot Hydro time of day rates were used for this analysis, these rates were averaged out over a week to give one average rate/kWh. Since hydro rates are set by the IESO, these rates will be the same for all residents of Ontario[39].

Total unit cost of NG (July 2020 rate from Kitchener Utilities)
= supply rate + variable delivery rate + federal carbon charge
= (0.135 + 0.070871 + 0.0587)$/m3
= 0.264571 $/m3

Annual fixed delivery charge for NG (July 2020 from Kitchener Utilities)
= 0.73$/day
= $266.45/yr

Average unit cost of electricity (July 2020 rate from Kitchener Wilmot Hydro)
= delivery and regulatory charges + weekly average electricity price
= delivery and regulatory charges +((5d*12h*off-peak)+(2d*24h*off-peak)+(5d*6h*mid-peak)+(5d*6h*on-peak))/7d*24h
= (0.0104 + 0.127786) $/kWh
= 0.138186 $/kWh

ASHPEFF = 3.0
WHHPEFF = 3.5
Constant values for various fuels

	oil	propane	NG	electric	ASHP
Avg furnace efficiency	79.14%	94.00%	92.44%	100%	300%
Avg water heater efficiency	53.11%	62.74%	57.63%	82.21%	350%
Conversion factor	0.03672 GJ/L[40]	0.02553 GJ/L[41]	0.038 GJ/m3	0.0036 GJ/kWh	0.0036 GJ/kWh
Price	0.7413$/L[42]	0.899 $/L[43]	0.264571 $/m3	0.138186 $/kWh	0.138186 $/kWh
Emission factor	2.753 kg/L[44]	1.515 kg/L[45]	1.888 kg/m3[46]	0.100 kg/kWh	0.100 kg/kWh

Calculating the operating cost difference for heating with NG vs an ASHP

- I only used values from homes that heat with NG for this analysis

Calculating the annual cost of NG for total space energy

m3/yr of NG used for space energy = SPACEENERGY/38MJ/m3

Cost of NG used for space energy = m3 NG * total unit cost of NG

Calculating the annual cost of operating an ASHP for total space energy

kWh/yr of electricity used for space energy with an ASHP
= SPACEENERGY*(FURSEFF*0.01)/(3.8MJ/kWh*ASHPEFF)

Cost of electricity used for space energy with and ASHP
= (kWh for space energy)*average unit cost of electricity

Cost difference between heating with NG and heating with an ASHP
= cost of NG - cost of electricity for an ASHP

Calculating the operating cost difference for heating water with NG vs HP

- I first calculated the average ERSWATERHEATINGENERGY from those datasets the included this value (n=7489)
  - Avg water heating energy consumption = 13641 MJ/yr
  - Avg water heating energy load = 8075 MJ/yr
    = (average of ERSWATERHEATINGENERGY*PDHWEF)
- I used the data subset that included homes that used natural gas for space and water heating (n=36,685)

M3 of NG for water heating
= avg water heating energy/(38 MJ/m3)

Cost of NG used for water heating = m3 NG * total unit cost of NG

kWh/yr of electricity used for water heating with a HP
= avg water heating load/(3.8MJ/kWh*WHHPEFF)

Cost of electricity used for water heating with a HP
= (kWh for water heating)*average unit cost of electricity

Cost difference between water heating with NG and with a HP
= cost of NG - cost of electricity for a HP

Calculating the total operating cost difference for fuel switching from NG to HP

= total NG costs for heating and water
+ annual fixed delivery charge for NG
- total kWh costs for heating and water

Calculating price equivalence point

Using average energy use, average furnace/water heater efficiency and current prices, the price needed to make one fuel source equal to the existing price of the other fuel source was calculated.

Cost = ((avg heating load)/(avg FURSEFF) + (avg water heating load)/(avg PDHWEF))/(MJ/m3 or MJ/kWh)*($/m3 or $/kWh)

Calculating carbon tax to make and ASHP cost equivalent to NG heating

Current c-tax = $30/t

= 0.003 $/kWh ($0.03/kg*0.1 kg/kWh)

= 0.0587 $/m3 (given on utility bill)

Cost = ((avg heating load)/(avg FURSEFF) + (avg water heating load)/(avg PDHWEF))/(MJ/m3 or MJ/kWh)*(($/m3 or $/kWh with current c-tax subtracted)+ ***X****(kg/kWh or kg/m3))

Set the costs as equal for ASHP and NG and solve for ***X***

Calculating the cost to heat and GHGe for all fuels

Cost = (Average energy load)/FURSEFF/ conversion factor * price

GHGe = (Average energy load)/FURSEFF/ conversion factor * emission factor

Calculating the extra electricity load for full electrification

Total of all energy use for space heating in housing in the Waterloo region

For each fuel type, calculate total energy use:

(Average energy load / Average FURSEFF(for that fuel))*(total p9 housing[47] in the WR)*(% of housing with that fuel in the NRCan sample)

Extra electricity load =

((Sum of total energy use for all fuels)/(0.0036 GJ/kWh)/(COP for ASHP) – (total energy use for electric heat))/(0.0036 GJ/kWh)

Total of all energy use for water heating in housing in the Waterloo region

Same as above using

- Avg water heating energy load
- Average PDHWEF for each fuel
- COP = 3.5

Calculating the average energy efficiency gain and GHGe reduction for fuel switching

% efficiency gain = 1 – (avg FURSEFF for original fuel)/(avg FURSEFF for new fuel)

%GHGe reduction = 1 - (GHGe for new fuel)/(GHGe for original fuel)

%GHGe reduction for the whole home (space heating system change only)

= (sum of new GHGe for heating, hot water and electricity)/(sum of original GHGe for heating, hot water and electricity)

Table 12 Absolute GHGe reduction potential per household from switching from various fuels for space and water heating to heat pumps

	oil	propane	Natural gas	electricity	Heat pump
GHGe from electricity	1.06 t	1.06 t	1.06 t	1.06 t	1.06 t
GHGe from space heating	8.0 t	5.3t	4.5 t	2.3 t	0.78 t
GHGe from water heating	1.1 t	0.76 t	0.70 t	0.27 t	0.064 t

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