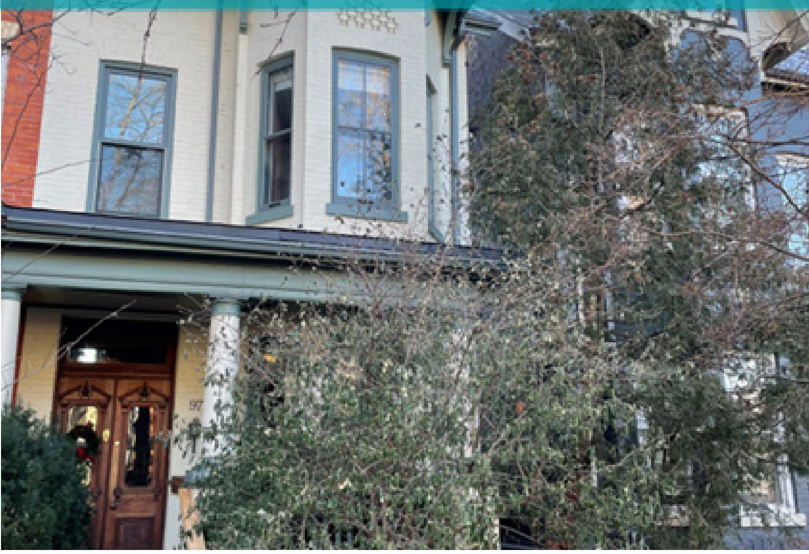
Sustainable Technologies EVALUATION PROGRAM

Supported by Toronto and Region Conservation Authority

TECHNICAL BRIEF

Residential Heat Pump Case Study 4: Cold-Climate Heat Pump in a Century Townhome



The Sustainable Technologies Evaluation Program (STEP) is a collaborative non-profit research initiative within the Toronto and Region Conservation Authority (TRCA). Among other priorities, STEP partners with government, utilities, non-profits, academic institutions, and private companies, to pilot and evaluate emerging low-carbon technologies for buildings with the aim of providing real-world data, analysis, tools, and outreach that promotes effective technological solutions for climate change mitigation.

INTRODUCTION

This is the fourth case study in a series evaluating heat pump installations in single-family homes in Ontario, focusing on the Greater Toronto and Hamilton Area. The City of Toronto targets net-zero emissions by 2040. Most of the emissions (57%) are from homes and buildings, primarily a result of natural gas used for space heating. Home energy retrofits on a massive scale are therefore needed. Cold-climate air-source heat pumps (ASHPs) are a low-carbon alternative that can completely replace conventional mechanical systems that rely directly on natural gas or other fossil fuels. This case study evaluates upfront costs, carbon reductions, and utility bill impacts of a Toronto installation.

SITE AND EQUIPMENT

The centrally-ducted cold-climate ASHP was installed in November 2020 in a Victorian townhome that was constructed in 1885 and is located in the Harbord Village neighbourhood. The ASHP replaced an aging high-efficiency furnace and A/C system. The home is approximately 2,400 ft^2 and has a single occupant. Various energy upgrades have been performed over the home's lifetime. Fibreglass insulation was added to walls in the 1980s. Insulation has also been added to both the roof (during a partial roof replacement) and basement walls/headers. Air-tightness has been improved through caulking windows and improving weatherstripping on doors. Many windows have been upgraded but 9 of 22 windows are original. The home has a solar hot water system assisted by an on-demand natural gas heater. When the budget allows, the homeowner plans to use electric water heating and disconnect natural gas entirely.

Air-source heat pumps (ASHPs) can completely replace conventional home heating and cooling systems that directly rely on fossil fuels like natural gas, propane, or oil. ASHPs are normally powered by electricity and provide heat to a home by extracting heat energy from cold outdoor air. Some **cold-climate** ASHPs operate in conditions as cold as -30°C. They also provide cooling. Because they "pump" heat, ASHPs can be approximately 3x more efficient than furnaces or boilers. In jurisdictions with a low-carbon electricity grid, ASHP retrofits can reduce carbon emissions and lifetime operating costs.

Table 1. Equipment schedule for the ASHP system.

	Equipment
ASHP	**PUZ-HA36NHA4** Mitsubishi Electric Zuba-Central Cold-Climate ASHP; Variable capacity; 3-Ton nominal; HSPF (IV/V) 11.0/9.0; 17.8 SEER **PVA-A36AA4** Air handler
Other	**EH15-MPAS-LB** 15 kW Back-up electric resistance heating coil; **Ecobee 4** thermostat; Small bypass humidifier

UPFRONT COSTS

A premium high-performance inverter-driven cold-climate ASHP with electric resistance back-up may currently cost between $19,000 and $25,000 (plus tax; not including rebates) for a single-family home. The cost for this ASHP installation was at the low end of this range. It includes all costs associated with the removal and recycling of the old system and the installation of the equipment listed in Table 1. Note that the federal Greener Homes Grant currently offers rebates up to $5,000 for large high-performance ASHPs. This was announced after the system was installed. Also, note that installed costs may be lower for ASHPs with lower performance ratings and/or shorter warranty periods.

There was an additional cost of approximately $3,500 (plus tax) to upgrade the electrical service of the home to 200A to accommodate the increased electricity demand. This also included a new circuit and receptacle for an electric stove that replaced a gas stove at the same time of the ASHP retrofit. Newer homes may not require a service upgrade. A conventional furnace-A/C replacement for a comparable home may cost between $6,000 and $10,000 (plus tax), or possibly more depending on the installer and the home. The additional upfront cost (post-rebate) of a high-performance central cold-climate ASHP system is then several thousand dollars to potentially more than $10,000. While this cost is substantial, the analysis will show that the lifetime operating cost savings can offset much (or nearly all) of the incremental upfront costs.

UTILITY BILL ANALYSIS

Natural gas and electricity bill consumption data were analyzed for 10-month periods directly pre- and post-retrofit. The pre-retrofit data was adjusted for weather and used as a baseline for comparison against the post-retrofit data. No other energy upgrades were undertaken alongside the retrofit. Current (January 2022) utility rates were assumed. The full analysis is available online.[1] It is summarized in Table 2. Overall, the system's utility impacts were in line with the expectations from the standardized performance ratings. The ASHP system reduced the total gas consumption of the home by 87%. At current rates, it approximately broke even on utility costs but savings is expected to grow to $193 per year by 2030 due to carbon pricing. There is uncertainty projecting into the future, but if carbon pricing continues escalating at the same rate beyond 2030 then lifetime (15 years) savings from the change in energy consumption could be near $2,600.

> "The machine works well. The heat is constant. The noise level inside the house is generally less than with my old gas furnace, but there is a bit of a rumble from the side wall of the kitchen when the heat pump begins its work. My anxiety about running costs was finally allayed by the bills over an entire year. The heat pump, running on electricity, cost virtually the same to run as my old gas furnace and electric central air conditioner." -Homeowner

Table 2. Utility bill analysis results.

Parameter	Value
Actual post-retrofit gas consumption (Jan 2021 to Oct 2021)	144 m^3
Baseline gas consumption	1,142 m^3
Total gas reduction from ASHP	998 m^3 (87 %)
Actual post-retrofit electricity consumption (Jan 2021 to Oct 2021)	7,813 kWh
Baseline electricity consumption	4,717 kWh
Total electricity increase from ASHP	3,096 kWh
Gas reduction for space heating due to ASHP system	100 %
Net utility cost savings (gas and electricity) at current rates	$26
Net space heating carbon reduction (2021 **annual** emission factor)[i]	1.8 tonnes (95 %)
Net space heating carbon reduction (2021 **marginal** emission factor)[i]	1.5 tonnes (81 %)

[i]There are different approaches to calculating emissions reductions. Marginal or annual emissions factors may be used. This is discussed in reporting from The Atmospheric Fund.[2] This table assumes an electricity grid emission factor of 37 g eCO_2/kWh and a marginal emission factor of 134 g eCO_2/kWh for 2021.[2]

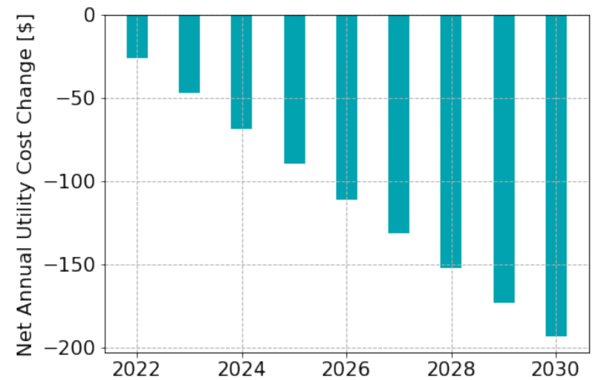


Figure 1. Estimated annual net utility cost changes from the ASHP considering carbon pricing. Electricity rates were assumed to increase at 2%/year from current values. Natural gas was assumed to only increase according to carbon pricing. Negative values indicate savings.

CARBON EMISSION REDUCTIONS

Carbon reductions are calculated in Table 2 using *current* grid emission factors (EFs). However, the EFs of grid electricity are forecasted to increase significantly due to nuclear reactor retirement and refurbishment, and planned increased dependence on electricity generation from natural gas. New policy and technology can change this trajectory. These details are outlined in reporting from The Atmospheric Fund (TAF).[2]

The combination of electric heat pumps and clean electricity is a key pathway to achieving net-zero emissions in buildings. However, the carbon reductions of electrification are reduced if there is a significant amount of natural gas generation on the grid. Using this retrofit as an example, and the *projected emission factors for 2036* within the forecast from TAF, carbon reductions from the utility change in Table 2 are 1.6 tonnes or 85% (annual EF) and 0.83 tonnes or 44% (marginal EF). This is still notable but it falls well short of net-zero emissions. Overall, TAF urges that "... **it is critical to curtail natural gas generated electricity by massive adoption of renewable generation, storage solutions, and conservation measures**. This will open much needed capacity for the continued electrification of transportation and heating."

HOMEOWNER EXPERIENCE

The homeowner is very happy with the decision to install an ASHP. The heat pump is quiet and provides comfortable temperatures. The utility costs are currently near pre-retrofit levels and carbon pricing should generate annual utility savings. The homeowner recommends thinking about an ASHP sooner rather than later, because the sizing and design process can be longer than with a conventional system. A furnace failure is not the ideal time to consider options.

FINANCIAL CASE FOR ELECTRIFICATION

It's helpful to discuss the broader financial case for electrification. However, a holistic lifecycle cost analysis is complex. The electrical service upgrade is costly but would not be required in every home. There is a rebate available for certain ASHPs and also potential reductions in property insurance. A significant new development is the planned offering of no-interest loans both from the City of Toronto and the CMHC. A source of savings in the context of no-interest loans is the avoidance of interest payments for financing conventional equipment.

No-interest loans also allow a homeowner to defer the upfront cost to future years with no penalty. Because of inflation and the ability to generate a return on investments, *future* cash flows have a lower value in today's dollars than *present* cash flows. Effectively, no-interest loans reduce upfront as well as make it more manageable by spreading it out over many years. A net present value (NPV) analysis is required. It determines the present value of a retrofit in today's dollars considering all anticipated cash flows in future years.

The financial analysis becomes more complex if considering fully electrifying the home and disconnecting from natural gas altogether. The motivation to consider this is that homeowners pay a fixed fee for a gas connection regardless of how much they consume. If electrifying the heating load but not the remainder of the home, the fixed fee could easily become the large majority of the overall gas bill. Currently, it is $25 per month ($300 per year). This can be avoided if electrifying.

Some homes use natural gas for only water and space heating, but each system may not be approaching end-of-life at the same time and there is a cost if replacing sooner than required. Water heating upfront and operating costs can go up or down depending on the electric and gas options being considered. Natural gas may also be used for other appliances like the stove, dryer, barbeque, or fireplace, and disconnecting from natural gas would require a homeowner to replace those appliances or, at least, discontinue their use in the case of the barbeque or fireplace. Gas appliances can be comparable in terms of upfront cost to electric options but there is also a cost for new electrical circuits. An ancillary benefit of electrifying the stove is improvements in indoor air quality.

It's clear that the full financial case for electrifying the heating load, or the whole home, is complex and going to vary greatly case-by-case. Tools and training for professionals are needed. For now, it's helpful to use data from this home as an example. The homeowner has not electrified the hot water, nor have they benefitted from rebates or other programs that are proposed or available. This analysis is for prospective system owners. Note that there is a range of equipment and installation costs with many influencing factors. **Homeowners ought to get multiple quotes from qualified contractors to evaluate their own financial case for different options.**

This home used natural gas for space heating, water heating, and a stove. The homeowner replaced the stove as part of the retrofit but it was only part-way through its useful life. The cost of the new stove circuit was included in the service upgrade cost provided previously. The homeowner currently has a 12-year old Navien 210 condensing on-demand water heater as the only remaining natural gas load. It potentially has several years left of an average 20-year serviceable life. Since her gas load for hot water is low, a simple alternative for this example is an electric resistance hot water tank. This has a lower upfront cost than a replacement of the on-demand water heater, but it would increase the utility costs for water heating. Homeowners should generally consider an air-source heat pump water heater. These can have comparable installed costs to on-demand gas options.

An NPV calculation was made for a 15-year time horizon to determine the value of fully electrifying the home, and also for only electrifying heating. The full calculation is provided online.[1] Results are shown in Table 3 considering different discount rates. The discount rate is the key parameter used to express future cash flows in terms of present dollars. A range of possible values is provided in Table 3. However, the discount rate does not greatly impact the net results because both future savings and costs are being adjusted.

DISCUSSION & CONCLUSION

For this example, Table 3 shows **electrification is expected to cost more than business as usual with natural gas but only by a small amount in some cases**. The equivalent additional cost of full electrification of the home was estimated to be between $8 and $12 per month for the lifetime of the system. This is useful for homeowners interested in electrification but concerned about upfront and operating costs. It's also clear that costs could shift either way for different homes. For example, **if no service upgrade was required with water and space heating as the only gas loads, electrification could be cost comparable or better**. Each home is different and a case-by-case analysis is required.

Table 3. Net present value calculation for (i) full electrification of home and (ii) electrification of only the heating load. The present value (PV) of each source of cost or savings is calculated for different discount rates (shown in brackets). Negative values are costs and positive values are savings.

Parameter	PV (2%)	PV (5%)	PV (7%)
Post-rebate ASHP and service upgrade cost[i]	-$17,496	-$14,134	-$12,402
Cost of electric water heater and install[ii]	-$1,808	-$1,808	-$1,808
Cost of new electric stove	-$1,000	-$1,000	-$1,000
Increase in water heating costs[iii]	-$2,036	-$1,644	-$1,442
Avoided cost of furnace-A/C installation[iv]	$9,571	$8,792	$8,326
Avoided cost of water heater replacement in 8 years[v]	$3,034	$2,406	$2,069
Avoided cost of stove replacement in 8 years[vi]	$853	$677	$582
Utility savings for space heating[vii]	$2,104	$1,587	$1,329
Property insurance reductions[viii]	$1,028	$830	$729
Avoided cost of gas customer charge[ix]	$3,855	$3,114	$2,732
NPV for full electrification of home	**-$1,894**	**-$1,179**	**-$885**
NPV for full electrification of home expressed as equivalent monthly payments over 15 yrs	**-$12**	**-$10**	**-$8**
NPV for electrifying only space heating[x]	**-$4,793**	**-$2,925**	**-$2,018**
NPV for electrifying only space heating expressed as equivalent monthly payments over 15 yrs	**-$31**	**-$24**	**-$19**

[i] Assumed an installed cost of $19,000 plus a $3,500 service upgrade (which includes a new stove circuit) plus tax minus a $5,000 rebate. The post-rebate cost is financed at 0% over a 15 year equipment lifetime.
[ii] Assumed a $600 equipment cost plus $1,000 installation cost plus tax.
[iii] Assumed the same fuel cost escalation as in Figure 2. The annual increase is on the scale of $160/yr.
[iv] Assumed mean furnace-A/C cost of $8,000 plus tax, financed at 4% over 5 years.
[v] Assumed $3,500 installed cost for like-for-like equipment plus tax minus a $400 Enbridge incentive.
[vi] Assumed nominal cost of $1,000 in 8 years.
[vii] Used same assumptions as Figure 2. Electricity increases at 2%/year. Natural gas increases only at rate of carbon pricing schedule. Assumed carbon pricing increases at same rate beyond 2030.
[viii] Assumed property insurance reduction of $80/year. This has been provided by a homeowner that has installed a similar system and received a reduction in their rates. This is **not** available from every insurer.
[ix] Assumed the gas customer charge stays constant at $25/month and $300/year.
[x] Ignores all costs related to stove and water heaters.

Note that this is a case study of a single installation. It looked at the impacts of replacing a high-efficiency furnace-A/C system near the end of its useful life with a new high-performance ASHP. Results in other homes may be different. A limitation of this analysis is that the future is uncertain. The gas customer charge may change and utility rates may escalate differently than assumed here. There is also uncertainty in the mix of Ontario's future electricity supply. For net-zero emissions, it is critical that the forecasted electricity supply mix changes from its current trajectory of increased dependence on natural gas. With this in mind, it should also be understood that **deep building envelope upgrades are an especially relevant approach for decarbonization**. Uncertainties around future electricity rates, supply mix, and grid capacity are alleviated when homes simply require much less heating.

Overall, this case study demonstrated that current and proposed public programs (carbon pricing, rebates, and no-interest loans) alongside a fulsome assessment of costs and savings can make fully-electric high-performance ASHP systems approach cost-competitiveness with conventional furnace-A/C systems in some cases. It follows that cold-climate ASHPs are a key technology, alongside other technologies and approaches, in the transition to net-zero carbon.

REFERENCES AND ENDNOTES

[1] The full data analysis for this document was completed in a Jupyter Notebook. It is freely available for review at a public online repository, located at: https://github.com/github.com/SustainableTechnologies/CaseStudy4

[2] The Atmospheric Fund. A Clearer View of Ontario's Emissions. 2021 Edition.

"Go for it. Do it now. Help the City, the country, the planet. Do it for yourself. For your kids. In a single stroke, you will land in a place where you have done your part to ensure the planet will be safe. Reach out to the City, to your councilor. But do it. The most frustrating position of all would be to wait, have your furnace fail, and have no time to install the heat pump option." -Homeowner

This communication has been prepared by the Sustainable Technologies Evaluation Program (STEP). STEP gratefully acknowledges the contributions of homeowner Susan Dexter. Equipment cost ranges in the "Upfront Costs" section have been provided by Imperial Energy. These cost ranges were reviewed by Belyea Brothers, the installing contractor for this installation. The contents of this report do not necessarily represent the policies of supporting agencies. Mention of trade names, vendors, and commercial products does not constitute an endorsement of those products or services.

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