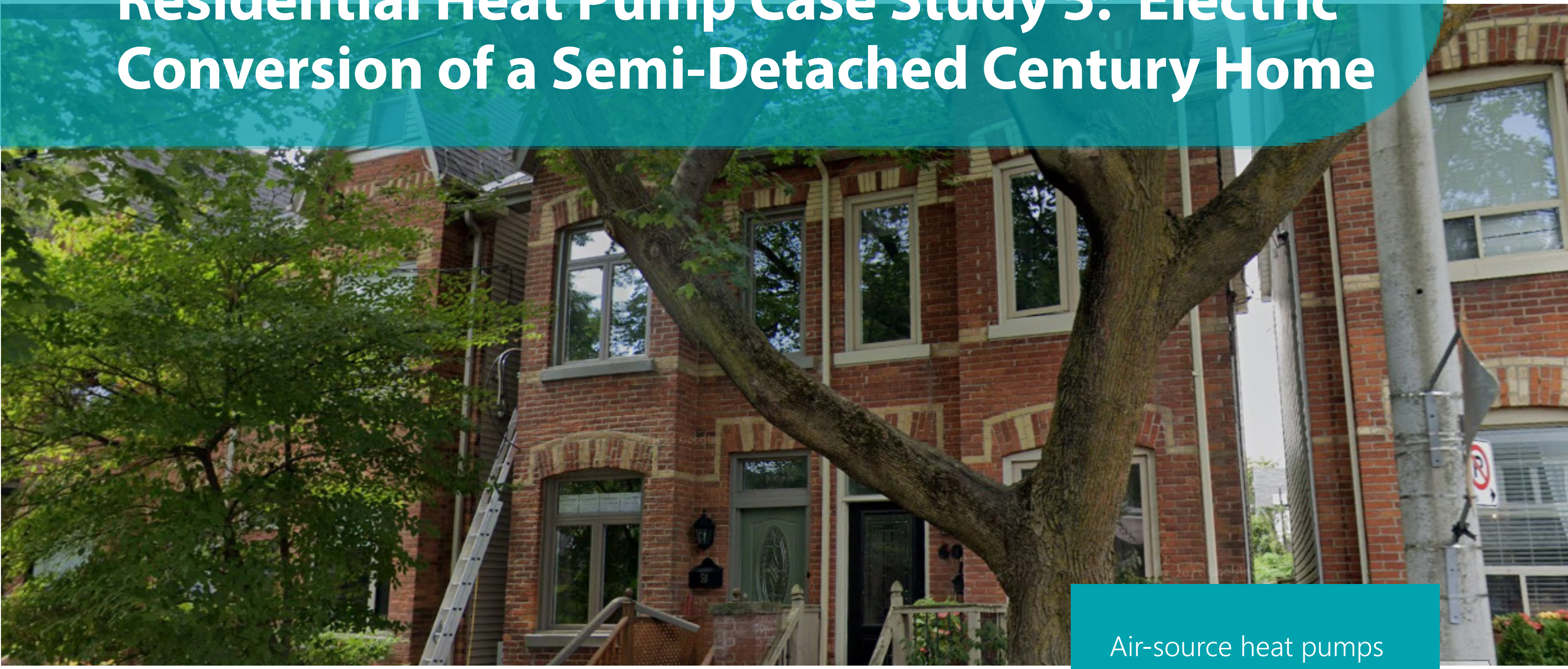
Sustainable Technologies EVALUATION PROGRAM

Supported by Toronto and Region Conservation Authority

TECHNICAL BRIEF

Residential Heat Pump Case Study 5: Electric Conversion of a Semi-Detached Century Home



EXECUTIVE SUMMARY

The City of Toronto targets net-zero carbon emissions by 2040. Most of the carbon emissions in the City come from homes and buildings, due to the combustion of fossil fuels (primarily natural gas) for heating. Home energy retrofits on a massive scale are therefore urgently needed. This case study evaluates the financial case and carbon reductions from a retrofit of a Toronto home where the gas furnace and water heater were replaced with electric heat pumps. The heat pumps have greater upfront cost than a like-for-like replacement of the gas equipment, but they also have lower utility bills. Considering both the upfront costs and the utility savings, the homeowners will likely end up paying more overall by having chosen the heat pumps. However, the equipment was selected prior to the federal rebate program and the availability of no-interest loans. With these programs, a homeowner undertaking a similar retrofit today could see net savings overall. Note that there is significant uncertainty in estimating lifetime savings, and the financial case and implementation challenges will vary home-to-home. The homeowners also report improved indoor comfort and are overall satisfied with the system.

SITE AND EQUIPMENT

The centrally-ducted cold-climate ASHP was installed in October 2021 within a 2.5-storey semi-detached century home in Toronto's Leslieville neighbourhood. The ASHP replaced an aging mid-efficiency furnace and A/C system that was serving the basement and first two floors. A ductless mini-split ASHP also replaced a ductless A/C unit on the third floor. The gas water heater was replaced by an ASHP water heater. A gas stove remains but the homeowners plan on replacing it soon with an electric stove, and disconnecting the home from gas entirely. In the years prior to the retrofit, the home had a variety of energy improvements, including air-sealing, windows and door replacements, roof insulation upgrades, as well as other measures.

Air-source heat pumps (ASHPs) can partly or 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.

UPFRONT COSTS

An itemized breakdown of the full retrofit is provided in Table 1 (costs include HST). Note that the retrofit had a broad scope, including an ASHP water heater, central and ductless ASHPs, an energy recovery ventilator (ERV), and significant ductwork changes. Not all of these costs would be incurred in a typical retrofit. For example, the scale of the retrofit resulted in increased costs for HVAC design and a permit. Furthermore, the original ductwork was poorly configured and contributed to poor thermal comfort within the home. Ductwork changes were required to accommodate the ERV and create a finished basement with adequate heating, cooling, and ventilation. Custom ductwork would have been required regardless of the central ASHP. A single ASHP may also be sufficient in other homes. While the total cost of all items was $52,667, the cost of the items directly related to the space heating ASHPs was $36,077. Note that the cost of the electrical service upgrade varies home-to-home and was on the high end for this home.

Table 1. Equipment and installation costs. Note costs will vary for different ASHP equipment and in different homes.

	Equipment	Description	Cost
1	HVAC Design and Permit Submission	-	$1,025
2	Electrical Panel, Conduit, and Meter Upgrade	Upgrade to 200 Amp service. Inclusive of permit submission and Toronto Hydro fees	$6,300
3	Electrical Connections for Equipment (240V)	Connections for central ASHP, ERV, and heat pump water heater	$1,250
4	Electrical Connections for Equipment (240V)	Connections for ductless ASHP	$1,500
5	Plumbing	Plumbing for heat pump water heater	$1,000
6	Additional Labour	-	$815
7	Custom Duct Work	-	$6,215
8	Central ASHP Equipment and Installation	**SUZ-KA30NAHZ** Mitsubishi Electric Central Cold-Climate ASHP; Variable capacity; 2.5-Ton nominal; HSPF (IV) 9; SEER 15; **SVZ-KP30NA** Air handler	$17,712
9	Auxiliary Heater for Central ASHP	**EH10-SVZ-M** 10 kW Electric resistance heating coil	$1,300
10	Ductless ASHP Equipment and Installation	**MSZ-FH09NA** Mitsubishi Electric Ductless Cold-climate ASHP; HSPF (IV) 12.5; SEER 30.5	$7,200
11	ERV	**Vanee 150** Energy Recovery Ventilator	$3,600
12	Heat Pump Water Heater	**Rheem Professional Prestige 80** USG Hybrid Heat Pump	$4,750
13		**Total**	**$52,667**
14		**Total Neglecting Permit (1), Ductwork (7), and ERV (11)**	**$41,827**
15		**Total Neglecting Permit (1), Plumbing (5), Custom Ductwork (7), ERV (11), and Heat Pump Water Heater (12)**	**$36,077**

"The duct-based heat pump is meeting our heating and cooling needs for the basement, first and second floor, and the ductless heat pump is meeting our needs for the third floor. Generally speaking, thermal comfort has significantly improved. Temperatures now remain relatively consistent year-round. Conversely, our two-stage natural gas furnace resulted in more significant temperature fluctuations in the heating months."
-Homeowner

The Canada Greener Homes Grant (GHG) currently offers up to $5,000 in rebates for heat pumps meeting program criteria. A key criterion is that the heat pump efficiency must be above a certain threshold value (HSPF 10). The central ASHP in this case study did not meet the efficiency requirements because it had an HSPF of 9. It was not eligible for a rebate despite the deep carbon savings it produced. When the homeowners were selecting equipment the GHG had not yet finalized its criteria. The only rebate available to the homeowners for this deep retrofit was $1,000 for the water heater.

By choosing ASHPs, the homeowners avoided the cost of conventional equipment. Neglecting the ERV, this includes a high-efficiency furnace and air-conditioner, a high-efficiency on-demand water heater, and a ductless mini-split A/C unit, estimated to total near $20,000 for premium equipment. The incremental cost for the heat pumps was therefore near $21,000 for this home (comparing against Table 1 Line 14, and including a $1,000 rebate for the water heater).

UTILITY BILL ANALYSIS

Natural gas and electricity bill consumption data were analyzed for 8-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 (to which savings could alternatively be attributed).

A small correction was made to account for the fact that the ERV increased the heating load post-retrofit by actively ventilating the home. No correction was made for a plug-in hybrid that was charged at the house starting in February 2021, and for this reason, the energy savings estimate is believed to be conservative. Current (November 2022) utility rates were assumed. It is worth noting the gas rates are currently much higher than recent historical levels. The full analysis is available online[1] and is summarized in Table 2.

Overall, the system's utility impacts (gas reduction and electricity increase) were near expectations from the equipment efficiency ratings. The retrofit reduced the gas consumption of the home by 98%. Recall that a gas stove remains but will soon be converted to electric. At current rates, the system is estimated to reduce utility costs by $580 for the heating season compared to the previous system. When the homeowners replace the stove and disconnect from gas entirely, there will be an additional savings of $300 per year from avoiding the monthly fixed customer charge paid to the gas utility.

Table 2. Utility bill analysis results.

Parameter	Value
Actual post-retrofit gas consumption (Oct 23, 2021 to Jun 22, 2022)	40 m^3
Baseline gas consumption	2,447 m^3
Total gas reduction from full retrofit	2,407 m^3 (98 %)
Actual post-retrofit electricity consumption	10,148 kWh
Baseline electricity consumption	2,428 kWh
Total electricity increase from full retrofit	7,720 kWh
Net utility cost savings (gas and electricity) at current rates[I]	$580
Annual carbon reduction (2021 **annual** emission factor)[II]	4.3 tonnes (95 %)
Annual carbon reduction (2021 **marginal** emission factor)[II]	3.7 tonnes (81 %)
Annual carbon reduction (2036 projected **annual** emission factor)[II]	3.8 tonnes (84%)
Annual carbon reduction (2036 projected **marginal** emission factor)[II]	1.9 tonnes (42%)

[I]This does not include savings from the fixed gas customer charge, and note that these savings are in reference to the previous system that used a mid-efficiency (assumed 80 - 85% efficient) furnace.
[II]There are different approaches to calculating emissions reductions. Marginal or annual emissions factors may be used, and these are projected to change over the lifetime of the system. The projections themselves may also change. This is discussed in reporting from The Atmospheric Fund.[2] This table assumes an annual electricity grid emission factor of 37 g eCO_2/kWh and a marginal emission factor of 134 g eCO_2/kWh for 2021. For projected values (in 2036; near the end of the system lifetime), an annual electricity grid emission factor of 94 g eCO_2/kWh and a marginal emission factor of 340 g eCO_2/kWh is assumed.[2] Note that the 2036 project marginal value is high because the current IESO outlook includes increased dependence on gas-powered electricity, but this may change.

FINANCIAL ANALYSIS

Table 2 utility savings are with respect to mid-efficiency gas equipment. Figure 1 offers a projection of future savings using high-efficiency natural gas options as a point of comparison, and also including estimated savings from September and October (where there was no post-retrofit data). Figure 1 includes fuel cost escalation to 2030 due to the federal carbon pricing schedule, and the gas customer charge savings. Note that **there is significant uncertainty projecting into the future**. Gas rates have risen dramatically in recent months and accurate predictions into the future are impossible. However, despite the uncertainty, it is important to discuss the lifetime savings of ASHPs because the higher upfront costs should be offset (to some level) by lifetime savings.

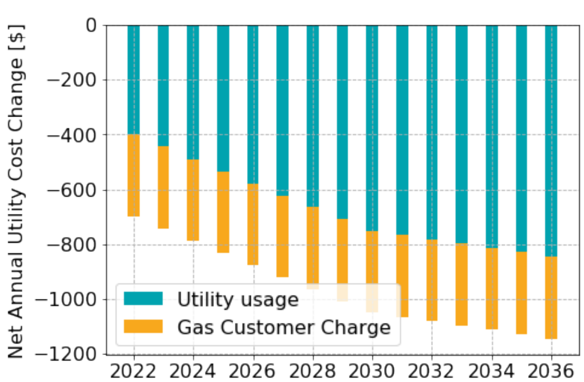


Figure 1. Estimated annual net utility cost changes from the ASHP considering carbon pricing. Electricity rates were assumed to increase at 2%/year from current values. Natural gas was assumed to only increase from current values according to carbon pricing. Negative values indicate savings.

For gas rates, Figure 1 assumed future rates are equivalent to the current rate escalated according to the federal carbon pricing schedule up to 2030, at which point the escalation continues at 2%/year. It also assumed electricity rates simply escalate from current values at 2%/year. It is not claimed that this is what will happen. It is only a potential scenario. Under this set of assumptions, 15-year cumulative savings would be $14,525 without adjusting for the time value of money.

However, a fulsome financial analysis must consider the time value of money and currently-available programs. Costs are better when they happen in the future, and savings are better when they happen today. Both leave more money in your pocket sooner. That money can be invested to earn interest, making more money. Money also has more purchasing power today than in the future due to inflation. Future cash flows (savings and expenses) can be expressed in today's dollars using a discount rate. This reduces their value.

The analysis should also consider current programs. New installs would likely select a central ASHP eligible for a rebate. They may also consider 0% financing currently available through the federal Greener Homes Loan Program. The Loan Program allows a homeowner to defer the upfront cost at no penalty and pay it off over 10 years. This makes the cost easier to manage because it is spread out, and the savings free up cash for the loan repayment. It also reduces the effective upfront cost in today's dollars.

Figure 2 calculates the net present value (NPV) of the ASHP retrofit for different scenarios. Both space and water heating systems were included in the analysis. NPV sums the incremental upfront costs of the ASHP retrofit against the lifetime (15 years) savings they produce when compared against conventional gas systems. NPV also considers the time value of money. If the NPV is $2,000, then the overall financial benefit of the ASHP retrofit is comparable to having an extra $2,000 in your pocket today. Conversely, if the NPV is negative then the ASHP retrofit overall costs more than a gas system.

The different scenarios include (i) no 0%-financing or 0%-financing with an additional rebate ($4,000 over and above the $1,000 already applied); (ii) gas rates stay high (illustrated in Figure 1) or gas rates come down by 20%; (iii) including or not including an electrical service upgrade; and (iv) discount

"Indoor noise levels have increased slightly, as a result of the plumbing and HVAC equipment we have introduced. Some of this results from the sump pump, ejector pump and ERV. However, all plumbing and HVAC equipment is housed in what will soon become an enclosed and acoustically insulated basement mechanical room. We anticipate this will bring noise levels down to a level compatible with basement living. Outdoor noise levels have improved in the cooling months. However, there is an increase in outdoor noise levels throughout the heating months, which stem from the fact that the outdoor unit is now used year-round." -Homeowner

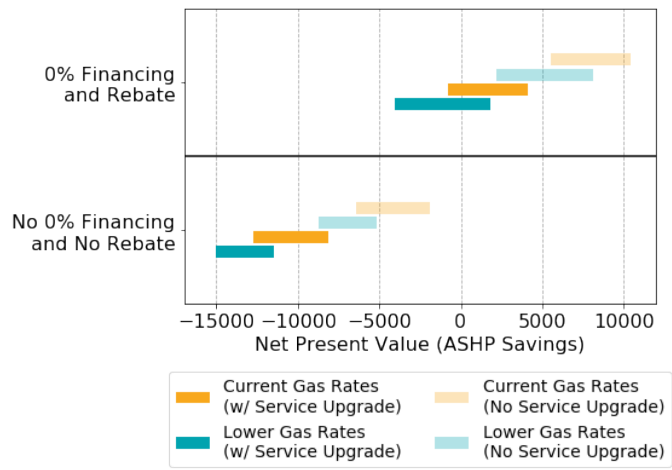


Figure 2. A net present value analysis evaluates the incremental costs of the ASHP retrofit against the lifetime savings it generates. Positive NPV indicates net savings overall. The coloured bars indicate the range of estimated NPV values.

rates from 2% to 7% (represented by the ranges in Figure 2). These are some of the key parameters impacting the results.

In general, with current programs and policies, the ASHP system can be lower cost overall if gas rates stay high. If gas rates reduce by 20%, it can still be lower cost if no costly service upgrade was required. To be clear, the homeowners did not receive 0% financing or the full federal rebate amount, and did require a costly electrical service upgrade. However, homeowners now have access to these programs and many newer homes would not require the upgrade. The scenario analysis is intended for future similar retrofits. Note again that to receive the federal rebate a slightly higher ASHP efficiency would have been required.

NPV will vary home-to-home and with different equipment. Some homes are more challenging to fully electrify if there are more gas loads (fireplace, dryer, etc.). This home also required two ASHPs. Financial results would have been stronger if only a single central ASHP was required, and this is more likely to be the case in many newer homes.

> "The heat pump water heater more than sufficiently meets our needs. While it produces more noise than its natural gas predecessor, the increase is minor, and was anticipated."
> -Homeowner

HOMEOWNER EXPERIENCE

The homeowners report being satisfied with the retrofit. Indoor and outdoor noise are within reasonable levels, and it was quieter in the backyard during the summertime compared to the previous system. Thermal comfort has improved significantly, and so has indoor air quality due to the ERV. An unanticipated impact of the retrofit is that the defrost cycle of the heat pump resulted in ice accumulation in a narrow shared pathway. This created a slip hazard and caused the concrete walkway to crack prematurely, which required fixing. The placement of the outdoor unit in regard to ice accumulation should be considered in future retrofits.

CONCLUSION

This case study showed that the ASHP performed near expectations from the equipment ratings. This builds confidence for future retrofits. It also demonstrated that, given current programs, full electrification can make sense in some homes from a purely financial perspective. Carbon savings were also significant. Overall, the homeowners were happy and were left with a more comfortable and livable home.

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/SustainableTechnologies/CaseStudy5

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

This communication has been prepared by the Sustainable Technologies Evaluation Program (STEP). STEP gratefully acknowledges the contributions of homeowner Blair Scorgie. 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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STEP@trca.ca | twitter.com/STEPLivingCity

Toronto and Region Conservation

Primary support for the creation of this case study provided by:

TAF

TORONTO

Additional base support for STEP Energy projects provided by:

Region of Peel

York Region