

# Case Study: Ductless Heat Pump Retrofits in an Ontario Rowhouse Complex

*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 leverages partnerships with municipalities, provincial and federal government bodies, utilities, non-profits, academic institutions, and private companies, to pilot and evaluate emerging low-carbon technologies with the aim of providing real-world data that informs effective technological responses to climate change. STEP team members are scientific monitoring and M & V experts, particularly as it pertains to renewable energy, HVAC and smart-grid. Research projects are conducted either in STEP's own state-of-the-art Living Labs or off-site in real-world buildings.*

## INTRODUCTION

Electric baseboards are the main heating source for 24% of all multi-unit residential building (MURB) and rowhouse units in Ontario. In this sector, heat pump retrofits represent a significant opportunity to conserve electricity, reduce carbon emissions and reduce operating costs, while simultaneously promoting tenant comfort and safety.

Various heat pump options are available, including both air- and ground-source (i.e. geothermal). Multi-split ductless air-source heat pumps (ASHPs) are a potentially good option because they are simple to retrofit and may entirely displace an electric baseboard heating system, while also providing a high-efficiency cooling system.

Multi-split ductless ASHPs have a single outdoor fan coil unit connected to multiple indoor fan coils through small diameter refrigerant piping that can be run on the exterior of a building or otherwise retrofitted into tight spaces within the building. This makes retrofits into an electrically-heated building straightforward.

This case study evaluated the performance of ductless multi-split air-source heat pump retrofits in a rowhouse complex located in Brantford, ON, during 2017/2018.

Air-source heat pumps (ASHPs) function on the same principle as an air-conditioner, in that a refrigeration cycle is used to “move” heat energy between a building's interior and the outdoor ambient air. However, unlike air-conditioners, ASHPs provide **both** cooling in the summer **and** heating in the winter. The key benefits of an ASHP in heating mode is that it supplements electrical energy used for space heating with heat energy extracted from the outside air to drastically reduce overall energy consumption.

## STUDY SITE AND INSTALLATIONS

Six 2- or 3-bedroom rowhouses, between 1,500 to 1,800 ft<sup>2</sup>, participated in the study. Four rowhouses received ductless multi-split heat pump retrofits (Units 1 to 4) in November 2017 and two rowhouses were incorporated as controls (Units 5 and 6). Heat pumps were donated by Daikin and Mitsubishi.

The 2-bedroom units were retrofitted with a 3-port multi-split. One indoor wall-mounted fan coil was installed in the main living space on the first level and the others were installed in each bedroom on the second floor. The 3-bedroom units were retrofitted with a 4-port multi-split using the same approach. Each indoor fan coil was controlled by its own remote creating a zoned system within the rowhouses.

The 2-bedroom units used a cold-climate version of the technology which is able to extract useful heat energy from outside air down to -25°C, and beyond. The 3-bedroom units used the conventional version, which has a manufacturer specified lower operational limit of a -15°C outdoor temperature. In practice, they continued operating down to -18°C.

Refrigerant lines connecting the indoor and outdoor fan coils were predominately run on the exterior of the building, creating a simple, quick and minimally-invasive retrofit. The installation was supervised by a Senior Project Manager from Cricket Energy and installed by a GreenON approved contractor. The installations were reviewed by both manufacturers.

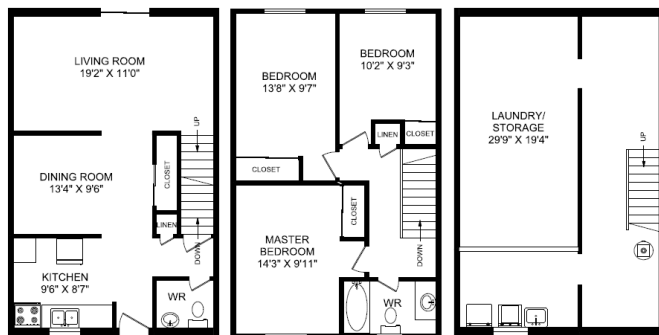


Figure 1. Example layout of a 3-bedroom rowhouse within the complex.



Figure 2. Outdoor coils were mounted in the back yard (left). Front bedroom fan coils were reached by routing refrigerant lines through the basement ceiling and then on the front exterior (right). This reduced the need for interior finish work.

In reference to the installation process: "There were no issues. See, I work out of town. I'm gone in the morning.

You guys come in and do what you have to do and you were pretty much done with it the time I come back. No issues." -Unit 3 Tenant



Figure 3. Wall-mounted indoor fan coils were used for an easy retrofit, although different indoor fan coil options, including floor-mount or recessed ceiling-mount, are possible.

## INSTRUMENTATION AND ANALYSIS

A remote monitoring package was installed in the six study rowhouses to calculate the energy savings of the heat pumps. The monitoring package included energy submeters and sensors for indoor and outdoor air temperature and humidity.

Monitoring commenced on November 20th 2017 and completed on August 1st 2018. To collect baseline data, heat pumps were shut off and baseboards were used between January 20th and March 1st, 2018.

Heating mode normalized energy savings calculations were adherent with the International Performance Measurement and Verification Protocol (IPMVP). Monitoring data was used to model the energy consumption of the rowhouses at different outdoor temperatures, using either the heat pumps or the baseboards. Energy savings was then calculated for a typical meteorological year (TMY) to generalize the findings.

Tenant interviews before and after the monitoring period captured the tenants experience with the heat pumps and informed adjustments to the dataset to ensure that the baseline and retrofit monitoring periods formed a fair comparison.

Q. "Did you find that the heat pump had any issues providing sufficient heat to keep your unit comfortable? For example, in December we had that really bad cold snap. It was like down to -20°C."

A. "It did more than enough. Like I said I didn't even have to turn the fan all the way up." -Unit 2 Tenant



## FINDINGS

**The heat pump retrofits reduce the total energy consumption of the rowhouse units by 19% to 32% during a typical heating season.** This is shown in Figure 4. Energy savings was demonstrated across the outdoor temperatures occurring during the heating season. As an example, experimental data for Unit 3 are shown in Figure 5. Normalized energy savings were calculated for Unit 3 and 4. Savings were *demonstrated* in Unit 1 and 2 but an accurate value could not be calculated.

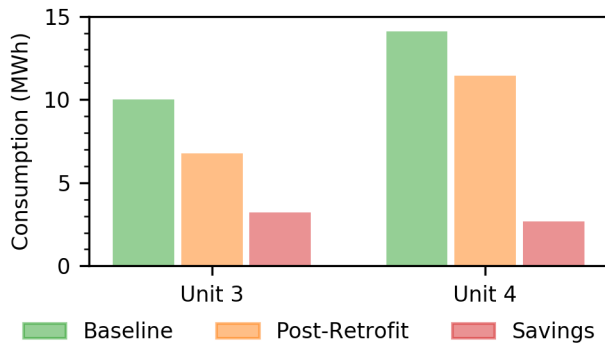


Figure 4. Total energy consumption during a Toronto TMY heating season decreases by 19% to 32% for Unit 3 and 4, due to the heat pumps.

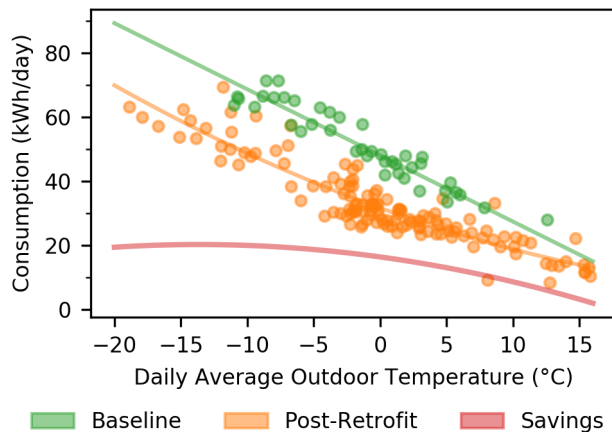


Figure 5. Example experimental data from Unit 3 shows that daily energy consumption is much lower when using the heat pump.

"If I had to continue paying heat for that [electric baseboard heater], I probably would be shopping for [another place to live] next year." -Unit 3 Tenant

**The heat pumps were estimated to use ~5x less energy than windows shaker air-conditioners.** To estimate cooling mode energy savings, the summertime temperature-dependent energy consumption of a retrofitted unit was compared against that from a non-retrofitted unit which was cooled with window shakers. The retrofitted unit was kept at cooler temperatures and believed to have greater heat gains, suggesting that the comparison is a conservative estimate of savings. The comparison is shown in Figure 6. Taking into account weather data, cooling mode savings was estimated at 1,150 kWh/year.

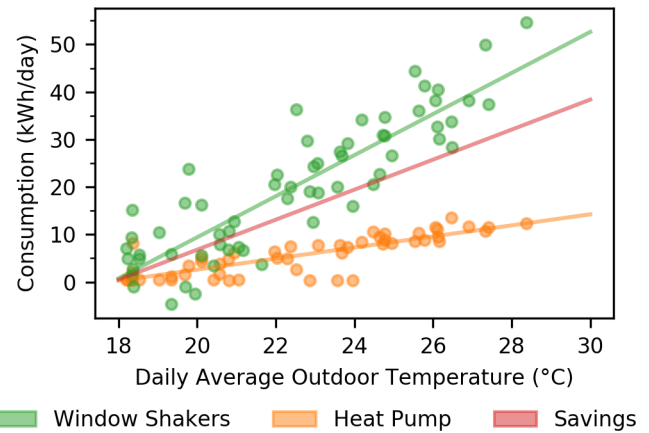


Figure 6. The heat pump energy consumption in cooling mode was about 5x less than that of the window shakers. Note that the plot is with respect to daily average temperature rather than daily high temperature.

This is a drastic difference in cooling energy consumption, much more so than would be predicted based on equipment efficiency alone. At least part of the difference is due to the poorer quality of the window shaker installation which would result in additional heat gains for the unit. Also of interest is that some tenants do not seasonally remove their window shakers (Figure 7). This would increase heating energy consumption. A heat pump installation would prevent this issue.

"...it's nice and clean [looking]. Like there is no wires, you know what I mean" -Unit 2 Tenant



Figure 7. Some units in the complex (although, not the six study units) did not remove the window shaker air-conditioners for the winter. This photo is from February.

**Average annual savings for the units were estimated at \$868 including both heating and cooling mode operation.** Average annual heating mode savings were estimated at \$624, and cooling mode, at \$244. There are also a number of non-energy benefits that were not quantified, including increases in property values; increases in the marketability of the units, tenant retention, and overall satisfaction; and improved health, safety, and comfort of tenants.

"...it was quiet. You didn't even know it was on, it's like, 'Are you sure that's on?'" -Unit 2 Tenant

Q. "How happy are you that you received the heat pump retrofit?"

A. "Very happy." -Unit 4 Tenant

**Several installation-specific factors impacted performance**, including high indoor thermostat set-points, parasitic heat losses from long refrigerant lines run outdoors, compressor cycling and occupant set-point changes. This highlights the fact that this is a case study. Savings are dependent on the behaviours of the tenants themselves as well as other installation-specific details. The authors acknowledge that other units may have greater or lower savings if they undertake a heat pump retrofit. Additional IPMVP-adherent studies would be helpful towards building further confidence in heat pump retrofit energy savings estimates and capturing a greater range of potential savings in different buildings.

**Tenants were very pleased with the heat pumps.** They appreciated the energy savings, the simplicity of the retrofit process, the user-friendliness of the remote controls and the increased thermal comfort over electric baseboards.

**The simple payback for the rowhouses in this study is estimated to be on the same scale as the expected equipment lifetime of 15 years.** Estimated installed system costs are shown in Table 1. Also shown are costs for a single-port mini-split heat pump (not installed in this study). Table 1 includes equipment and installation costs but neglects certain soft costs which may push total installed cost towards \$14,000 retail for the 3- and 4-port heat pumps. These prices neglect incentives, or savings from bulk purchasing. Potential system owners are encouraged to consider the impact of these factors for their application and context. Project partner Cricket Energy also explored costs for a rental ownership model with the results available in the companion project report. Ultimately, although the annual savings are strong, the capital cost is large compared to business-as-usual and this results in the estimated ~15-year simple payback.\*

Table 1. Total installed cost for different ductless ASHP options.

System Type	Estimated Installed Cost
2-ton single-port cold-climate (i.e. mini-split)	\$4,400
2-ton 3-port cold-climate	\$10,600
3-ton 4-port conventional	\$10,700

\*Note that this assessment is intended to evaluate the financial potential of heat pump retrofits but it neglects certain complexities of the MURB sector landscape, like the "split-incentive" problem which describes the scenario where the one party must undergo the expense of the retrofit (the property owner) but another party receives the benefits (the tenants). A discussion of this and other similar consideration is beyond the scope of this work. In the study units, the tenants pay their own electricity bill and all equipment was donated.

**Other heat pump retrofit options may further promote cost-effectiveness.** Having multiple indoor fan coils provided tenants with a high degree of thermal comfort but a lower cost is important for many applications. A ductless mini-split heat pump installed in the main living space may strike a more economical balance between comfort, energy savings, and installed costs. Baseboards may even be left in place for other areas of the unit. For larger MURBs, variable refrigerant flow (VRF) ASHP systems may help to bring the per-unit installed costs down. These approaches should be evaluated in future work.

## CONCLUSION

Ductless heat pumps have significant conservation potential in the electrically-heated MURB and rowhouse sector. In this study, they reduced energy costs, were easy to retrofit, reliable, user-friendly, quiet and they significantly improved the thermal comfort of tenants. They also provide high-efficiency cooling. While it is clear that heat pumps are effective at reducing energy bills, further IPMVP-adherent evaluations are recommended to help identify the ideal heat pump retrofit options for different applications.

"... you would definitely see the savings in the long run. Honestly, who wouldn't want to convert from those [baseboard] heaters to something far better, right?"  
-Unit 1 Tenant

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