Sustainable Technologies
EVALUATION PROGRAM
Supported by Toronto and Region Conservation Authority

TECHNICAL BRIEF

Real-world Efficiency of a Monobloc Heat Pump for Multi-Unit Residential Buildings

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

The Atmospheric Fund (TAF) has estimated that nearly a quarter of all multi-unit residential building (MURB) suites in Ontario are heated with electricity, primarily with electric resistance baseboards.[1] These systems are much less efficient than other electric heating options. Their low efficiency creates high operating costs for owners and reduces the grid capacity for the electrification of other buildings and sectors. Many of these buildings also have no central cooling or have relied on window air-conditioners, but window air-conditioners are now banned in some MURBs due to the risk of them falling from the window and causing injury or death. A compounding issue is that cooling is becoming increasingly critical for the health of MURB occupants as the number of heat waves and related health impacts are on the rise.

Retrofitting electrically-heated MURBs with heat pumps is a significant opportunity to drastically decrease utility bills for owners, reduce the demand on the electricity grid, and ensure occupant well-being. This study evaluated the heating efficiency of a new monobloc air-source heat pump (ASHP) for MURB applications. The heat pump was installed at the MURB Test Suite of the Archetype Sustainable House (ASH), located in Vaughan, ON (pictured above). The MURB Test Suite is 300 ft^2 and sits above a garage. It has a heat loss on the scale of an actual MURB suite and is used as a platform for evaluating suite-level MURB heating and cooling technologies. Using performance data collected at the MURB Test Suite during Winter 2021/2022, the ASHP efficiency was determined and used to predict the energy savings of retrofits in different cities across Canada.

Air-source heat pumps (ASHPs) provide high-efficiency heating and cooling for homes and buildings. In heating mode, they operate by extracting renewable heat energy from the outdoor air. In cooling mode, they function similarly to an air-conditioner. While many ASHPs are "split" systems, meaning there is an outdoor coil and an indoor coil, monobloc ASHPs package the components into one unit. In a multi-unit residential context, it typically sits on the inside of a suite with outside air ducted in and out. There are several advantages to this approach, especially when there is no balcony to place an outdoor coil.

TECHNOLOGY OVERVIEW

The Innova 2.0 is a monobloc ASHP and may also be referred to as a "packaged terminal heat pump" (PTHP), although a key difference is that most PTHPs are installed within a wall sleeve, whereas the Innova 2.0 uses two 6" ducts to access outdoor air. This makes for easier retrofits. This study used the "12 HP ELEC DC Inverter" version. Manufacturer-provided specifications are in Table 1. It uses R-410A refrigerant and is equipped with a 1 kW supplemental electric resistance heating coil.

Table 1. Specifications summary provided by the manufacturer.

Parameter	Value
Maximum cooling capacity	10,600 BTU/hr
Maximum heating capacity	10.400 BTU/hr
Cooling EER	11
COP*	3.3
Weight	48.5 kg
Size	1030 x 55 x 165 mm
Indoor noise	27 dB
Heat pump minimum outdoor operating temperature**	-10 ºC

*Reference conditions for COP not provided.
**The 1 kW electric resistance coil can still provide heating below -10 ºC.

STUDY DESIGN

Heat pump efficiency is termed the coefficient of performance (COP). The COP is a ratio of the heating energy provided by the heat pump, divided by the electrical energy consumed. Heat pump COPs can be much greater than 1 (i.e. they output more energy than they consume) and this is the key factor driving energy savings. The primary aim of this study was to determine the COP in different outdoor temperatures and estimate seasonal average COPs for different Canadian cities. COP was determined using two independent methods.

METHOD 1: ENERGY COMPARISON

In a MURB suite currently heated with baseboards, the energy consumption of an ASHP replacement can be estimated by dividing the baseboards' energy consumption with a seasonal average ASHP COP for the given location (Equation 1). For example, a COP of 2.0 means that the heat pump should consume 50% less energy for heating than the baseboards.

$$Energy_{Heat\ Pump} = \frac{Energy_{Baseboards}}{COP_{ave}} \quad (1)$$

The first method was based on Equation 1. Rearranging to solve for COP yields a ratio of baseboard energy consumption over heat pump energy consumption. COP can then be calculated if the energy consumption for the two different systems is known for the same suite and the same indoor/outdoor environmental conditions. In this study, electric baseboard heaters were also installed in the MURB Test Suite. For different periods during Winter 2021/2022, either the ASHP or baseboards were used to heat the suite (Table 2).

Table 2. Equipment operating schedule for the study period.

Parameter	Value
09/25/2021 - 01/11/2022	Heat pump
01/11/2022 - 03/09/2022	Baseboards
03/09/2022 - 04/28/2022	Heat pump
04/28/2022 - 05/30/2022	Baseboards

The daily energy consumption data for each system was plotted against the mean outdoor temperature and small adjustments were made to account for variations in the indoor temperature. This ensured comparable indoor/outdoor environmental conditions.

For different outdoor temperatures, the baseboard energy consumption was divided by the heat pump energy consumption to estimate a temperature-dependent COP curve. The estimated COP from this approach included all real-world factors like defrost, cycling, and also the two large building penetrations to duct the system to the outdoors. Whenever the baseboards were used, the pre-retrofit building envelope was simulated by using foam plugs in the ducts.

METHOD 2: DIRECT MONITORING

It is also possible to calculate COP directly by measuring system temperatures, airflows, and energy consumption. The heat pump is ductless on the indoor side and ducted on the outdoor side. The *outdoor* side was more conducive to measurements because of the ducting.

The heat provided by the ASHP was calculated as the sum of the heat removed from the outdoor air (based on temperature and airflow measurements) and the electrical energy consumption (which ends up as heat indoors). Integrating grids were used for the airflow and intake/exhaust air temperature measurements.

Figure 1 shows the ASHP and part of the monitoring system. Details on the monitoring hardware, sensor verifications, and equations, are available alongside the data and full analysis notebook in an online public repository.[2]

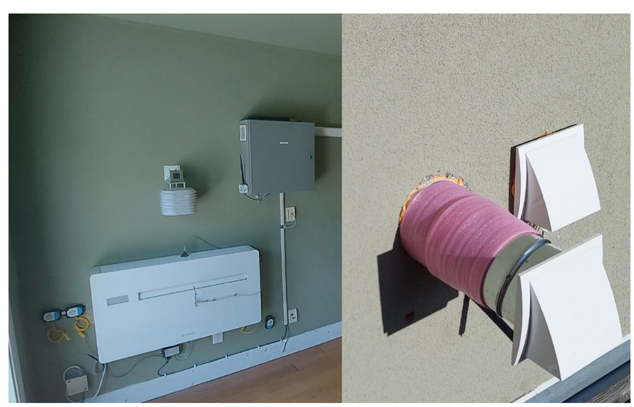

Figure 1. (Left) Instrumentation is shown for the indoor side of the heat pump. (Right) A short run of ducting was added to the exhaust on the outdoor side of the heat pump. This was required for accurate airflow measurements. This additional duct is permissible according to the manufacturer's installation requirements.

CHALLENGES

Manufacturer instructions were followed for the installation with the exception of the condensate drain. The instructions specified a U-bend trap. The condensate line was instead installed with a constant slope. In a cold climate, a U-bend could freeze. After installation, the ASHP was left to operate in "Auto" mode, where the indoor fan modulated between three different speeds according to its own controls.

The unit provided for testing had an issue with the indoor temperature sensor. It functioned properly in warm outdoor conditions but read an offset from the actual temperature in cool or cold conditions. For the testing, the setpoint was simply adjusted such that the desired indoor temperature was achieved. As an example, in cold temperatures, if the unit was set to maintain the indoor temperature at 19 ºC, it would actually maintain it closer to 22 ºC. This solution was the only solution available to the research team. It is not believed to have impacted system performance.

RESULTS

The average indoor temperature when using the baseboards was 23.3 ºC, and when using the heat pump it was 21.6 ºC (in part, due to the sensor issue). To account for this discrepancy, the daily energy consumption for each system was first plotted against the *difference* between the daily mean indoor and outdoor temperatures (Figure 2). It is this *difference* that dictates the heat loss of the suite and the heat energy it requires. Plotting against this difference accounts for the indoor temperature discrepancy and allows for a fair comparison.

Data were normalized to an indoor temperature of 22 ºC in Figure 3. Also shown are regression model fits of the ASHP and baseboard daily energy consumption. The heat loss of the MURB Test Suite at -10 ºC is approximately 1 kW. This is equal to the heat output of the ASHP's supplemental heater. It follows that the ASHP was sized such that it could meet the heating requirements of the suite above outdoor temperatures of -10 ºC, which is the ASHP's stated operational range.

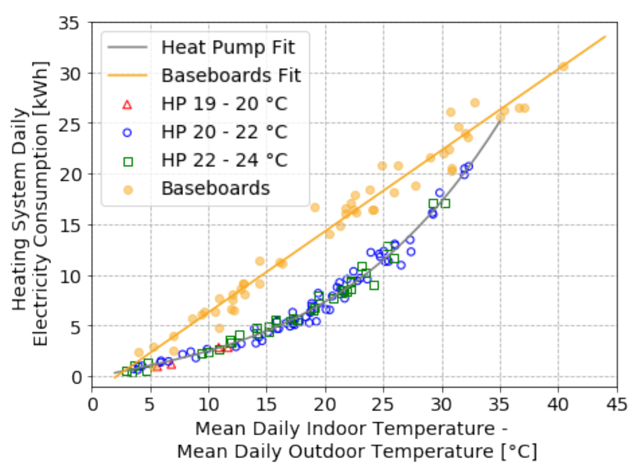

Figure 2. Daily electricity consumption for the baseboards and the ASHP is plotted against the difference between the mean indoor and outdoor temperatures. "HP 19 - 20 ºC" indicates ASHP energy consumption data when the mean indoor temperature was between 19 and 20 ºC. The ASHP uses much less energy than baseboards.

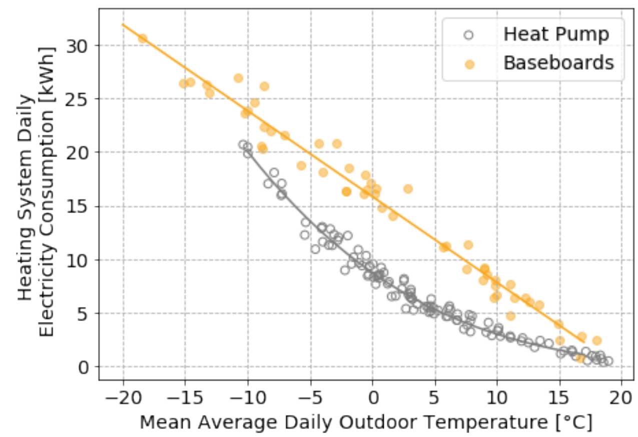

Figure 3. Daily electricity consumption for the baseboards and the ASHP are plotted against the mean outdoor temperature. The solid lines are regression models.

The suite was therefore a good match for testing. If the heat loss was greater, then the supplementary heater would be required more frequently in colder temperatures and this would have degraded the cold-weather COP. If the heat loss was lower, then there would have been greater COP degradation in warmer temperatures due to cycling

The daily COP from both Method 1 and Method 2 is shown in Figure 4. There is good agreement but the Method 2 COP is slightly higher in colder temperatures. This is because the direct monitoring did not include the impacts of defrost. Defrost uses heat energy from the suite to periodically remove frost on the evaporator coil. This heat energy was not calculated because there was no airflow during defrost.

A decibel meter was used to evaluate the indoor and outdoor noise produced by the ASHP. Indoor noise ranged from 45 dB to 57 dB, and outdoor noise ranged from 62 to 67 dB (in both cases taken at head height and a 2 m distance). A reading of 45 dB is near the ambient noise in a home, while 57 dB is near that of a quiet office. A reading of 67 dB is approaching the noise from a vacuum cleaner. The MURB Test Suite has wood stud walls which may have impacted noise levels.

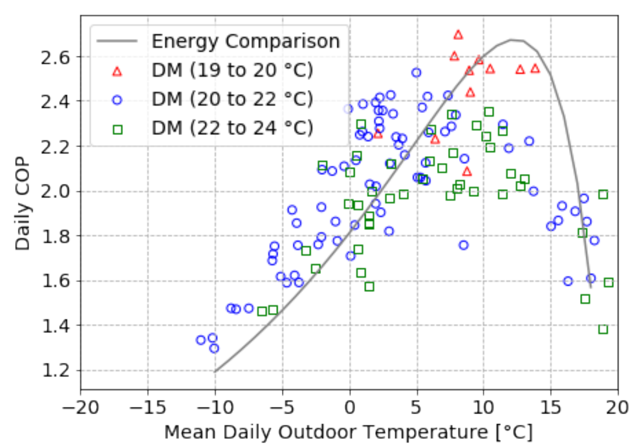

Figure 4. Daily COP from Method 1 (Energy Comparison) and Method 2 (Direct Monitoring) is shown. Note that "DM (19 to 20 ºC)" indicates it is the COP from Direct Monitoring and the mean indoor temperature was 19 to 20 ºC. The Method 1 COP was determined by dividing the baseboard curve with the heat pump curve (Figure 3). Note that COP degrades in warm temperatures due to equipment cycling.

As a final calculation, the regression models shown in Figure 3 were used to model the energy consumption of the ASHP and the baseboards in different Canadian cities using 10 years of historical temperature data. For each year, and also cumulatively across all years, the total COP was calculated by dividing the energy consumption of the baseboards by the energy consumption of the ASHP. Below -10 ºC, the energy required in the ASHP scenario was considered to be equivalent to the baseboards. Practically, this means there would need to be an electric resistance baseboard as back-up if temperatures reached that low and the 1 kW supplemental heater of the ASHP was not sufficient to meet the heat load.

Table 3. Modeled seasonal COPs and energy savings for Canadian cities.

City	Average Seasonal COP (Over Previous 10 years)	Average Heating Energy Savings (Over Previous 10 years)
Toronto	1.66	40%
Ottawa	1.45	31%
Vancouver	2.24	55%
Halifax	1.78	44%
Edmonton	1.39	28%
Quebec City	1.42	29%

Table 3 shows that an average seasonal COP of 1.66 was calculated for Toronto. The highest seasonal average COP is expected for Vancouver, at 2.24. Note that the actual COP and energy savings will depend on the sizing of the ASHP relative to the heat loss of the suite. These calculations apply to the MURB Test Suite heat loss (which was well-matched to the ASHP). For suites with a larger heat loss, the percentage heating energy savings will be lower (unless more than one heat pump is used) since baseboards would need to handle a larger fraction of the heating.

DISCUSSION & CONCLUSION

Two independent methods showed good agreement on the COP. The MURB Test Suite is particularly effective for performance evaluation of suite-level MURB technologies. It is neither a standardized lab (which may not fully reflect actual operational conditions) nor an installation in an actual MURB (where monitoring is more challenging). It is something in between; real-world monitoring with a high degree of control. The energy comparison method was a new approach to performance evaluation that is both simple and effective.

This study showed that the electricity conservation potential of the ASHP in electrically-heated MURBs is substantial. However, perhaps not as substantial as other ASHP options more specifically designed for a cold climate and having higher COPs - but COP is not the only criterion for a retrofit.

This ASHP is aesthetically well-designed, easy to operate, and quieter than most standard window A/C units. No refrigerant connections are required on-site, making for a simpler installation and lower likelihood of refrigerant leaks. Maintenance may also be easier than with other options. If servicing is required, the ASHP can be easily detached from the wall and replaced with a functional one. Furthermore, the ASHP does not require balcony space for an outdoor condenser.

Future work will evaluate cooling performance. Overall, monobloc ASHPs have significant advantages in some MURBs. It is one technology, amongst others, than can improve the efficiency of buildings and occupant well-being.

REFERENCES AND ENDNOTES

[1]The Atmospheric Fund. Pumping Energy Savings: Ontario EMURB Market Characterization Study. 2016.

[2]Data, analysis, and supporting information is freely available for review at a public online repository, located at: https://github.com/SustainableTechnologies/MonoblocHeatPump

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