Demonstration of Packaged Inverter-Driven Heat Pumps for Apartments

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NEW YORK STATE

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Demonstration of Packaged Inverter-Driven Heat Pumps for Apartments

Final Report

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Abstract

This study evaluates the performance and feasibility of a packaged inverter-driven heat pump for retrofit applications in multifamily buildings to support building electrification and carbon reduction efforts. Methodology included operational testing of a prototype unit, site assessments across four buildings, and long-term monitoring in an occupied apartment. Results demonstrated that the heat pump achieved measured efficiency in cold climates with a coefficient of performance (COP) of up to 2.52 and significant energy savings, reducing heating energy use by approximately 80% compared to baseline systems, although interior conditions differed from baseline due to occupant operational choices. Resident feedback highlighted improved cooling comfort but identified challenges with heating control and airflow drafts. The findings suggest that room-by-room heat pump units can reduce energy consumption, offering a scalable solution for decarbonizing existing multifamily housing. This research underscores the potential of inverter-driven heat pumps to accelerate building electrification and support climate goals.

Keywords

cold climate air-source heat pumps, measurement and verification, building electrification retrofit, packaged unitary heat pumps, single vertical packaged heat pumps

Acknowledgments

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Acronyms and Abbreviations

AHRI	Air-Conditioning, Heating, and Refrigeration Institute
COP	coefficient of performance
COVID-19	Coronavirus Disease 2019
DB	dry bulb
HDD	heating degree day
HPAC	heat pump air conditioner
HSPF	heating seasonal performance factor
HUD	U.S. Department of Housing and Urban Development
HVAC	heating, ventilation, and air conditioning
LL97	New York City Local Law 97
M&V	measurement and verification
NIOSH	National Institute for Occupational Safety and Health
NYC	New York City
NYSERDA	New York State Energy Research and Development Authority
PTAC	packaged terminal air conditioner
PV	photovoltaic
SVPHP	single vertical packaged heat pump
XPS	extruded polystyrene

Units of Measurement

~	approximately
°F	degrees Fahrenheit
amp	ampere
Btu	British thermal unit
Btu/hr	British thermal units per hour
Btu/(hr)(ft2)(°F)	British thermal units per hour per square foot per degree Fahrenheit
CFM	cubic feet per minute
CFM50	cubic feet per minute at 50 pascals
dB(A)	A-weighted decibels
ft	feet or foot

hr	hour
in.	inch
kW	kilowatt
kWh	kilowatt-hours
mT CO_2e	metric tons of carbon dioxide equivalent
Pa	pascal
rpm	revolutions per minute
sq ft	square feet
V	volt
W	watts

Executive Summary

Electrification of existing building stock with efficient heat pumps will be crucial to achieve New York State's carbon emissions reduction goals. This project, conducted under New York State Energy Research and Development Authority's (NYSERDA) Program Opportunity Notice (PON) 3519, demonstrated a packaged inverter-driven heat pump produced by Innova, called the heat pump air conditioner (HPAC) 2.0, that meets these criteria, operates in heat pump mode below freezing ambient temperatures, and is suitable to replace both central heating systems and packaged terminal air conditioners (PTACs).

This project included operational testing of a sample unit; assessments of retrofit feasibility at four multifamily buildings; installation of two units in an occupied apartment for long-term monitoring, analysis of data on heat pump performance and baseline apartment heating system use, and interviews with residents about satisfaction with the heat pumps.

Operational testing in Taitem Engineering offices was conducted on an early model imported into the U.S. from Italy. The testing was conducted on a unit with 6-in. air ducts; later versions with 8-in. ducts have higher capacity and efficiency. Steady-state efficiency was calculated by dividing the total output capacity over the test period by the measured input power over the test period. Table ES-1 presents the results from the steady state tests.

Table ES-1. Steady State Testing Capacity and Efficiency Results

Outdoor Temperature	Test Date	Avg. Capacity (Btu/hr)	Peak Capacity (Btu/hr)	Calculated Efficiency
21°F	3/22/2020	4,7	5,311	1.69 COP
23°F	3/7/2020	5,533	6,953	2.03 COP
47°F	5/21/2020	5,920	6,330	2.48 COP
84°F	7/28/2020	6,420	6,886	2.52 (cooling COP)
98°F	7/27/2020	5,432	5,971	1.90 (cooling COP)

The heat pumps operated quietly. Some air leakage was observed in the unit, an issue the manufacturer has addressed in later models. Supply air temperatures appeared reasonable, with a slight tendency to overheat the space during heating operation. The compressor did not operate in full variable mode; this issue has been corrected in current versions of the product. Defrost cycles were every 2-3 hours for about 5 minutes.

The site assessment included four multifamily buildings. All four were deemed feasible for retrofit by the HPAC 2.0. Some physical constraints would need to be overcome by removing existing terminal units; however, meeting thermal loads was not a problem. The largest challenges were related to confirming satisfactory electrical connections, disposing of defrost meltwater, and shifting the cost of heating charges from the building owner to the tenant's electric meter.

The selected demonstration site was a 1987 building in Queens, New York, NY, heated by a natural gas-fired boiler with hydronic distribution and cooled via air conditioners (ACs) in through-wall sleeves in each room. A one-bedroom apartment with two air conditioner sleeves was selected for the installation. The existing through-wall air conditioner sleeves were used for the HPAC 2.0 unit to avoid additional wall penetrations. The heating loads in both the living room and bedroom could be met by heat pumps alone. The living room air conditioning circuit did not require any changes except to remove the receptacle and hardwire the heat pump. The bedroom required replacing the circuit breaker with a double-pole breaker to provide a 20-amp, 208-V circuit and removing the receptacle to hardwire the heat pump. The total installed cost of the two units was $14,981. Prior to the installation, the apartment air leakage was 902 CFM50; following the installation, it was 800 CFM50, a decrease of 102 CFM50.

Monitoring the two adjacent apartments would be performed to assess the comparative energy use of the Innova heat pumps versus the existing hydronic heating and through-wall air conditioning. Over 1 year, the baseline heating and cooling systems consumed nearly 7,500 kWh, while the Innova heating and cooling systems consumed close to 1,500 kWh. The 1-year periods were not identical, and the indoor temperatures maintained by each system differed, resulting in reduced heating and cooling loads for the Innova demonstration apartment. Several comfort and operational issues negatively affected the resident experience during the heating season; the manufacturer reports that it has addressed most of these issues in later product models. The resident was satisfied with the cooling season experience.

During winter, the demonstration apartment was kept at significantly lower temperatures than the baseline apartment. This may be a combination of the user's desired setpoint, operating conditions (made possible by packaged controls and individual heat pumps in each room), and a lack of heating control in the baseline apartment. An advantage that unitary heat pumps have over a central heating plant is greater room-by-room control. In contrast to a set-it-and-leave-it approach, this method can sometimes lead to dissatisfaction due to the longer time variable speed air-source heat pumps take to warm up a room compared to radiant-based systems.

Lessons learned from the monitoring efforts include that significant differences in operating conditions can exist between two nearly identical apartments, especially when room-by-room occupant controls are provided; that apartment access can significantly delay progress; that backup data systems are important to maintain continuity; and that pipe insulation over temperature sensors is important for accurate fluid temperature readings.

1. Project Introduction and Overview

New York State has recognized that extensive electrification will be crucial to achieve its carbon emissions reduction, and essential for this endeavor will be electrifying the existing building stock objectives (Office of the Governor 2018, PSC 2018). Heat pumps will be a key technology toward achieving this goal; however, the market lacks cost-effective, efficient heat pump products that can be easily retrofitted into existing multifamily buildings. This project demonstrated a packaged inverter-driven heat pump that meets these criteria, operates in heat pump mode at ambient temperatures below freezing, and is suitable for replacing both central heating systems and packaged terminal air conditioners (PTAC).

The market for this product type in New York State is significant due to the high average age of buildings and building systems. Many homes in the State have their original, inefficient central heating systems, which often provide inadequate comfort due to equipment age and suboptimal distribution. About 52% of homes in the Northeast Census region (which includes New York State) are heated by central warm-air furnaces, most of which use natural gas (EIA 2020). Of the remaining 48%, roughly half use steam or hot-water systems fueled by fossil fuels, while others rely on inefficient electric systems such as electric resistance heating or heat pumps with low heating-season performance factor (HSPF) ratings. Efficient electrification of these buildings' space-conditioning systems, paired with on-site photovoltaics (PV) and a future clean electric grid, can reduce carbon emissions compared to burning fossil fuels on-site in furnaces and boilers.

1.1 Objective

This project aimed to evaluate the performance of a new heat pump product type, referred to as a single vertical packaged heat pump (SVPHP). Performance metrics of interest were capacity at cold ambient temperatures, noise levels, delivered air temperature, efficiency, airtightness, and resident satisfaction. Cost, installation, and compatibility with existing multifamily building stock were also of interest. The product used for this investigation was the Innova HPAC 2.0.[1] Developed in Europe, the HPAC 2.0 was first introduced to the Canadian market and then to the U.S. market around the time this demonstration began. Rather than using thermally inefficient through-wall sleeves, it is wall-mounted inside the apartment with two small penetrations to the outside for air exchange, and a third, smaller penetration for condensate and meltwater discharge.

Because it has no outdoor unit and its only connection to the outdoors is through two 6-in. or 8-in. diameter ducts, it can be used for both retrofit applications and new construction. Figures 1 and 2 show the dimensions and component elements.

Figure 1. Innova HPAC 2.0 Dimensions and Airflow Diagram

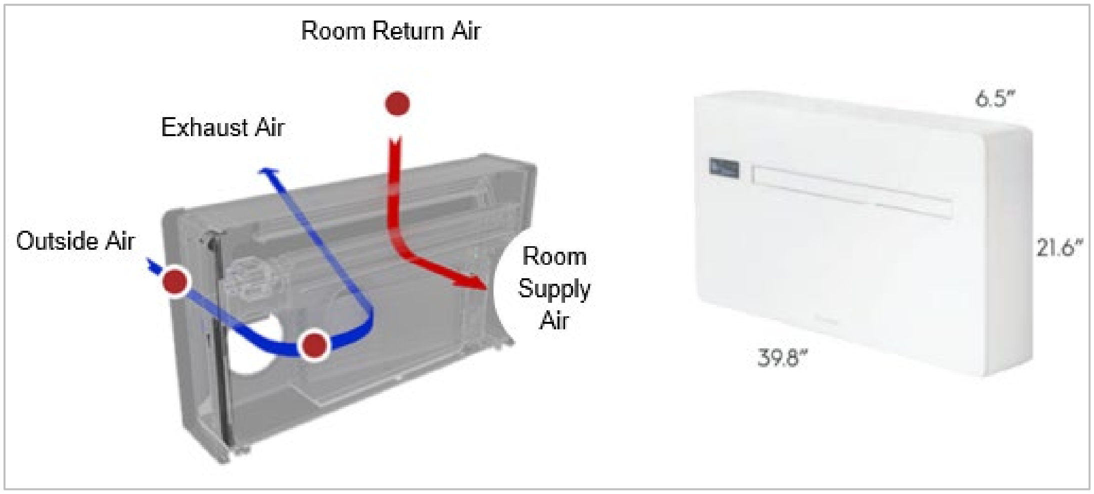
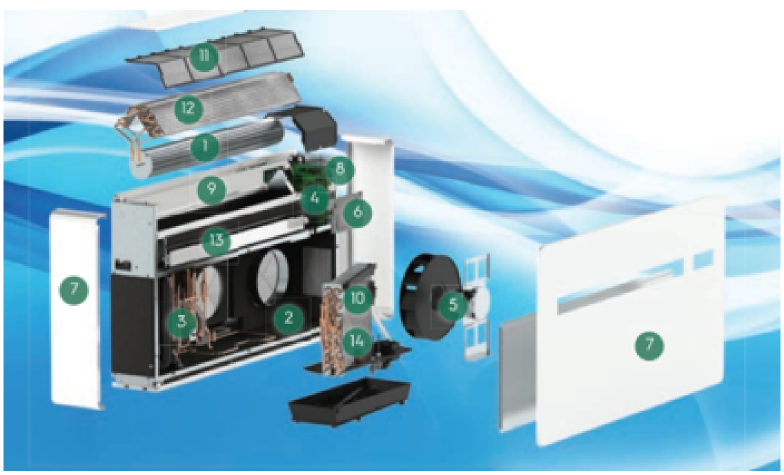


Figure 2. Innova HPAC 2.0 Components



1. Electrically commutated (EC) Crossflow Blower Fan.
2. Insulation.
3. Inverter brushless direct current (DC) compressor.
4. Temperature sensors.
5. EC condenser fan.
6. Touch-screen display.
7. Metal paintable cabinet.
8. Electrical connection.
9. Optional fresh air intake (not included in operational or demonstration testing unit).
10. Condensate mister (not included in operational or demonstration testing unit).
11. Washable filter.
12. Indoor heat exchanger.
13. Adjustable air louver.
14. Outdoor heat exchanger.

The Innova units used in this study were manufactured in 2020 and were among the earliest units imported into the U.S. market. Subsequently, newer models have been released with changes made based on feedback from U.S. users. Notes throughout this report indicate some instances of these manufacturer-reported changes.

1.2 Scope

The scope of this project included the following:

- Operational testing of a sample unit at the Taitem Engineering facility in Ithaca, NY.
- Site assessments of four multifamily buildings of differing types and vintages to determine compatibility and feasibility of a retrofit.
- Recruiting one demonstration retrofit site to install two units in a single apartment for long-term monitoring.
- Engagement with residents, building owner/manager, and contractors to facilitate installation and instrumentation of the heat pumps and a similar apartment for baseline monitoring.
- Collecting and analyzing data on heat pump performance and baseline apartment heating system use.
- Interviewing the resident to obtain input on satisfaction with the heat pump.
- Conducting dissemination activities and preparing this final report, covering all aspects of the work.

2. Operational Testing

Taitem Engineering performed operational testing to assess the heat pump's seasonal and steady-state efficiency and capacity. The operational testing was conducted on an Innova model available in 2020. Since then, the manufacturer reports that later models have addressed many of the issues identified in this testing, including air leakage, installation mechanics, and firmware control logic. This has not been verified through additional testing by these researchers.

The Innova HPAC 2.0 equipment was installed in Taitem Engineering's offices in early March 2020. Shortly after installation, the Coronavirus Disease 2019 (COVID-19) pandemic occurred, and the State and Taitem's offices were closed. As a result of the late winter installation and factors around the COVID-19 pandemic, long-term efficiency (seasonal) testing was limited. In addition to the limited testing duration, the results of the testing performed, including the baseline co-heat test, showed no clear correlation between efficiency and outdoor temperature. As a result, it is not possible to make accurate claims regarding the seasonal efficiency of the Innova unit.

Steady-state efficiency and capacity tests were successfully performed, and the test results are summarized below, along with other operational observations. This report indicates where the manufacturer's later product upgrades are reported to have addressed operational issues.

2.1 Steady-State Test Results

Steady-state capacity and efficiency tests were conducted at outdoor temperature conditions near key design and rating conditions. The coldest outdoor temperature for testing was 21°F. Tests were conducted over 1- to 2-hour periods, with 30–60 minutes of steady-state operation used for the analysis.

The unit's total heating output capacity (Btu/hr) was determined by measuring the return and supply air temperatures and total airflow of the indoor fan.

The unit's total cooling output capacity (Btu/hr) was determined by measuring the temperature and relative humidity of the return and supply air, as well as the airflow of the indoor fan coil. Using the temperatures and relative humidity, Taitem was able to incorporate the unit's latent cooling capacity to get the total cooling output capacity.

Steady-state efficiency was calculated by dividing the total output capacity over the test period by the measured input power over the same period.

For the heating tests, the indoor temperature was maintained at around 70°F dry bulb (DB), which is typical for Air-Conditioning, Heating, and Refrigeration Institute (AHRI) test conditions. For the cooling tests, the indoor temperature was maintained around 75°F DB, which is lower than the AHRI test condition of 80°F DB, but is a more typical indoor temperature setpoint. To maintain these interior space temperatures, additional heating and cooling loads were supplied to balance the overall load. During the heating tests, the ductless split system mounted elsewhere in the room was run in cooling mode, and during the cooling test, a space heater was used. Table 1 presents the results from the steady-state tests.

Table 1. Steady-State Testing Capacity and Efficiency Results

Outdoor Temperature	Test Date	Avg. Capacity (Btu/hr)	Peak Capacity (Btu/hr)	Calculated Efficiency
21°F	3/22/2020	4,717	5,311	1.69 COP
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Since Taitem Engineering installed the Innova HPAC 2.0 unit and performed operational testing, Innova has modified the backplate design to increase airflow across the outdoor air coil by increasing the intake and exhaust openings from 6-in. round to 8-in. round. The operational testing Taitem Engineering performed and detailed in this report was performed on a 6-in. round version of the unit. As a result of changes to the backplate, Innova expects to increase the unit's capacity and efficiency. Appendix A and Appendix B provide the heating performance data for the two Innova units.

Additional testing notes:

- The unit was forced to run continuously at its maximum output by adjusting the setpoint so that it was several degrees higher or lower than the room temperature.

- For the steady-state tests, the indoor fan coil fan speed was set to operate at the fastest selectable fan speed. The unit offers an Auto fan setting that automatically adjusts speed based on an internal algorithm. A Turbo setting is included, which operates the unit at the highest capacity for 30 minutes. Neither the Auto nor the Turbo setting was used for the steady-state testing. The selected fan setting may affect capacity and efficiency results.
- Testing was conducted over short periods of time and intentionally excluded defrost cycles.

2.2 Testing Observations

The following observations were made during operational testing:

- Operational testing showed higher low-temperature heating capacity than Innova initially reported. Heating efficiencies were lower than reported. Cooling capacities and efficiencies calculated during operational testing are shown below the manufacturer's performance data.
- Measured supply air temperatures in heating and cooling appeared reasonable and unlikely to cause comfort complaints. In heating, the supply air temperature was measured around 100°F, even when the outdoor temperature was as low as 21°F. During cooling, the supply air temperature was measured at around 60°F under a design-day condition of 98°F outdoor temperature and at 55°F under the outdoor temperature of 84°F.
- The Innova unit is very quiet, and in discussions with other Taitem staff, none reported it to be distracting when using the space. The biggest noise contributor appears to be the indoor coil fan, which is no louder than the existing air-source heat pump fan coil in the conference room.
- The installation of the Innova unit resulted in air leakage in two categories: (1) air leakage between the back of the unit and the wall sleeves for the outdoor coil, and (2) air leakage within the outdoor chamber section of the unit. For both categories of air leakage, the leakage is exaggerated because the unit's outdoor chamber is under a higher pressure than the room during operation. According to the manufacturer, the product's construction was updated in early 2024 to resolve air leakage. The redesign focused on improving the installation mechanics for a more robust, forgiving fit and reengineering the seals for the unit's chassis and its rear connections to ensure superior airtightness.
- During heating, the Innova unit tended to overheat the space. For example, if the setpoint was 70°F, the space temperature was 72°F–74°F. To keep the unit at a 70°F space temperature, the controller had to be set to 66°F–67°F.

- While the Innova specifications indicate a variable speed compressor, in operation, the compressor appeared to operate in three stages correlating to three different power draws: ~300–350W for the lowest stage, ~475–525 W for the middle stage, and ~750–850 W for the highest stage. According to the manufacturer, the new 2024 firmware has unlocked the full frequency range of the compressor, enabling true, seamless variable-speed modulation.
- Standby power in heating mode was approximately 20 W. This is equivalent to approximately 0.48 kWh/day. When in heating mode, the indoor fan shuts off once the setpoint is reached.
- In cooling mode, the indoor fan coil fan was observed to run continuously even when set to Auto and after the space temperature had been met. This appears to be an intentional setting because it was not the case when in heating mode. As a result, the Standby power during cooling, including the indoor fan coil fan, is approximately 38W, resulting in approximately 0.91 kWh/day. According to the manufacturer, continuous fan operation in cooling was an intentional design choice, acting as a “comfort fan” to de-stratify room air and prevent stuffiness. A major change in the 2024 firmware was reducing the fan speed for this function to the minimum possible (600 rpm).
- During heating, the frequency of defrost cycles varied depending on outdoor conditions. Typically, defrost cycles were about 2–3 hours apart. However, instances occurred where defrost cycles were as frequent as every 1.5 hours.
- The typical defrost cycle was observed to last approximately 5 minutes. During the defrost cycle, the indoor fan shuts off. The unit reverses the refrigerant cycle and runs in cooling for about 2 minutes (sending hot refrigerant to the outdoor coil), then switches back to heating and about 2 minutes later restarts.

3. Site Assessment

Researchers assessed the feasibility of retrofitting the Innova HPAC 2.0 in four multifamily buildings in New York City (NYC). The assessment included economic analysis, engineering evaluation, energy analysis, and a cost estimate for the installation. The objectives were to evaluate the feasibility of installing the HPAC 2.0 units and to recommend a demonstration host site for the installation and monitoring phase of this project.

Note that the performance metrics of Innova HPAC 2.0 were in flux at the time of these analyses because the final testing and product development were not yet complete. The specification used in this assessment report is for the 8-in.-diameter ducts configuration. The following summarizes the site assessment results.

3.1 Site 1

The property is a 92-unit, 7-story U.S. Department of Housing and Urban Development (HUD) Section 202 senior housing development with space conditioning provided by a central hydronic natural-gas-fired boiler with through-wall sleeves for air conditioners in each room. The assessed apartment was a top-floor non-corner unit. Projected carbon emissions reduction was estimated at 53%, with installed costs of $10,287 for two units. Key findings and implementation considerations include:

- Meeting thermal loads with heat pumps
- Installing units using existing wall air conditioner sleeves
- Adding new circuits, which would require split breakers or a new electric panel due to inadequate space
- Demolishing existing hydronic baseboards
- Expelling defrost meltwater to the outside would
- Shift of heating cost to tenant meters currently prohibited under affordable housing regulations
- Maintaining or decommissioning of hydronic boilers
- Servicing units and changing filters for HPAC 2.0

3.2 Site 2

The property is a 42-unit, 7-story building with space conditioning provided by a central hydronic natural-gas-fired boiler with through-wall sleeves for air conditioners in each room. The assessed apartment was a top-floor corner unit, representing a worst-case scenario for thermal load. Projected carbon emissions reduction was estimated at 54%, with ease of installation rated as standard and installed costs estimated at $10,541 for two units. Key findings and implementation considerations include:

- Meeting thermal load with heat pumps (using the electric resistance model in the living room)
- Installing units using existing wall air conditioner sleeves
- Completing minor electrical work to add circuits, with some uncertainty of the electrical panel fill requirements
- Removing existing hydronic baseboards
- Expelling defrost meltwater to the outside using balcony drains and planted areas
- Modifying leases to permit billing for heat to tenants
- Maintaining or decommissioning hydronic boilers
- Servicing units and changing filters for HPAC 2.0

3.3 Site 3

The property is a 631-unit, 42-story building with space conditioning provided by PTAC connected to a central steam system. The assessed apartment was a middle-floor non-corner unit. Projected carbon emissions reduction was estimated at 51%, with ease of installation rated as standard and installed costs estimated at $9,330 for two units. Key findings and implementation considerations include:

- Meeting thermal loads with heat pumps
- Installing units in place of existing PTACs
- Using existing electrical service, which appears adequate for the proposed installation
- Managing condensate and meltwater disposal, which would be challenging; options include using existing steam return lines (which pose significant challenges), installing new drain lines at exterior walls at high cost, running drain lines to interior plumbing at high cost and disruption, or misting water to the exterior via equipment that is not yet available
- Servicing units and changing filters for HPAC 2.0

3.4 Site 4

The property is a 3-unit, 3-story building with space conditioning provided by a central hydronic natural-gas-fired boiler and window-mounted room air conditioners. The assessed apartment was a top-floor unit. Projected carbon emissions reduction was estimated at 55%, with ease of installation rated as standard and installed costs estimated at $12,204 for two units. Key findings and implementation considerations include:

- Meeting thermal loads with heat pumps, with integral electric resistance backup required due to poor thermal envelope performance
- Completing minor electrical work, with some uncertainty regarding electrical panel fill requirements
- Installing units through wall penetration or using the through-window configuration using an optional duct fitting
- Expelling defrost meltwater to the outside, which would be challenging due to the adjacent sidewalk
- Modifying leases to permit billing for heat to tenants
- Maintaining or decommissioning hydronic boilers
- Servicing units and changing filters for HPAC 2.0

4. Implementation

4.1 Design

The selected demonstration site was Site 2 (Figure 3). This building was constructed in 1987, is heated by a natural-gas-fired boiler with hydronic distribution, and cooled via air conditioners in through-wall sleeves in each room. A one-bedroom apartment with two air conditioner sleeves was selected for the installation. The existing through-wall air conditioner sleeves were used for the HPAC 2.0 unit to avoid additional wall penetrations (Figure 4).

Figure 3. Site 2 Exterior View and Typical Interior

Figure 4. Site 2 Air Conditioner Sleeves

Interior (left) and exterior (right) view of air conditioner sleeves.

The apartment included a living room/open-plan kitchen, an entry foyer, one bathroom, and one bedroom (Figure 5). The apartment was divided into two thermal zones for load calculations: the living room and the bedroom. According to construction drawings on file, Site 2 has brick cladding with masonry backup wall and 2-in. foil-faced batt insulation (Table 2

This was estimated at a value of 0.08 Btu/(hr)(ft^2)(°F). The apartment was a mid-floor unit, so no heat loss was assumed through the floor or ceiling. The assumed exhaust ventilation rate was based on the NYC Mechanical Code minimum ventilation rates for bathroom (20 CFM) and kitchen (25 CFM) exhaust (NYCDOB 2022).

Figure 5. Site 2 Floor Plan

Highlights indicate Innova locations.

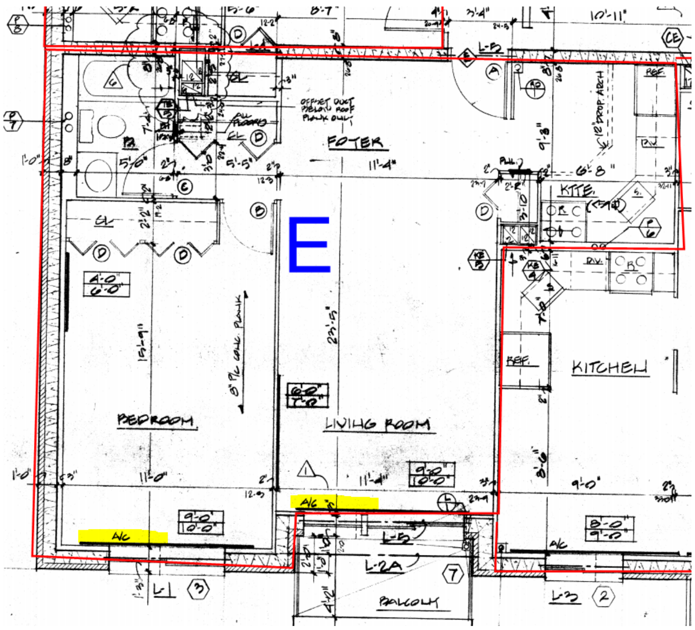


Table 2. Site 2 Load Calculation Parameters

Parameter	Information
Exterior wall	U-value: 0.08: 3-5/8-in. brick, 3/4-in. air space, 8-in. brick, 1-5/8-in. steel studs with 2-in. foil-faced batt, 1/2-in. gypsum board
Fenestration	U-value: 0.67, SHGC 0.62: non-low E, double pane clear glazing
Infiltration (CFM at natural pressure)	Cooling 28 CFM, heating 55 CFM
Ventilation	45 CFM (bath and kitchen exhaust)

The heating loads in both the living room and bedroom could be met with heat pumps alone, and even then, the living room had significantly more capacity than needed. However, due to equipment availability, these models with supplemental heat resistance were ordered. The supplemental heat will likely never be needed or used, and the variable speed compressors can ramp down to lower loads. Table 3 shows the thermal loads and the capacity of the selected heat pumps. The bedroom unit has 6-in.-diameter ducts rather than 8-in., resulting in quieter operation due to smaller fans, which is preferable for a bedroom.

Table 3. Space Heating and Cooling Loads Compared to HPAC 2.0 Equipment Capacity at Design Temperatures

Site/Rooms	Heating Capacity at 13°F (Btu/h) (Estimated)	Required Heating Load	Cooling Capacity at 95°F (Btu/h) Duct Versions	Required Cooling Load	Installed Equipment
Living room	6,900 + 6,100 (electric resistive) = 13,000	3,562	15,000	2,186	APK10N4L2
Bedroom	5,600 + 6,100 (electric resistive) = 11,700	4,894	10,200	3,995	AWP10N4H2

4.2 Installation

The existing buildings' electrical infrastructure was inspected to determine suitability for adding the HPAC 2.0 unit, which replaced the through-wall air conditioner. A 60-amp service panel is located at the entrance foyer (Figure 6). The living room air conditioning circuit did not require any changes, except to remove the receptacle and hardwire the heat pump. The bedroom required replacing the circuit breaker with a double-pole breaker to provide a 20-amp 208V circuit and removing the receptacle to hardwire the heat pump.

Figure 6. Site 2 Electrical Panel

The Innova units were mounted on the wall in front of the existing air conditioner sleeve, which was trimmed flush with the wall. The two round air duct openings aligned with the existing air conditioner sleeve opening (Figure 7). The wood moldings under the windowsills were trimmed to ensure a flush fit against the wall. The existing baseboard convectors were removed to ensure clearance under the units. The air conditioning electrical outlets were removed and replaced with hardwired connections to the heat pump.

The sleeves were insulated with 1-in.-thick extruded polystyrene (XPS) foam, and a 1-in.-thick XPS foam barrier was installed to divide the air conditioner sleeves into two side-by-side chambers: one for air intake and one for air exhaust. The existing exterior grilles remained in place. All sleeve modifications and installations were done from the interior.

The drainage line (label D in Figure 8) was passed through a new hole drilled through the wall. The drain lines terminated approximately 2 inches from the exterior wall, draining to the balcony floor drain (living room unit) and to a planted area beneath the apartment (bedroom unit).

Figure 7. HPAC 2.0 Mounting Diagram

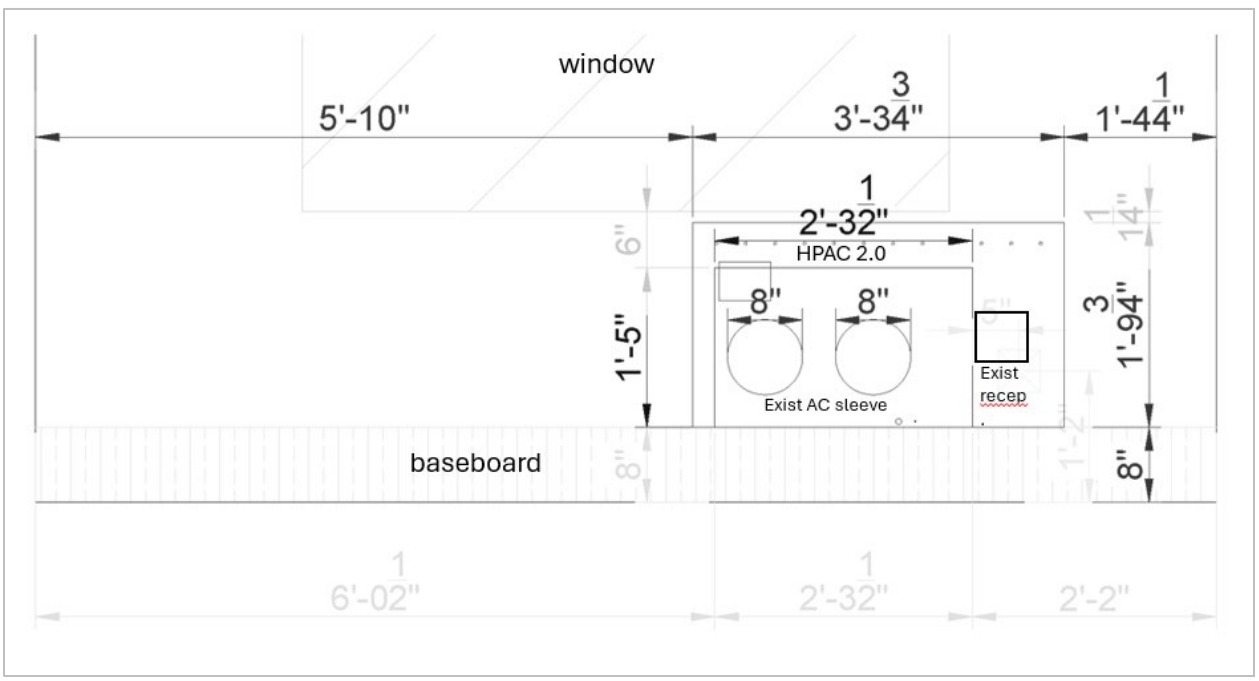
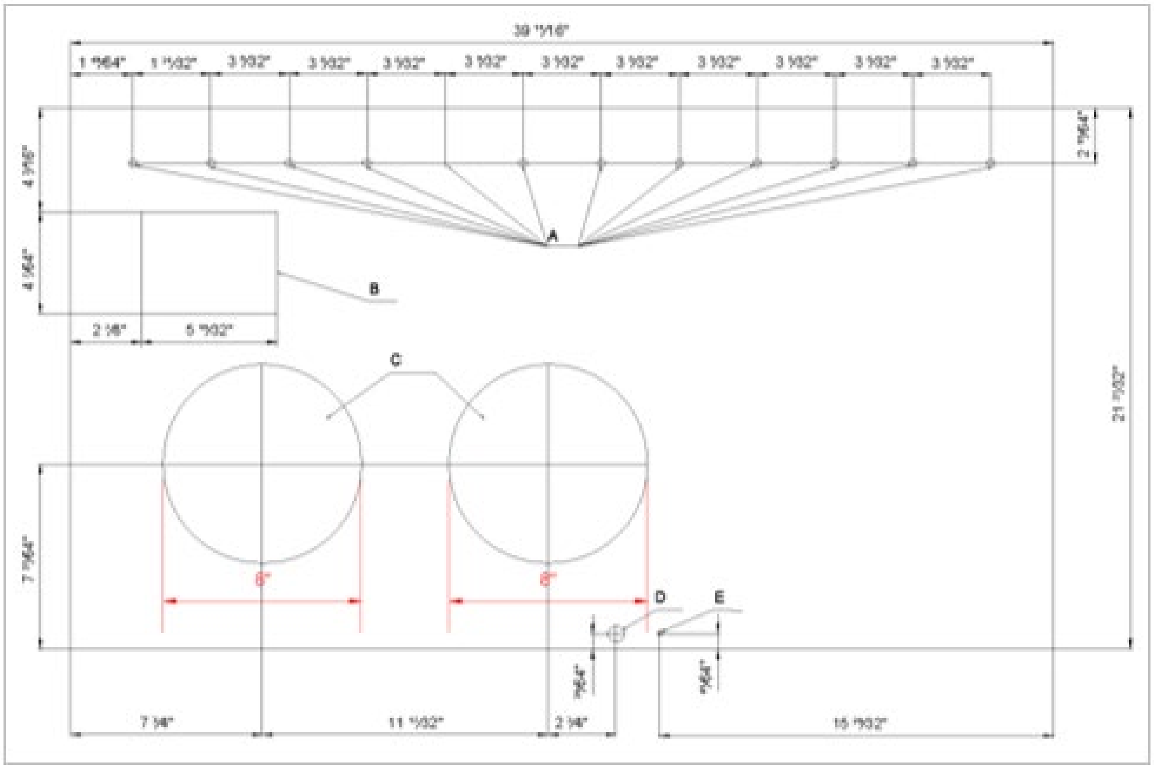


Figure 8. Innova HPAC 2.0 Mounting Template with Opening Dimensions

The round openings align with the existing air conditioner sleeve opening.



A Holes for fastening wall bracket
B Electrical connection area
C Holes for air vent pipes
D Holes for external condensate drain
E Anti-lifting bracket hole

The following summarizes the installation steps, followed by photos of the installation process:

1. The sleeve was prepared with XPS foam (1-in.-thick), cut and fit to divide the air conditioner sleeve into air inlet and exhaust portions. The edges of the XPS were sealed to the sleeve walls with spray foam. Another XPS panel was fitted to seal the sleeve from the interior with two round holes for the air ducts.
2. The metal bracket and mounting plate were fastened to the wall using the wall template for placement.
3. A hole was drilled through the wall for the drain line.
4. The electrical line was spliced and connected to the heat pump wire terminal.
5. The drain line was fastened to the heat pump drain outlet and passed through the wall.
6. A bead of silicone was applied around the duct openings.
7. The heat pump was mounted on the wall using the bracket and screwed in place at the bottom.

Figure 9. Air Conditioner Sleeve Mounting Details

At left, bracket and mounting plate installed over foam insulation at the living room air conditioner sleeve; at right, exterior view of living room air conditioner sleeve showing spray foam at the interface between the internal sleeve barrier and grille.

Figure 10. Drain Line Installation

Drain line routed through the wall beneath the air conditioner sleeve.

Figure 11. Heat Pump Installation, Living Room Unit

At left, the rear of the Innova unit showing foam padding forming an air seal against the mounting plate; at right, installation of the heat pump on the mounting bracket in the living room.

Figure 12. Installed Heat Pump Units

At left, an edge view showing the seal against the living room wall; at right, the bedroom unit installed.

Table 4 summarizes the costs incurred.

Table 4. Summary of Costs

Cost shown in U.S. dollars.

Item	Amount
Innova equipment (full list price, not including discount for demonstration project; not including airfreight shipping cost)	$7,900
Electrician: changed bedroom receptacle to 208 V, replaced breaker to 2-pole 20 amp	$381
Plumber: removed baseboard radiators in the bedroom and living room	$1,000
Heat pump installation labor (2 technicians x 1 day) and miscellaneous materials	$5,700
Total	**$14,981**

4.3 Commissioning

Commissioning was conducted by MaGrann Associates on a warm summer day and included visual inspection, operational checks, blower door testing, leakage testing of wall sleeves, and sound measurements.

Visual inspection: Units were square, level, secure, and without visible damage. Both units appeared to be well sealed to the wall with no light showing through the sides of the duct connections. The bottom fastening screw was installed securely, keeping the heat pump against the wall. The drain hose was installed and functional. Chipping of the brick at the exterior was observed. No water was observed draining from the unit during the on-site visit.

Operational checks: Upon arrival, the living room and bedroom units were in cool mode. All functions were tested and operated as expected: heat, cool, fan, and dehumidify.

Blower door testing: Blower door testing was conducted using an Energy Conservatory blower door and DG1000 monometer to measure apartment infiltration before and after installation of the Innova units. Prior to the installation, the leakage was 902 CFM50; following the installation, the leakage was 800 CFM50; a decrease in air leakage of 102 CFM50, indicating the retrofit resulted in a more airtight apartment as a result of sealing the air conditioner sleeves. During the testing, the kitchen exhaust was sealed with tape. The bathroom exhaust was not working, and it was left as found during blower door testing.

Leakage testing of wall sleeves: Leakage at each air conditioner sleeve was measured with an Energy Conservatory Duct Blaster and DG-1000 Gauge manometer. A test chamber was constructed of foam panels and sealed to the wall and floor. Pre-retrofit testing was conducted with baseboard convectors in place, creating challenges in achieving an airtight seal. Therefore, pre-retrofit testing may have included more internal leakage than post-retrofit testing. As shown in Table 5, the leakage was lower after the Innova equipment was installed.

Table 5. Air Conditioner Sleeve Air Leakage Testing

	Pre-retrofit 3/30/23			Post-retrofit 7/27/23		
Room	**Pa**	**CFM**	**Duct Blaster Ring**	**Pa**	**CFM**	**Duct Blaster Ring**
Living room	25	154	3	25	53	3
Bedroom	16.5[a]	196	3	25	68	3

[a] Could not depressurize to 25 pascals.

Figure 13. Sleeve Air Leakage Testing

Sound measurements: Measurements were made using the National Institute for Occupational Safety and Health (NIOSH) Sound Level Meter App installed on an iPhone approximately 4 ft in front of each unit and 4 ft above the floor. Because units have variable-speed fans and compressors, measurements were made during steady-state operation after ramp-up to setpoint. Pre-retrofit measurements were not possible because air conditioners were not present in the sleeves (Table 6).

Table 6. Sound Levels

In decibels.

Mode	Living room	Bedroom
Heat (high fan)	63.5	63.8
Cool (high fan)	59.2	60.1
Heat (low fan)	53.5	50.2
Cool (low fan)	51.5	48.2
Fan only (high)	66.0[a]	56.2
Fan only (low)	51.2	47.4

[a.] May have been affected by background noise.

Temperature measurements: Measurements were made of the supply airstream using an infrared thermometer during steady-state operation after ramping up to the setpoint (Table 7).

Table 7. Supply Air Temperatures

In degrees Fahrenheit.

Mode	Setpoint	Living Room	Bedroom
Heat	85	97	94
Cool	65	60	No data

5. Demonstration Testing

5.1 Measurement and Verification Design

The heat pumps installed in the demonstration apartment were:

- Bedroom: AIO Heat Pump Wall Mounted Pro APP10N4L2 (KP92LDSO). AIO Wall Pro Heat Pump W/O ERV R410A LCDI Power Cord 208/230V.
- Living Room: AIO Heat Pump Wall Mounted Pro APK10B4L2 (KK92LDSO). AIO Heat Pump Wall Mounted Pro 1,800W Resistance Heat 220v LCDI cord R410A.

To minimize the impacts of variable external factors, simultaneous monitoring of two adjacent apartments was conducted to compare the energy use of the Innova heat pumps with the existing hydronic heating and through-wall air conditioning systems. Both apartments were mid-floor corner units with two exterior walls and two interior walls, and both floors and ceilings were located within the building’s thermal envelope. Figures 14 and 15 show diagrams of the monitoring points.

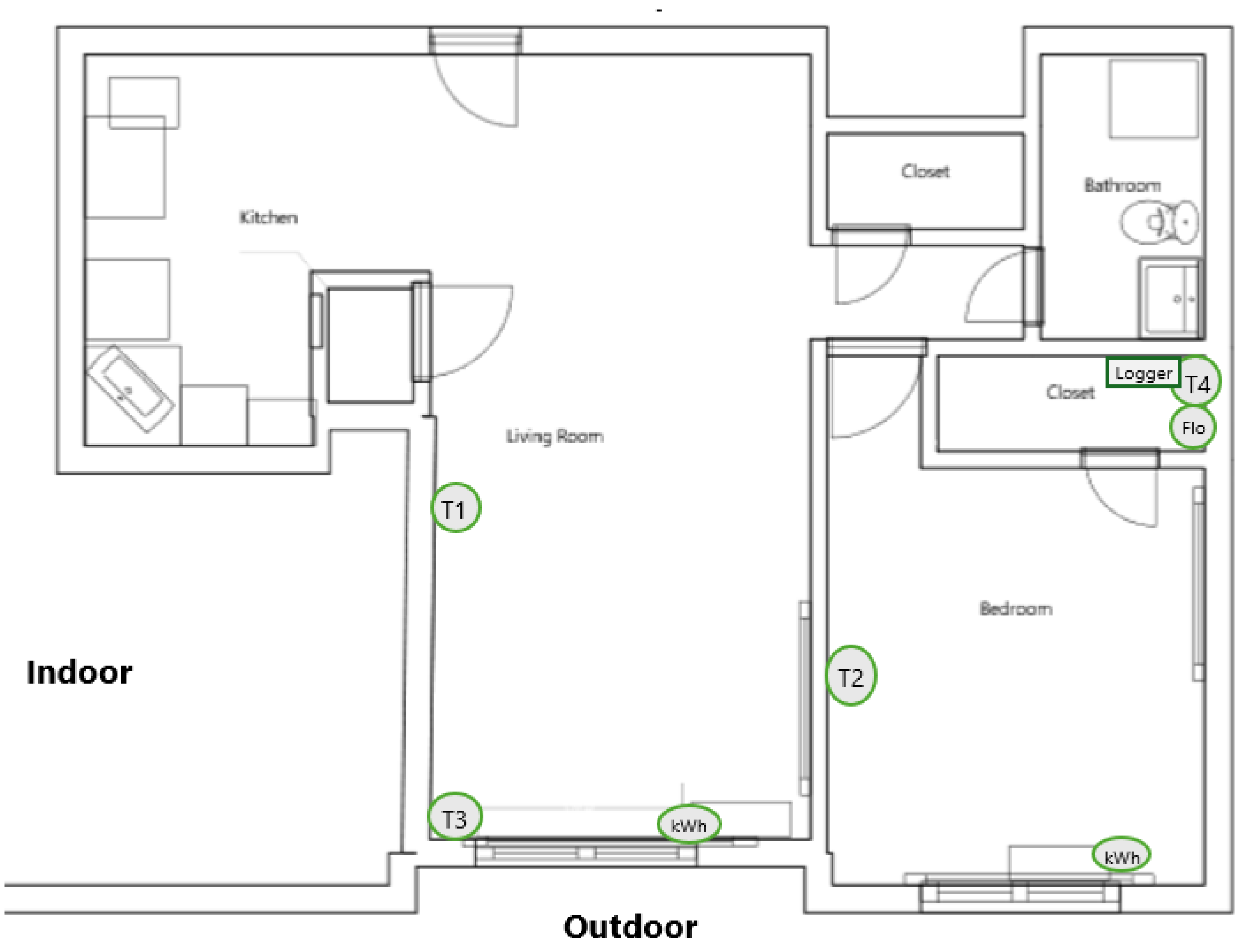
Figure 14. Demonstration Apartment

Diagram of apartment floor plan and monitoring setup (not to scale).

Sensor Legend:
T1 = Indoor space temperature (living room).
T2 = Indoor space temperature (bedroom).
T5 = Outdoor air temperature.
kWh = Wattnode energy meter with wireless transmitter, mounted as an inline plug in an enclosure underneath the Innova.

Figure 15. Baseline Apartment

Diagram of apartment floor plan and monitoring setup (not to scale).



Sensor legend

T1 = Indoor space temperature (living room).

T2 = Indoor space temperature (bedroom).

T3 = Leaving water temperature (at radiator).

T4 =Entering water temperature (on pipe near flow meter).

Flo =Ultrasonic Flow Meter with wireless transmitter.

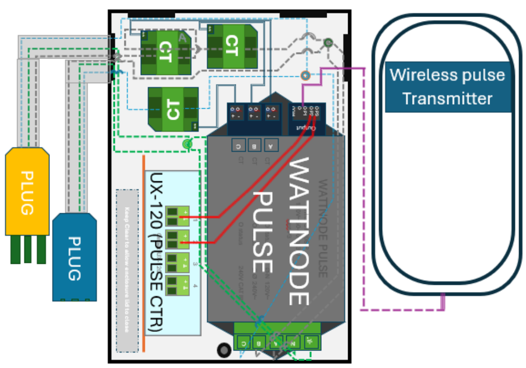
kWh = Wattnode energy meter with wireless transmitter, mounted as an inline plug-in enclosure underneath air conditioning systems. The wireless data logger station (the "Logger" in the figure), receiving signals from the sensors, was in the baseline apartment closet. This location was chosen due to the installation of a supplemental power outlet for the flow meter and to avoid running exposed wires in the apartment.

5.2 Measurement Points

The points monitored are described below.

Innova HPAC 2.0 heat pump power consumption (Figure 16) The total power consumption for the heat pump, including the compressor, fans, controls, and supplemental electric resistance heater, was measured using an Onset Hobo RX2105 wireless data logger base station connected to a pulse-input remote sensor reading from a Wattnode true RMS kWh transducer. The Wattnode kWh transducer and pulse-input wireless transmitter were configured and mounted in a preconfigured enclosure with an inline power cable extension. This setup allowed installation with minimal disruption to occupants and no additional exposed wires.

Figure 16. Innova (and Baseline Air Conditioner) Power Consumption Measurement Setup



Baseline apartment heating energy consumption (Figure 17): The energy consumption of the hydronic heating system in the baseline apartment using a flow meter and entering and leaving water temperatures. Hydronic flow was measured using an Onset Hobo RX2105 wireless data logger base station connected to a pulse-input remote sensor that reads a Keyence FD-H20 ultrasonic flow meter. Temperatures were measured using Onset Hobo wireless sensors (RXW-TMB-900) placed in contact with the entering and leaving hot water pipes and insulated.

Figure 17. Hydronic Flow and Temperature Measurement Systems for Baseline Heating Energy Measurements

Indoor space temperature: The average indoor air temperature was measured using additional wireless sensors connected to the Onset Hobo RX2105 base station. Measurements were collected in the living room and bedroom of both the baseline and demonstration apartment to compare operating conditions and evaluate any negative impacts on occupant comfort.

Outdoor air temperature (Figure 18): The average outdoor air temperature and relative humidity were measured using a wireless sensor (Onset RXQ-THC-900) with a wired temperature probe that extended through-wall penetration of the Innova heat pump air conditioner sleeve. This communicated with the same RX2105 wireless data logger base station as the other sensors.

Figure 18. Outdoor Air Temperature and Relative Humidity Sensor

Additional data: Apartment-level energy utility data (electric) was also expected to be collected for use in comparing use patterns and reviewing cooling operation. Unfortunately, despite including access to this data in leases and other contractual requirements, the occupant of the demonstration apartment declined to provide it upon project completion.

6. Demonstration Results

6.1 Energy Use

Over 1 year, the baseline heating and cooling systems consumed nearly 7,500 kWh of energy, while the Innova heating and cooling systems consumed close to 1,500 kWh of energy. As discussed below, the 1-year periods were not identical, and the indoor temperatures maintained by each system differed, resulting in reduced heating and cooling loads for the demonstration apartment (Table 8). Some of the more significant caveats for these results are explored in detail later in this section.

Table 8. HVAC Energy Use Comparison: Full Year

Apartment Type	Time Period	Annual HVAC Energy Use	Annual Heating Only Energy Use	Annual Cooling Only Energy Use	Notes
Baseline	12/4/23–12/3/24	7,480 kWh (25,523 kBtu)	6,314 kWh (21,546 kBtu)	960 kWh	Some air conditioning circuit usage was collected during winter. This is included in the total HVAC use, but not the heating or cooling energy.
Demonstration	10/4/23–10/3/24	1,489 kWh (5,080 kBtu)	1,182 kWh (4,035 kBtu)	91 kWh	Very different interior conditions from the baseline apartment.

As mentioned earlier, one full year of data was collected for both systems; however, that year has slightly different start and end dates for each system. This is a result of sensor calibration and apartment access. Considering only the period that both systems were operational (December 4, 2023–October 20, 2024), yields the results in Table 9.

Table 9. HVAC Energy Use Comparison: Overlapping Monitoring Period

Apartment Type	Time Period	Annual HVAC Energy Use	Heating Only Energy Use	Cooling Only Energy Use	Notes
Baseline	12/4/23–10/20/24	7,444 kWh (25,399 kBtu)	6,278 kWh (21,421 kBtu)	950 kWh	Some air conditioning circuit usage was collected during winter. This is included in the total HVAC use, but not the heating or cooling energy.
Demonstration	12/4/23–10/20/24	1,289 kWh (4,399 kBtu)	1,171 kWh (3,997 kBtu)	91 kWh	Very different interior conditions from the baseline Apartment.

These results come with several important caveats, explained in detail below. Due to these caveats, these results should be treated as preliminary indications of comparative performance only, and not conclusive results that can be extrapolated without sufficient caution.

6.1.1 Caveats

Sample size: The results from this demonstration study are based entirely on the operation of heat pumps in two apartments in a single building. These are not controlled laboratory conditions, and as such, it was recognized from the beginning that this sample size would be too small to establish any characteristic efficiency results. The intent and what it provided were to establish a proof of concept, gain insights into how occupants are using these systems, and identify a limited number of operational concerns.

Study date range: The systems monitoring the Innova heat pumps were operational and reporting correctly as early as October 4, 2023 (with space temperature data added November 14, 2023); however, accurate hot water Btu consumption from the baseline apartment was not available until access could be arranged to insulate the pipe temperature sensors on December 4, 2023.

Conversely, data collection systems for the Innova heat pumps were largely removed from the site as of October 28, 2024; however, baseline system heating energy consumption data continued to be collected through January 11, 2025.

Differences in apartment temperatures and use: Differences in space temperatures between the baseline and demonstration apartments were typically 5°F to 10°F. This may be partially or entirely user-driven, but results in different heating and cooling loads, making direct comparisons of energy use between apartments difficult.

Several instances occurred in which the Innova demonstration apartment was maintained at reasonable temperatures (70°F) with no heat provided by the Innova systems, even when ambient outdoor conditions were 40°F–50°F.[2] This was likely due to internal gains and heat transfer from adjacent warmer apartments on the demonstration apartment's heating needs.

Equipment operation: Both apartments encountered issues with their heating, ventilating, and air conditioning (HVAC) systems. A valve leak-by in the baseline apartment heating system may have reduced occupant control and overheating, an issue that could presumably be addressed, at least in part, by replacing the valve.

The demonstration apartment resident reported instances of their Innova heat pumps not operating as expected and comfort issues during the winter. The resident reported that, as a result, they kept their heat pumps off for extended periods, allowing indoor temperatures to drop below their normal comfort range. According to the manufacturer, the operational issues were due to the equipment's control logic, which has since been modified in firmware updates to address U.S. consumer expectations.

Operating anomalies: Ongoing low levels of electric use from the baseline apartment air conditioning circuits were recorded during the 2023–24 winter. This use was excluded from the heating and cooling-season-specific use reported earlier in this report, but it was included in the total consumption aggregate. It is suspected that this use was from other devices plugged into the wall outlets used for the (120 V) air conditioning systems.

Weather conditions: The monitored period was over a mild winter,[3] which would likely skew results to the advantage of the Innova heat pumps, which are more efficient in heating at milder ambient temperatures, and provide more room-by-room control for users, allowing more aggressive setbacks and operating control, particularly in milder weather conditions when a system could be turned off completely.

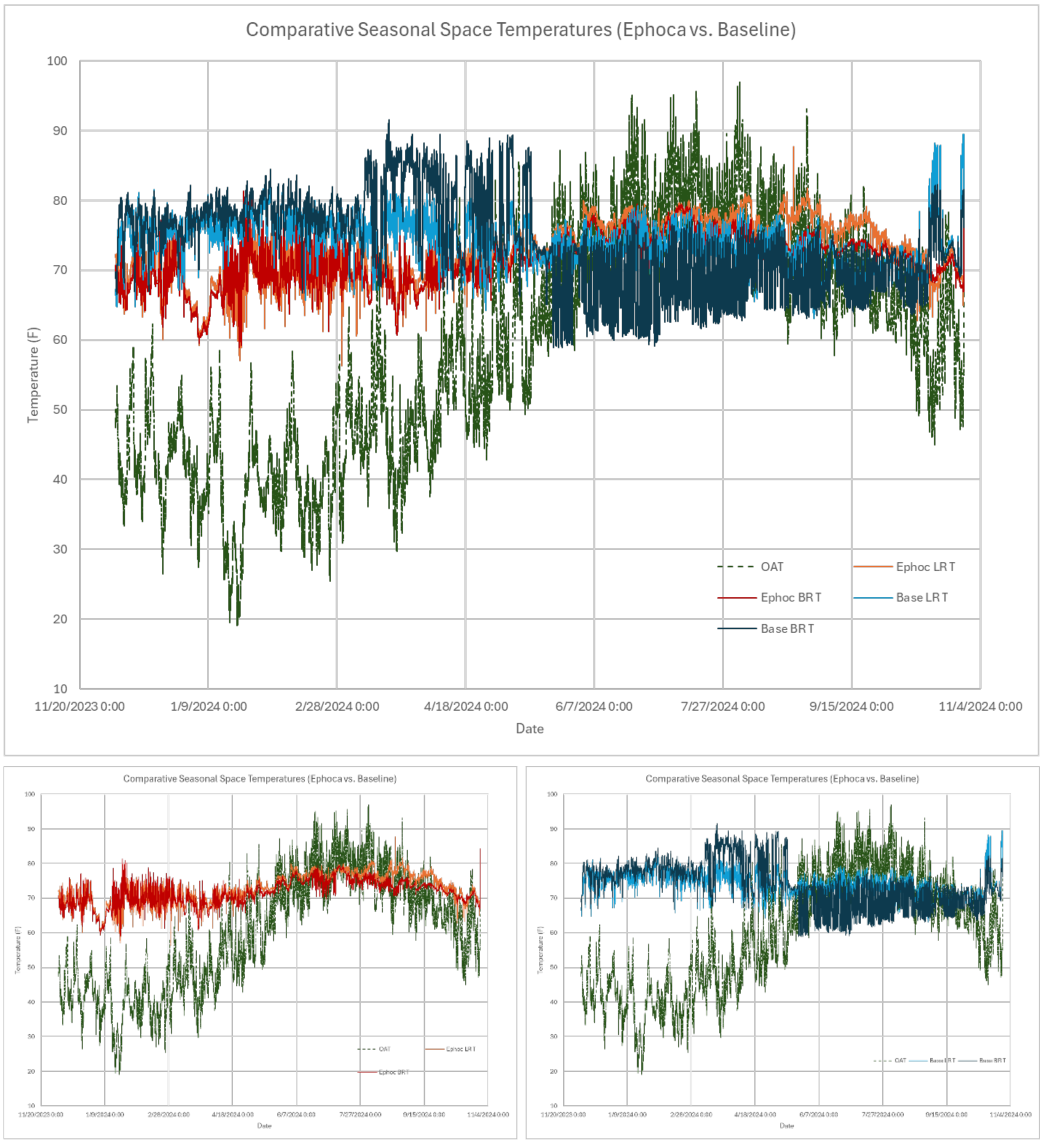
As noted above, regular periods occurred when the Innova heat pumps remained off entirely while outdoor temperatures were in the mid-40s°F. This condition could not be replicated in the baseline apartment. At the same time, the heating plant was active, either because of the owner's preference for warmer temperatures or due to poor temperature control in the apartment.

6.2 Apartment Temperatures

6.2.1 Full Monitoring Period

Observing the graphical trends of the comparative space temperatures from the Innova demonstration apartment versus the baseline apartment, as outdoor temperatures shifted from colder winter periods (left of the chart) to summer (middle) and back again, the baseline temperatures consistently show warmer temperatures in the winter, cooler temperatures in the summer, and more cycling within each period than the demonstration apartment. While the baseline apartment residents may not have had full control of space temperatures during the heating season, they did have full control during the cooling season. This indicates a significant difference in user preference between the two apartments, as mentioned in Section 6.1.1.

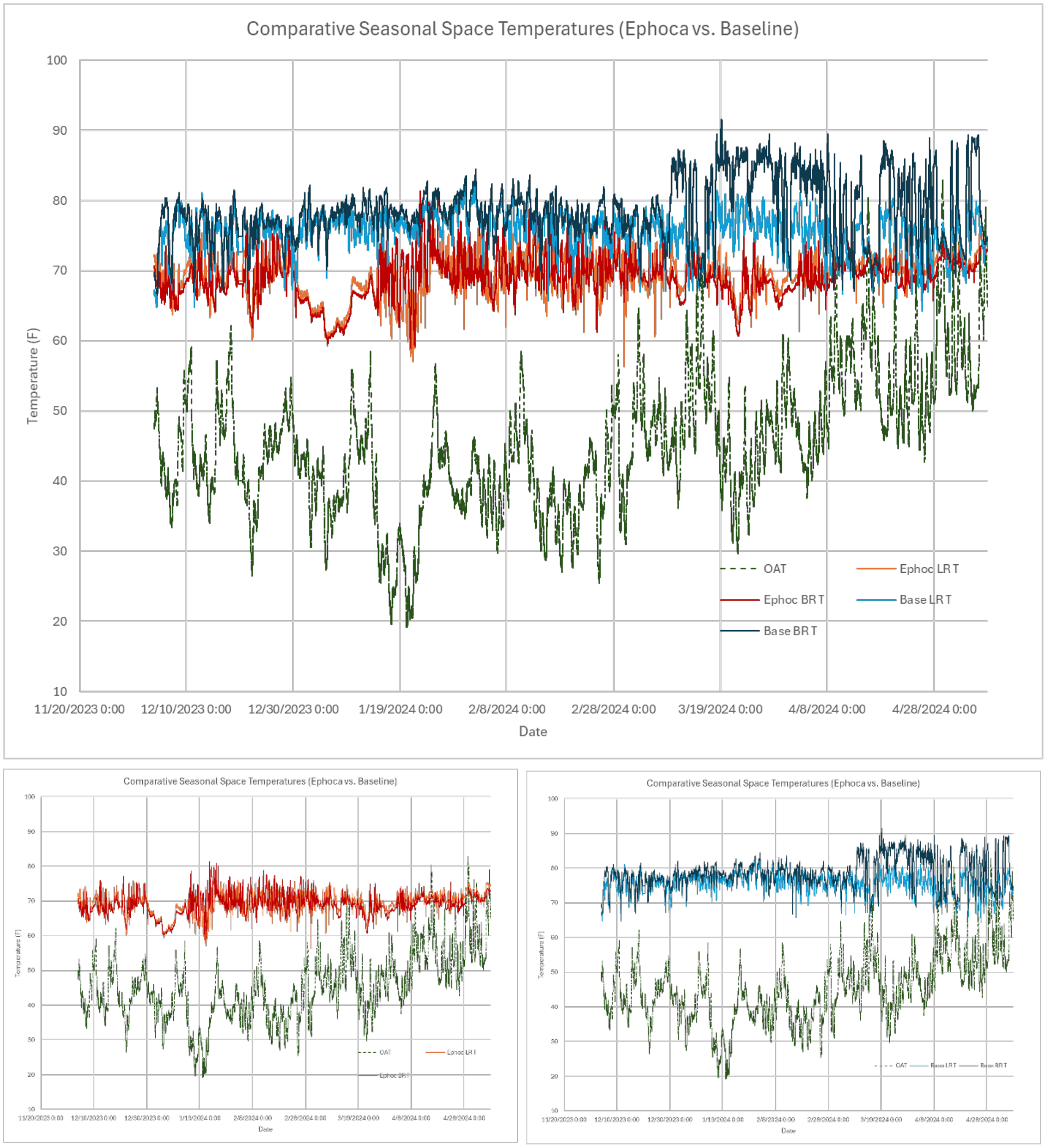
Figure 19. Ambient and Apartment Temperatures, December 4, 2023–October 28, 2024



6.2.2 Heating Period

As with the observations for the entire period, the winter indoor temperatures maintained in the baseline apartment were higher than in the demonstration apartment[4]. The variability (swings between higher and lower temperatures) of indoor temperature in the demonstration apartment was lower than that in the baseline apartment.

Figure 20. Ambient and Apartment Temperatures, December 4, 2023–May 7, 2024



The higher apartment temperatures, combined with some ongoing low-level flow and temperature measurements from the monitoring equipment, provide evidence that the heating control valve for the baseline apartment was experiencing some leak-by. That sort of issue is not unusual for an older hydronic heating system.

Table 10. Winter Temperatures, December 4, 2023–May 8, 2024

Temperatures in degrees Fahrenheit.

Category	Average	Max	Min
Ambient temperature	45	79	21
Baseline apartment	78	89	65
Demonstration apartment	69	79	58
Baseline apartment living room	76	81	66
Demonstration apartment living room	69	75	58
Baseline apartment bedroom	79	89	68
Demonstration apartment bedroom	69	79	60

A roughly 10°F difference in average temperature existed between the two apartments.[5] This difference likely resulted from user preference and increased control over the system; however, some variation could be attributed to intermittent operational behavior of the heat pumps, particularly for the recorded minimum temperature readings.

The magnitude of the temperature difference between the two apartments was significant. Attempts were made at rough normalization and corrections to estimate a projected efficiency; however, given the magnitude of the temperature variations and the suspected differences in user operation, within a range of reasonable assumptions, results could vary enough that a meaningful metric was not possible.

6.2.3 Cooling Period

The summer indoor temperatures maintained in the baseline apartment were lower than those in the demonstration apartment. Notably, the baseline apartment exhibited greater cycling and temperature swings, primarily driven by the bedroom. This pattern suggests occupants used the air conditioning on demand when the bedroom was in use. In contrast, demonstration apartment spaces and the baseline apartment living room displayed a much subtler pattern of use, indicating those spaces were either largely unconditioned or operated with a thermostatically controlled, set-it-and-forget-it style approach.

Figure 21. Ambient and Apartment Temperatures, May 15, 2024–September 15, 2024

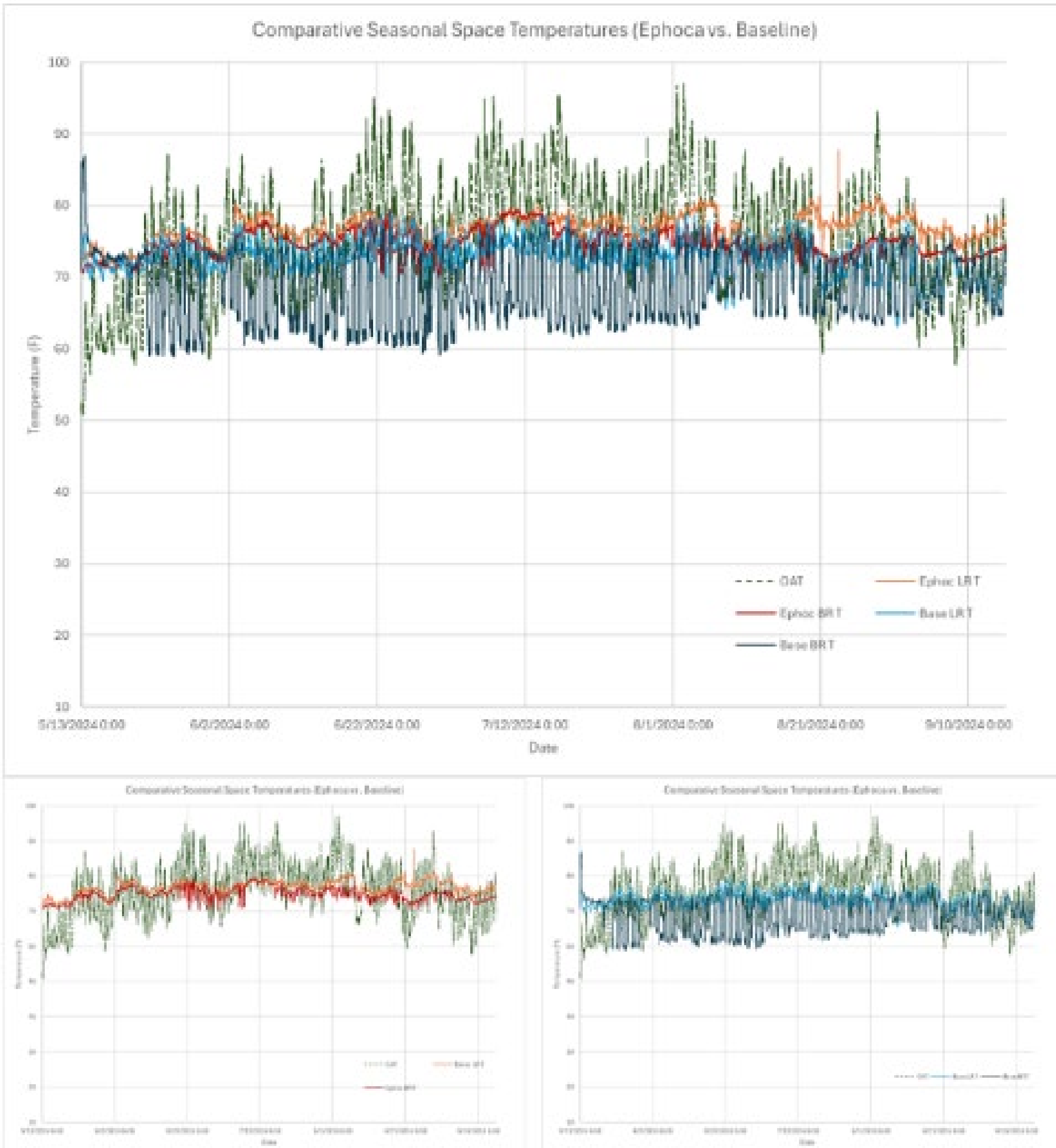


Table 11. Summer Temperatures, May 15, 2024–September 15, 2024

Temperatures in degrees Fahrenheit.

Category	Average	Max	Min
Ambient temperature	76	97	58
Baseline apartment	71	79	59
Demonstration apartment	76	88	70
Baseline apartment living room	73	79	63
Demonstration apartment living room	77	88	71
Baseline apartment bedroom	69	77	59
Demonstration apartment bedroom	75	80	70

Note that the baseline apartment was kept an average of 5°F cooler than the demonstration apartment. This means that the cooling energy consumption for each apartment is not directly comparable (because the baseline apartment was operating at a lower setpoint and thus experiencing greater load conditions). No attempt was made to normalize for the different indoor temperatures because relative humidity complicates calculations.

6.3 Utility Analysis

As supporting data, electric utility data from the two apartments were expected to be collected and used to evaluate whether a reasonably accurate future savings analysis could be completed using utility analysis alone. Indoor and outdoor temperatures were collected throughout the monitoring period and would be used to corroborate the utility results.

Unfortunately, a utility analysis was not possible, as one of the sample apartment tenants was not willing to cooperate with this request, despite it being a condition of their lease.

7. Conclusions

7.1 Energy Efficiency

Limited data indicate potential for high energy savings. Energy use measurements indicate the demonstration apartment used approximately 20% of the baseline apartment's space-heating energy. This result is not corrected for differences in apartment temperatures and thus is not a comparison under identical operating conditions, but may be a realistic reflection of how these types of products drive occupant behavior and reduce energy consumption through increased room-by-room control and higher efficiency. An argument can be made that an investment in improved controls for the existing system would result in some of the observed savings; however, such controls have been available for many years without wholesale adoption in older buildings.

These results should not be taken out of context and come with caveats, as addressed elsewhere in this report; however, even a preliminary result of this order of magnitude is notable and warrants further testing on larger-scale deployments (particularly in suitably cold climates, where low-ambient performance can be assessed).

Cooling efficiency appears promising, but calculations were not within the scope of this project. This area may be of interest, given the transition from refrigerant R-410A, which may open a market for new heat pump systems with fully self-contained refrigeration systems.

7.2 Qualitative Performance

In-practice use of these systems may be dictated more by equipment-user interaction than technical performance factors. For example, the demonstration apartment resident reported feeling cold air coming from the heat pumps during the heating season. Several gaps around the base of the units had been missed during installation and were subsequently sealed; however, the comfort issues remained. Directional supply airflow from the heat pumps was felt up to 15 ft away, even at low fan speed. When the room neared the setpoint temperature, the heat pumps would slow the compressors down, reducing heat output and the supply air temperature. These supply air temperatures, only a few degrees higher than space temperature, felt cold to the resident. As a result, the resident reported turning off the heat pumps until the space temperatures were low enough to maintain a warmer supply air temperature for some time. The manufacturer reports that it modified firmware in 2024 to prevent cold drafts in later models. Nevertheless, retrofit designers may wish to consider the configuration of heat pump supply outlets relative to the home's interior.

Initially, the resident believed that the unit could not cool the entire space. Perhaps its relatively quiet operation compared to a room air conditioner led them to believe it was not as "powerful." In the end, the resident was satisfied with the cooling performance.

Some unexpected equipment operation was reported by the resident and observed by Taitem at the end of the study. These included:

- Supply air louver did not open automatically at system start.
- Bedroom heat pump powered down without user input.
- Fan speed would revert to higher speeds without user input, even when the space temperature was satisfied.

This unexpected equipment operation made recommending the heat pumps for heating use difficult for the resident. According to the manufacturer, all these behaviors were normal operational features built into the control logic but have been refined in response to U.S. consumer input in the 2024 firmware release.

7.3 Usage Patterns

Significant differences in operating conditions (and temperatures): During winter, the demonstration apartment was kept at significantly lower temperatures than the baseline apartment. This was likely due to a mismatch between the user's desired setpoint and the operation (made possible by packaged controls and individual heat pumps in each room), as well as to inadequate heating control in the baseline apartment.

During the summer, the baseline apartment had colder temperatures and clear indications of active, on-demand style use of air conditioning. The demonstration apartment had a more stable, warmer, and consistent temperature range. It was still below ambient outdoor temperatures, but not as intensively cooled as the baseline apartment.

Overall, the baseline apartment had much greater temperature swings during normal operation (suggesting much less temperature control), appeared to overheat in winter, and showed clear evidence of air conditioning equipment cycling during cooling. Hot water valve leak-by likely caused overheating during the winter and may have necessitated excessive cooling use during the fall and spring while the heating plant was active.

The difference in use patterns for two effectively identical apartments speaks to a challenge that manufacturers and implementers of new technologies will face. Individual user preferences will play a significant role in determining what load conditions these systems will see. Any new product that seeks to replace a central building-wide heating system (which has the advantage of being able to supply a heating load in aggregate, allowing higher and lower users to average out) and occupant-provided air conditioning cooling solution (which have the advantage that users can select a system that best fits their individual needs) will need to have the flexibility to meet a wide range of user needs.

More control over individual space temperatures: Conversely, an advantage that unitary heat pumps have over a central heating plant is greater room-by-room control. Summer data from the baseline apartment clearly shows that the occupant used the air conditioning on demand, with regular use patterns indicating this strategy was driven by space occupancy. Specifically, the bedroom air conditioner was only turned on when the bedroom was occupied and turned off when the occupant left in the morning.

This sort of on-demand usage is something observed in winter use on other similar projects. When occupants have a room-by-room controllable heating solution, they tend to treat it like a room air conditioner. For example, heating setpoints can be reduced (or heat pumps turned off completely) in living rooms when the occupant goes to bed at night.

This specific operating pattern was not observed in the demonstration apartment for this project; however, as noted earlier, much lower overall space temperatures in the winter suggest that finer temperature control was being used, with periods when the unit appeared to be turned off while the occupant was presumably away.

Directional airflow comfort issue: Occupants complained of drafts, which were more likely due to fan-speed regulation and supply air temperatures only a few degrees above the space temperature as the room approached the setpoint. This type of heat pump, with supply air directed into the room at approximately waist height, will need to reduce this "blowing cold air" perception from occupants who may spend considerable time directly in front of the unit.

7.4 Measurement and Verification Lessons

Significant differences in operating conditions (temperatures) between two nearly identical apartments: An attempt was made to estimate the COP of the heat pumps, even though this was not within the project's scope. However, variations in indoor temperatures between apartments were effectively impossible to normalize, preventing calculation of a field-measured COP with reasonable confidence. Studies with a dedicated goal of field measurements of COPs could involve an increased sample size; however, given the difficulties with access, scheduling, and site selection for this single installation, this undertaking may prove functionally implausible without the direct involvement of a large developer or housing operator. Even with a much larger sample size, the variability in use and the impact of room-by-room control on how users operated these unitary systems compared with the existing hydronic heat will likely make any direct comparison of efficiencies impossible without extensive normalization.

Apartment access is difficult: Installation was delayed several times, and several months of data could not be used due to issues obtaining sufficient time in the apartments for the initial installation or returning to make minor corrections to the data collection systems (e.g., insulating pipe sensors). This lack of access added significant complexity and expense (requiring multiple visits) to the measurement and verification (M&V) process.

Backup data systems are always a good idea: Issues with the installation and apartment access meant that some of the systems intended as redundant backups had to function as the primary data collection devices. This was true of the flow meter system, which was supposed to be configured to communicate directly with the remotely accessible Onset base station, but instead had to be read out manually. Additional redundant sensors were used to cross-check certain data points and establish a calibrated time offset between the flow meter readings and the centralized monitoring system (necessary because the flow meter was no longer directly connected to that system and had been found to have an unreliable internal time clock).

Insulation of pipe temperature sensors is necessary for accurate readings: Taping of temperature sensors to the exterior of pipes to record temperatures is a common practice among control contractors. The argument is that temperature readings are reasonably accurate and can be cleaned up with a calibration factor. In the initial installation of the M&V platform, the sensors were not insulated due to a lack of time, access, and materials. The integral flow meter temperature was used for calibration; however, variations in readings quickly became apparent, with results highly affected by ambient room temperature (or wall cavity temperature in the case of one sensor) and the rate of temperature change. A reliable calibration equation was not possible until insulation was installed around the sensors to isolate them from the ambient conditions.

7.4.1 Operating Anomalies

Ongoing low levels of electric use from the baseline apartment air conditioning circuits were recorded during the 2023–24 winter. These data were excluded from the heating and cooling-season-specific use reported earlier in this report, but were included in the total consumption aggregate. This use was likely due to other devices plugged into the wall outlets used for the (120 V) air conditioning systems.

8. Product Feasibility

8.1 Design and Installation

The site survey analysis found that the HPAC 2.0 was feasible to retrofit into various building types built from 1905 through 2011. The level of work required varied depending on existing wall openings, interior obstructions, and electrical infrastructure. The largest challenge was meltwater disposal, which becomes more difficult in taller buildings. Installation in the demonstration apartment was straightforward but more time-consuming than expected due to the precision required to seal the air-conditioner sleeves and cleanly mate the heat pump air conditioner (HPAC) to the walls. Measured air leakage results showed improvement over pre-retrofit conditions. Thermal load calculations indicated the equipment was easily capable of meeting the heating and cooling loads.

8.2 Economics

Despite the relatively simple installation of the HPAC unit, the final cost is on par with other efficient heat pump alternatives, such as mini-splits, due to the price of the equipment and the labor involved in retrofitting the air-conditioner sleeve and mounting the unit. Two experienced technicians needed a full day to install two units over existing air-conditioner sleeves. Additional costs were incurred for the electrician and plumber to prepare the site.

Based on the site assessment, the operational costs of the HPAC would be about one-third higher than those of baseline systems with gas-fired heating, assuming a unit-for-unit fuel-switching analysis. This is because the higher costs for electric heating, even when efficient, compared to natural gas, outweigh the reduction in electric cooling costs. However, the modeling analysis that led to this projection did not factor in the large difference in indoor temperature driven by operating behavior (and presumably lower overheating waste) observed in the demonstration test. This would result in additional energy reduction for the unitary HPACs compared to central systems.

Furthermore, if the cost of emissions is factored in using the NYC Local Law 97 (LL97) penalty rate of $268/metric tons of carbon dioxide equivalent (mT CO_2e), additional savings would result. Note that not all buildings (two of the four analyzed) are subject to paying these fines; one of the remaining buildings is too small (below 25,000 sq ft), and the other is categorized as affordable and therefore can comply via prescriptive measures.

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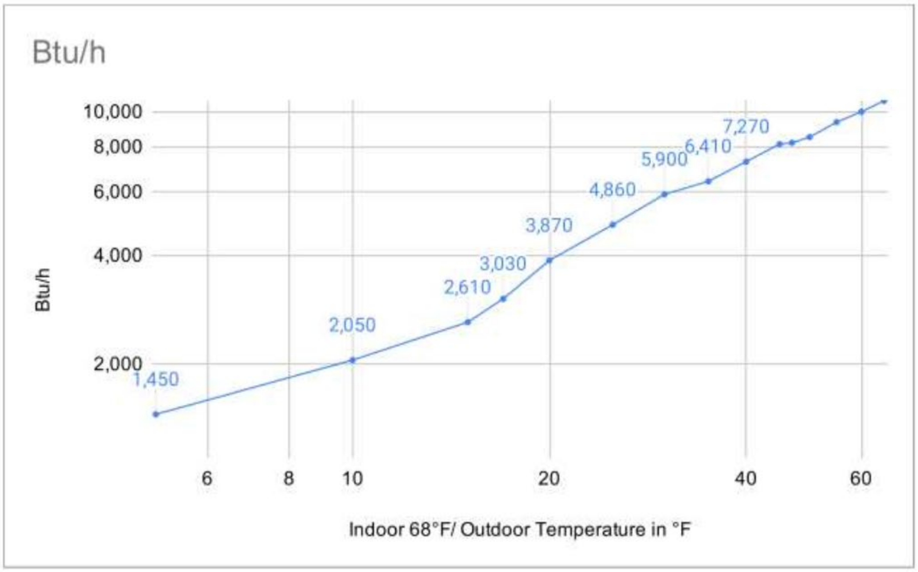
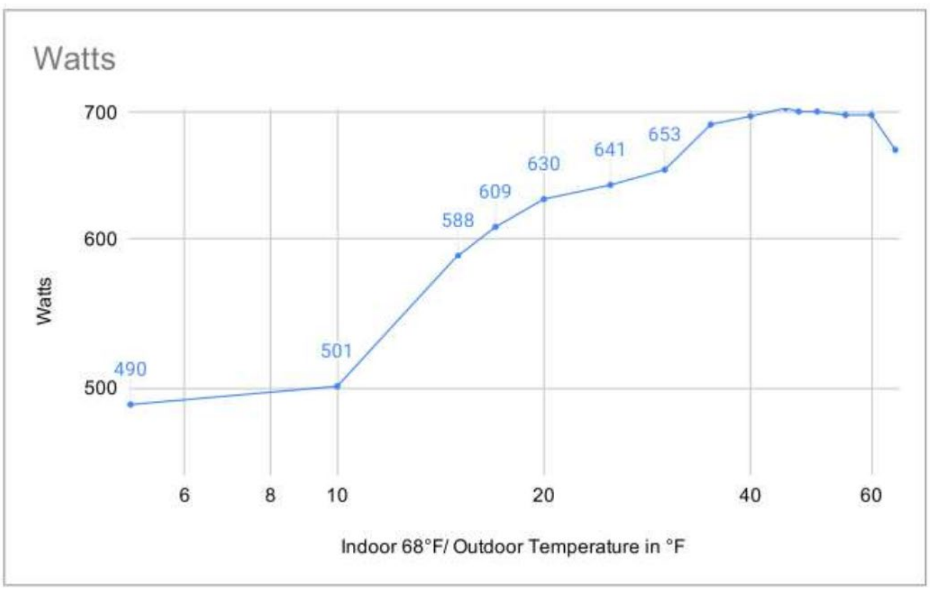
Appendix A. HPAC 2.0 Heating Performance Data, 6-inch Ducts

Figure A-1. Heating Output versus Outdoor Air Temperature



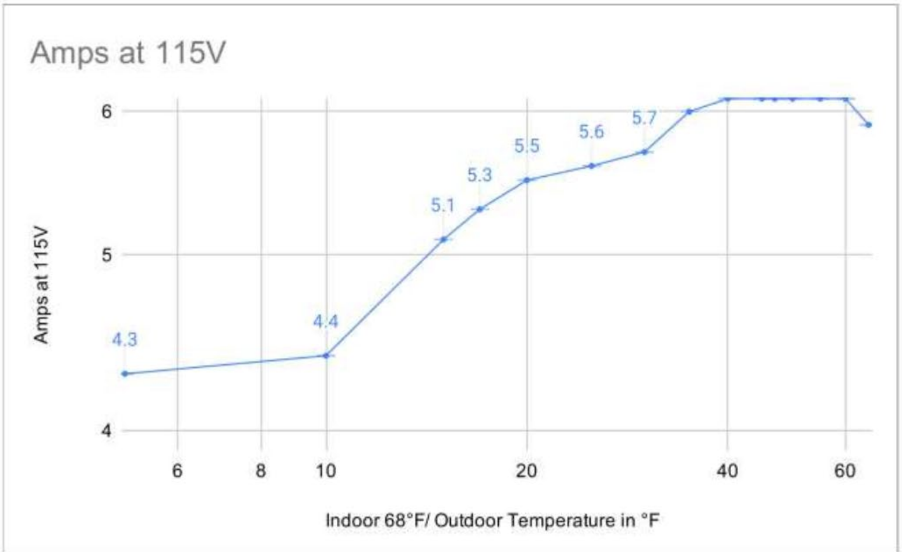
Temp °F	Btu/h
0	1,100
5	1,450
10	2,050
15	2,610
17	3,030
20	3,870
25	4,860
30	5,900
35	6,410
40	7,270
45	8,130
47	8,200
50	8,500
55	9,350
60	9,990
65	10,710

Figure A-2. Power Usage versus Outdoor Air Temperature



Temp °F	Watts
0	450
5	490
10	501
15	588
17	609
20	630
25	641
30	653
35	690
40	697
45	704
47	701
50	701
55	698
60	698
65	669

Figure A-3. Amperage versus Outdoor Air Temperature



Temp °F	A at 115V
0	3.9
5	4.3
10	4.4
15	5.1
17	5.3
20	5.5
25	5.6
30	5.7
35	6
40	6.1
45	6.1
47	6.1
50	6.1
55	6.1
60	6.1
65	5.9

Appendix B. HPAC 2.0 Performance Data, 8-inch Ducts

Figure B-1. Heating and Cooling Performance Data

COOLING PERFORMANCE

EER 11.9

SEER 16

EXPANDED HEATING PERFORMANCE

Outdoor Temp	Indoor 62 °F			Indoor 68°F			Indoor 70°F		
	Btu/h	Watts	COP	Btu/h	Watts	COP	Btu/h	Watts	COP
-5 °F	3,855	979	1.15	3,412	960	1.04	3,348	964	1.02
0 °F	4,284	924	1.36	3,791	906	1.23	3,720	909	1.20
5 °F	4,760	871	1.60	4,212	854	1.44	4,133	858	1.41
10 °F	5,102	838	1.78	4,515	822	1.61	4,430	825	1.57
15 °F	5,470	806	1.99	4,840	790	1.80	4,749	793	1.76
17 °F	5,677	790	2.11	5,024	774	1.90	4,930	778	1.86
20 °F	5,893	774	2.23	5,215	759	2.01	5,117	762	1.97
25 °F	6,318	745	2.49	5,591	730	2.24	5,486	733	2.19
30 °F	6,772	716	2.77	5,993	702	2.50	5,881	705	2.45
35 °F	7,260	688	3.09	6,425	675	2.79	6,304	678	2.73
40 °F	7,783	662	3.45	6,887	649	3.11	6,758	652	3.04
45 °F	8,343	637	3.84	7,383	624	3.47	7,244	627	3.39
47 °F	8,660	625	4.06	7,664	613	3.66	7,520	615	3.58
50 °F	9,284	601	4.53	8,216	589	4.09	8,061	592	3.99
55 °F	9,952	578	5.05	8,807	567	4.55	8,642	569	4.45
60 °F	10,669	556	5.63	9,441	545	5.08	9,264	547	4.96
65 °F	11,437	534	6.27	10,121	524	5.66	9,931	526	5.53

Appendix C. Resident Surveys

C.1 Part 1, after 4 Months

Date: November 13, 2023

Administrator: George Aiken (Taitem)

1. What heating setpoint do you typically use for each heat pump?

   80°F

2. Do you ever change the heating setpoints or turn the heating system off? If so, when, why, and how frequently?

   Yes, turn off, roughly hourly

3. Do you use any of the programmable features, such as automatic setbacks?

   No

4. How do you feel the temperature is in your apartment?
   a) Too warm
   b) Slightly too warm
   c) Just right
   d) Slightly too cold
   e) Too cold

5. Have there been any maintenance problems relating to the heat pumps?

   Yes [further elaboration not given, though they did mention that "The air conditioner in the bedroom operates as if it's in auto mode, which it's not. It usually stops and restarts on its own or shuts down after being out for a long time."]

6. Overall, how satisfied, or dissatisfied, are you with the heat pumps?

   Somewhat satisfied

7. Do you have any other comments about the heating and cooling system in your apartment?

   It does not feel like it can cool off an entire open space, just specific areas.

C.2 Part 2, after 15 Months

Date: October 28, 2024

Administrator: Jordan Dentz (MaGrann)

1. What heating setpoint do you typically use for each heat pump?

   80°F

2. What cooling setpoint do you typically use for each heat pump?

   72°F–75°F

3. Do you ever change the heating setpoint or turn the heating system off? If so, when, why, and how frequently?

   Turn on when needed. Living room unit typically use no more than 3 hours at a time. Bedroom unit turn on for the night, but it goes off by itself overnight—seems like a glitch.

4. Do you ever change the cooling set point or turn the cooling system off? If so, when, why, and how frequently?

   Same as heating

5. Do you use any of the programmable features, such as automatic setbacks?

   No

6. How do you feel the temperature is in your apartment in winter?

   a) Too warm

   b) Slightly too warm

   c) Just right

   d) Slightly too cold

   e) Too cold

7. How do you feel the temperature was in your home during the summer after the heat pump installation?

   a) Too warm

   b) Slightly too warm

   c) Just right

   d) Slightly too cold

   e) Too cold

8. How do you feel about your electric utility bills in winter (heating)?
    a) Much higher than expected
    b) Higher than expected
    c) As expected
    d) Lower than expected
    e) Much lower than expected
9. How do you feel about your electric utility bills in summer (cooling)?
    a) Much higher than expected
    b) Higher than expected
    c) As expected
    d) Lower than expected
    e) Much lower than expected
10. Have there been any changes over the past year that may have impacted your energy use, such as a change in the number of people residing in your apartment, the use of a thermostat setback/setup, or any other control changes? Approximately when did these happen?

    No

11. Have there been any maintenance problems relating to the heat pumps?

    No

12. Overall, how satisfied or dissatisfied are you with the heat pumps?

    Satisfied for cooling. Unsatisfied for heating.

13. Do you have any other comments about the heating and cooling system in your apartment?

    Draft from airflow in heating mode is uncomfortable, even a desk approximately 20 feet away (in front of the unit). Also feels there is air leakage around the unit.

Endnotes

[1] In 2019, Innova entered the U.S. Market as Innova USA. In 2021, to avoid confusion with a similarly named company, Innova rebranded as Ephoca for the U.S. market. In 2026, Ephoca was rebranded back to Innova for the U.S. market.

[2] A 2-week period of no use occurred in January 2024, likely due to a vacation. During this time, apartment temperatures dropped to roughly 60°F, while ambient lows reached the mid-30s.

[3] Note that in this context, "mild" refers both to the minimum temperatures reached and to longer durations at more moderate heating loads. According to LaGuardia Airport weather data, the 2023–24 winter had 3,478 heating degree days (HDD) through March 31, while the 2024–25 winter had 3,695 HDD, a 6% increase. In terms of minimum temperatures, January 2025 saw temperatures below 10°F and was regularly under 20°F, while January 2024 only occasionally reached 20°F or fell slightly below.

[4] The period was selected as most representative of the heating operation. Due to differences in space setpoints, and other external factors, such as New York City (NYC) requirements to ensure apartments are adequately heated (resulting in the boiler plant running from October 1 through May 31), suspected valve failure, and similar issues, led to periods in the spring and fall when the two apartments operated in different modes. Although this reflects a real and significant difference attributable to the greater level of occupant control provided by the Innova heat pumps, it complicates direct comparison during those swing seasons. Therefore, for the purposes of evaluating specific heating and cooling trends, the analysis was limited to periods when both systems were operating in the same mode.

[5] Note that this analysis was also run on an extended date range (December 4, 2023–May 15, 2024, and September 15, 2024–October 28, 2024), which encapsulated all observed heating activities, at the expense of also including more borderline conditions and some instances of active cooling. The average temperature difference between apartments in this expanded range was closer to 5°F. Observed maximum and minimum temperatures were similar.

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