Double Duct Packaged Terminal Heat Pump Field Demonstration

Final Report

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Program paid for by ratepayers.

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Executive Summary

Many multifamily and light commercial buildings, such as hotels, use through-the-wall packaged terminal units as an affordable option for space heating and cooling. However, this product class is generally less efficient than other product types for distributed, ductless conditioning, such as variable speed refrigerant systems or ductless heat pumps. A new type of packaged terminal heat pump with a more compact form factor and two small duct penetrations for outside air exchange has recently entered the market. This double duct packaged terminal heat pump (DDPTHP) has a number of features that enhance efficiency and differentiate it from the incumbent options.

Compared to past packaged terminal units, the DDPTHP minimizes building envelope disruption, eliminates outside equipment, includes multi-speed and variable-speed motors, eliminates electric resistance defrost, and can provide efficient, affordable electrification of heating. The emerging technology's distinct double duct design brings air into the condenser coils in the packaged system, which allows the unit to transfer heat in and out of the indoor space. Its architecture minimizes penetration of the building envelope to preserve exterior wall insulation and reduce infiltration. DDPTHPs also feature a variable-speed inverter-driven compressor and multi-speed supply fan, which allow the unit to improve efficiency at part-load conditions. However, these efficiency benefits and product performance had not yet been previously evaluated in California. This project took on that goal by performing a field evaluation of the technology in four homes within a new construction, affordable housing multifamily building.

The project team monitored equipment component energy usage and loads for six months at each site and used the data to compare performance to an equivalently sized, code-minimum packaged terminal unit baseline. The emerging technology's performance was quantified in terms of energy savings, cost effectiveness, and other impacts, as seen in Table 1. Site 1 demonstrated an unusual load profile due to atypical occupant preferences and thus had unexpected results. The project also acquired some basic user and stakeholder feedback that relates to installation and product usage.

Table 1: Impacts summary

Site	Energy Savings (kWh/yr)	Total System Benefit ($/yr)	Avoided Greenhouse Gases (tons CO_2e/yr)	Energy Cost Savings ($/yr)	Simple Payback (yrs)
Site 1	-81	-28	-0.006	-27	N/A
Site 2	82	8	0.005	27	9.2
Site 3	284	45	0.033	94	2.7
Site 4	186	23	0.023	61	4.1
Average Impacts	**118**	**12**	**0.014**	**39**	**5.3**

This emerging technology shows promise for convenient, affordable, and efficient electrified heating and cooling, including in retrofit scenarios. In parallel with other ongoing laboratory work, a modeling study of the technology should be done to establish savings across a range of California building types and climate zone conditions so that a rebate measure support workpaper can be established for heating and cooling efficiency and electrification programs.

Abbreviations and Acronyms

Acronym	Meaning
Btu	British thermal units
COP	Coefficient of Performance
DDPTHP	Dual duct packaged terminal heat pump
DHP	Ductless heat pump
EER	Energy efficiency ratio
EIR	Energy input ratio
eTRM	Electronic Technical Reference Manual
GHG	Greenhouse gas
GWP	Global warming potential
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HVAC	Heating, ventilation, and air conditioning
IOU	Investor-owned utility
IPMVP	International Performance Measurement and Verification Protocol
kBtu	Thousand British thermal units
kW	Kilowatt
kWh	Kilowatt-hour
PG&E	Pacific Gas and Electric Company
PLR	Part load ratio
PTAC	Packaged terminal air conditioner
PTHP	Packaged terminal heat pump

Acronym	Meaning
TSB	Total System Benefit
V	Volts
VAC	Volts alternating current
VRF	Variable refrigerant flow

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Introduction

In multifamily and light commercial buildings such as hotels, packaged terminal air conditioners (PTACs) and packaged terminal heat pumps (PTHPs) are commonly installed as relatively low-cost, distributed heating and cooling solutions. In buildings without ducting, they are often used as a lower-cost, easy-to-install alternative to ductless heat pumps (DHP) or variable refrigerant flow (VRF) systems. However, most conventional PTACs and PTHPs available today are relatively inefficient due to common features such as electric resistance heating when outdoor temperatures are low, costly defrost cycles, smaller components, and constant-speed compressors and fans. Additionally, installing conventional through-the-wall PTAC and PTHP units often compromises the building's thermal envelope by requiring large openings in the insulated structure, increasing air leakage and a large conductive, thermal path between the indoor and outdoor space.

The dual duct packaged terminal heat pump (DDPTHP)—sometimes referred to as a "micro heat pump" or "room heat pump" (Bansal, et al. 2024)—provides space heating and cooling at higher efficiency than traditional PTHPs due to differences in design features. It can enable cost-effective electrification, with efficiency benefits similar to VRF and DHPs when compared to typical PTHPs. The DDPTHP offers several advantages over incumbent products that serve this market segment, such as PTACs, PTHPs, and window units. Unlike other alternatives, the DDPTHP does not need an exterior condensing unit, further reducing the initial cost while improving building aesthetics. All the system components—including condenser coils—are contained in a single package, as seen in Figure 1.

Figure 1: DDPTHP at host site before occupancy.

The technology has several notable beneficial design features:

- An installed DDPTHP is located entirely inside the conditioned space with outside air exchange using two duct penetrations through the building envelope. The DDPTHP is installed on an interior perimeter wall and relies on two 8-inch diameter circular duct penetrations through the wall to provide air to the condenser coils inside the box.
- The packaged design eliminates the on-site handling of refrigerants and refrigerant lines, simplifying the installation and reducing initial costs and harmful refrigerant emissions.
- The DDPTHP efficiently matches output and equipment speed to space conditioning load with a variable-speed inverter-driven compressor. The DDPTHP can therefore achieve efficiency beyond typical PTHPs and window units while costing far less and with lower installation complexity than VRF or DHP options.
- The new technology includes models that use low global warming potential (GWP) refrigerant, R-32, in alignment with California's energy goals.

To date, only feasibility assessments, laboratory testing, and applications testing study of the product have been completed. Applications testing at a single-family residence in Seattle, Washington involved approximately two weeks of operation in both heating and cooling modes (BPA 2022). Despite the limited duration, results showed that the unit's heating performance aligned with the manufacturer specifications, achieving a Coefficient of Performance (COP) between 2.5 and 3.0. In contrast, the cooling performance was lower than expected, with a COP ranging from 1.4 to 2.4. This reduction is attributed to unusually high outdoor temperatures during the test period, which coincided with an extreme heat event, with outside temperatures reaching up to 107°F.

This report presents field study findings of a whole-building application of the technology in a low-income multifamily property in Daly City, California. This study monitored a sample of installed units over several months to assess and characterize performance under real-world conditions. Analysis of the representative sample enables normalization of results and supports broader conclusions for the statewide market. Additionally, the study quantifies costs, benefits, and performance contrasts relative to a baseline PTHP system alternative.

Background

Cost-effective, efficient, electrified space heating and cooling systems are becoming increasingly important for California's growing multifamily building sector—which, over the last 15 years, has accounted for 50 percent of all new housing development in the state (VEIC 2023). Figure 2 displays the percentage of multifamily housing units as a share of total housing units within each census tract in California (ESRI 2018). The map reveals a high concentration of multifamily housing units across much of the state, including in the most populated cities, such as Los Angeles, San Diego, San Jose, and San Francisco.

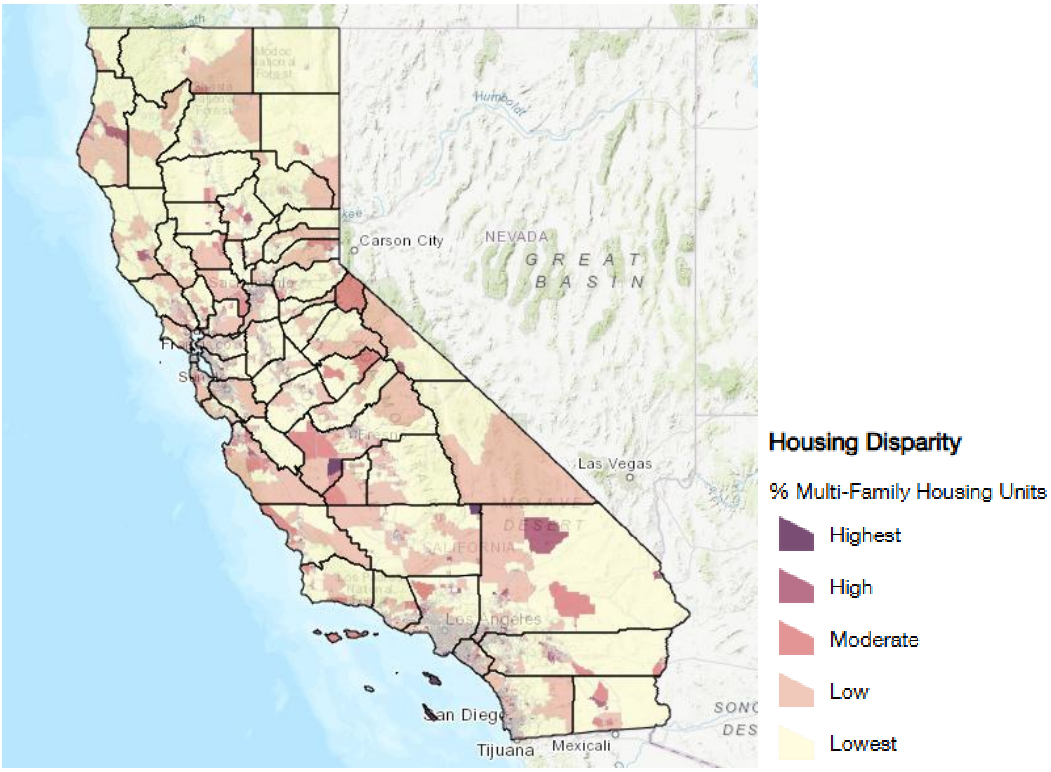

Figure 2: Percent of multifamily housing units in California.

Source: (ESRI 2018).

As climate change causes a progressive temperature rise, air conditioning use also increases. Consequently, this increased usage has been raising summer energy demand on the regional electric grid. California Energy Commission reporting found that electricity demand continues to increase and peak in the summer based on observations of historical trends through 2024 (CEC 2025). As a result, the market needs more efficient cooling equipment to meet space conditioning needs in the multifamily and light commercial market. Simultaneously, the installation of cooling equipment also provides an opportunity for decarbonizing heating loads through installing heat pumps. Using heat pumps for these increased cooling demands can also supply electrified heating for the cold weather months. However, the typical ductless solutions that are marketed and selected for these multifamily loads are costly DHP and VRF systems or relatively inefficient, lower-cost PTAC or PTHP products (BPA 2022). DDPTHP products potentially offer a low-cost, energy efficient alternative, enabling cost-effective electrification and healthy living conditions for multifamily residents.

Incumbent Technology

A DDPTHP serves as a direct alternative technology to a PTAC or a PTHP, collectively referred to as packaged terminal units. The US Department of Energy defines a PTAC as industrial equipment intended for mounting through the wall that has a wall sleeve and a separate un-encased combination of heating and cooling assemblies (DOE n.d.); a PTHP is similar but also allows for cycle reversing to provide heating. PTHPs often include a supplementary heat source, typically electric resistance heating, which is activated during cold weather conditions that are below the heat pump operating limits. The late 1950s saw the introduction of the well-known 16”-by-42” PTAC form factor (EPRI 1990). By the 1980s, manufacturers—such as GE, Carrier, Trane, Amana, and others—were fully invested in the market, with packaged terminal units commonly used in hotels and motels. From there, PTHPs experienced commercial market growth from 0.6 percent to 1.2 percent from 1980 to 1990. By 2014, packaged terminal units accounted for about 6.5 percent of the total heating, ventilation, and air conditioning (HVAC) systems used in commercial buildings (CPUC 2014).

The packaged design of PTAC and PTHP solutions allows for simple installation and maintenance. They are relatively low cost and ideal for a small, confined space, and are especially well-suited to buildings without ducted space conditioning that have distributed, self-contained conditioned spaces with exterior wall access—which is common in hotel, light commercial, educational, and multifamily buildings.

Some drawbacks include compressor noise, low efficiency, and air leakage (NYSERDA 2018). Additionally, PTAC and PTHP equipment installation requires large penetrations of the exterior building walls that other HVAC products do not. The large grills and boxy condenser section hanging outside the building wall not only impact the building aesthetics but also act as a direct pathway for unwanted outside air, conductive thermal bridging, and noise to enter the interior. Figure 3 summarizes a few strengths and weaknesses of PTACs and PTHPs.

Figure 3: PTHP and PTAC design strengths and weaknesses.

Source: (BPA 2018).

Common rated capacities for PTACs and PTHPs are 7,000, 9,000, 12,000, and 15,000 British thermal units (Btu) per hour (NYSERDA 2018). Table 2 shows the minimum energy efficiency ratio (EER) and COP required by the California Appliance Efficiency Regulations, Title 20, and the California Building Energy Efficiency Standards, Title 24, for new buildings and retrofits (eTRM 2024).

Table 2: PTAC and PTHP California code requirements.

Equipment and Mode	Installation Type	Efficiency Requirements
PTAC (cooling mode)	New construction	$EER \geq 14.0 - (0.3\ x \frac{Capacity}{1{,}000})$
PTAC (cooling mode)	Retrofit	$EER \geq 10.9 - (0.213\ x \frac{Capacity}{1{,}000})$
PTHP (cooling/heating mode)	New construction	$EER \geq 14 - (0.3\ x \frac{Capacity}{1{,}000})$ $COP \geq 3.7 - (0.052\ x \frac{Capacity}{1{,}000})$
PTHP (cooling/heating mode)	Retrofit	$EER \geq 10.8 - (0.213\ x \frac{Capacity}{1{,}000})$ $COP \geq 2.9 - (0.026\ x \frac{Capacity}{1{,}000})$

Source: (eTRM 2024).

Currently, there are approved, active deemed measures for installing PTAC or PTHP units with capacity below 24 kBtu per hour that exceed the minimum efficiency requirements outlined in Table 2. The deemed measure savings assume new or retrofitted PTHP or PTAC units to have EER and COP values that are 20 percent higher than the code baseline (eTRM 2024).

Refrigerants

Until the 1990s, PTACs and PTHPs often used R-22 refrigerant. Legacy hydrochlorofluorocarbon (HCFC) refrigerants—such as R-22 and subsequent high-GWP options—are being phased out due to ozone depletion and climate impacts (NYSERDA 2018). In 2010, US policy banned R-22 production, import, and use, except for continuing service needs of existing equipment (EPA 2015). Since 2020, servicing with R-22 can only rely on recycled or stockpiled quantities (EPA 2015).

Thus, most of the units sold in recent years use hydrofluorocarbons (HFC) such as R-410a, which has little ozone layer effect but a higher GWP score of 2,088 (EPA 2025). In 2014, residential and light-commercial space conditioning equipment accounted for about 22 percent of national refrigerant emissions in the United States, as presented in Figure 4 (EPA 2025).

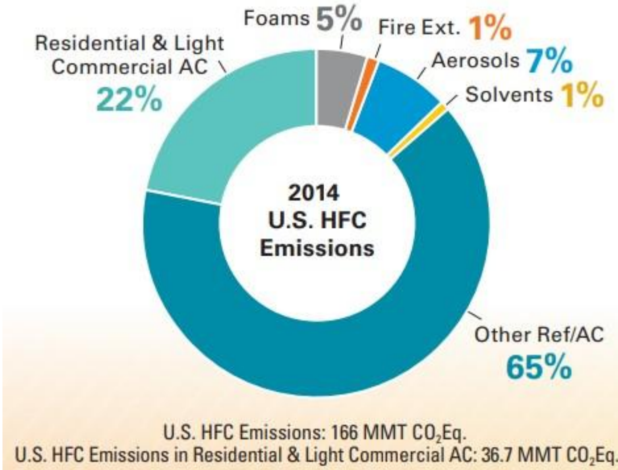

Figure 4: 2014 HFC emissions in the United States.

Source: (EPA 2025).

In the continued push towards lower GWP refrigerants, R-410a is also slated to be phased out in many space conditioning products. Heat pumps and air conditioners that use R-32 have gained a significant market share internationally and are now starting to come to the US market. R-32 is also an HFC refrigerant but has a lower GWP score of 675 (EPA 2025); R-32 and other similar lower-GWP options are expected to continue to replace R-410a, with assistance from federal and California regulations encouraging the progressive transition to low-GWP refrigerants (NYSERDA 2018). DDPTHP products are currently available in both R-410a and R-32 options.

The following is a list of current regulations on refrigerants:

- Federal Regulations on Refrigerant GWP
  - Restricts the use of higher-GWP HFCs in new aerosol, foam, and refrigeration, as well as air conditioning and heat pump products and equipment.
  - Restricted products or systems of residential and light commercial air conditioning and heat pump systems with a GWP limit of 700, manufactured or imported on January 1, 2025 (eTRM 2024).
- Federal Regulations on Refrigerant Recovery
  - Section 608 of the Clean Air Act includes prohibitions on venting, requirements of safe disposal of appliances, proper evacuation, maintenance and repair, and recordkeeping.
  - Standards on recovery equipment and technician certification (eTRM 2024).
- Federal Regulations on Refrigerant Reclamation
  - The US Environmental Protection Agency regulates reclamation to reduce emissions of HFCs and other substitutes (eTRM 2024).
- California Air Resources Board Regulations on Refrigerant GWP

- Prohibits the use of refrigerants with a GWP of 750 or greater, specific to PTAC and PTHPs for both the base and measure case (eTRM 2024).

- California Air Resources Board Regulations on Refrigerant Reclamation
    - Requires the use of reclaimed refrigerant, also known as previously used or recovered refrigerant (eTRM 2024).

Market Share and Energy Use

There is a large market size for this emerging technology. According to the California Commercial Saturation Survey, which collected data from eight different commercial building types, packaged terminal units accounted for 6.5 percent of the HVAC systems in all commercial buildings (CPUC 2014). Since commercial buildings in California consumed roughly 83 terawatt-hours of electricity—and HVAC systems consume about 29 percent of that—the market share of the emerging technology is roughly 1.56 terawatt-hours (CEC 2024) (CPUC 2014). Because multifamily buildings were not included in this survey, the market share and impact use could be even greater.

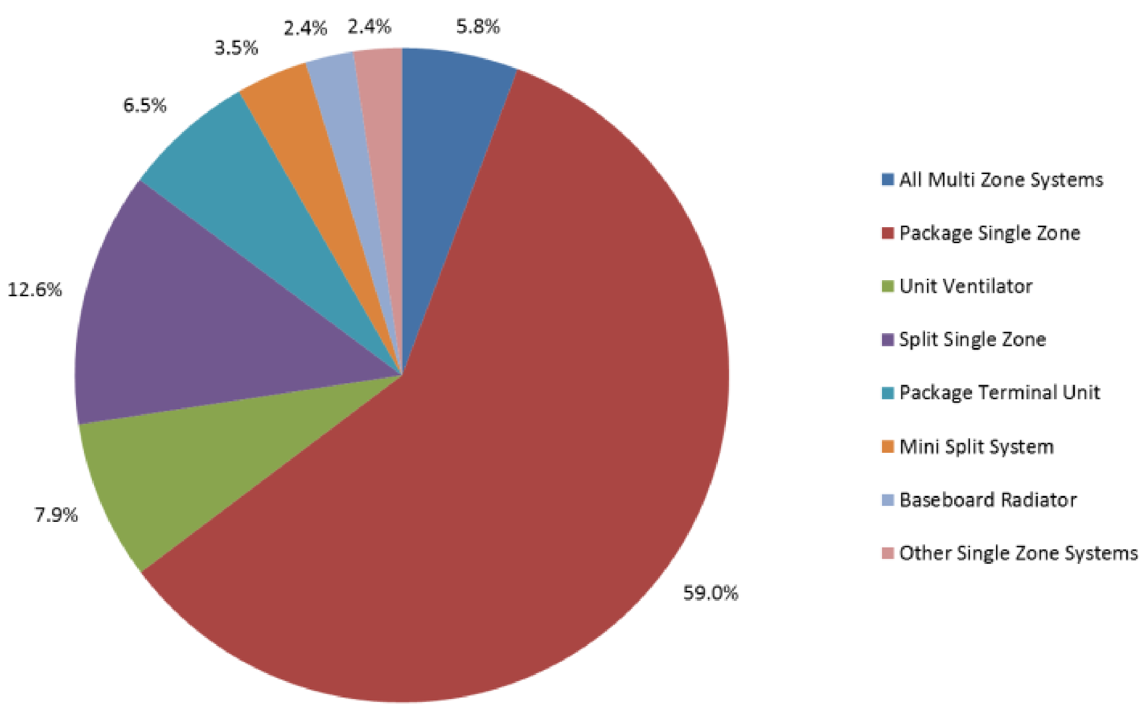

Figure 5: Distribution of HVAC units by system type.

Source: (CPUC 2014).

The Emerging Technology

The DDPTHP under study was designed to provide cooling and heating for single-family, multifamily, and light-commercial buildings. The product is a convenient, all-in-one path to cooling efficiency upgrades and efficient electrification of heating loads. Product features include a variable-speed, inverter-driven compressor; variable speed condenser fan; multi-speed evaporator fan; standard thermostatic control; reverse cycle defrost; built-in condensate slinger; and condensate disposal via gravity drain. The design eliminates the need for refrigerant piping that split systems entail, simplifies electrical and control systems over most heat pump alternatives, and manages condensation of approximately one gallon of water per day during winter (BPA 2022).

Figure 6: DDPTHP with front cover removed (front view).

The DDPTHP is installed entirely in the building interior on a perimeter wall and relies on two 8-inch duct penetrations through the wall to provide airflow across the condenser coil. Compared to PTACs and PTHPs, DDPTHPs minimize penetrations of the insulated building envelope, thus preserving more exterior wall insulation, reducing unwanted heat transfer, and maintaining air tightness if installed with sealing measures. Additionally, without exterior condensing units, there are no unappealing aesthetics and exterior structural support. Some DDPTHP models use a low-GWP refrigerant, R-32, which aligns with California's energy goals; DDPTHPs also have a smaller refrigerant charge, require less handling, and eliminate the need for refrigerant lines compared to VRF and DHP alternatives.

Installation

The DDPTHP mounts on the interior side of a perimeter wall with two small duct penetrations, which is the three-step part of the installation. Figure 7 below summarizes the four steps of DDPTHP mounting: locating and template, duct cut-outs and mounting bracket, installing the external grills, and mounting the packaged unit inside.

Figure 7: DDPTHP installation process.

Source: (BPA 2022).

The units can be hardwired or powered by a standard 120-volts-alternating-current (VAC) electrical outlet and minimize the space needed at the electrical panel. There are also other DDPTHP models available that require 208 V to 230 V. DDPTHP maintenance involves only regular air filter cleaning for proper operation (BPA 2022).

Performance

The DDPTHP selected for this field demonstration is rated at 3.0 COP in heating mode and 9.7 CEER in cooling mode. As an efficient heating electrification measure, the DDPTHP unit uses roughly one-third of the energy used by gas-fired furnaces or electric resistance heaters. However, like other heat pump systems, the heating performance of the DDPTHP declines in cold weather. Available DDPTHPs are claimed to operate efficiently in heating mode down to 5°F outside air temperature; based on this lower limit, manufacturers call them "cold climate heat pumps." Typical PTHPs do not include a heat pump defrost cycle and must heat with electric resistance at low ambient temperatures, which uses more energy. The DDPTHP excludes backup internal electric resistance and instead relies on more efficient reverse cycle defrost. Table 3 highlights key design feature differences between traditional PTHPs and DDPTHPs that contribute to system efficiency.

Table 3: Summary of design features: traditional PTHPs vs. DDPTHPs.

Design Features	Traditional PTHPs	DDPTHP
Compressor/ Fan Speed	Constant, which causes more energy use and inefficiency	• Variable-speed, inverter-driven compressor which allows the unit to operate at part-load conditions and avoid inefficient cycling. • It matches output and equipment speed to space conditioning load.
System Architecture	Single-duct systems that recirculate indoor air	• Double-duct design that brings air into the condenser coils in the package system. • The design allows the unit to transfer heat in and out of the indoor space.
System Architecture	Requires large penetrations of exterior wall causing air leakage and conductive thermal bridging	• Minimizes penetration of insulated building envelope, which preserves exterior wall insulation, reduces unwanted heat transfer, and maintains air tightness.
Supplemental Heat Source	Electric resistance which uses more energy	• Does not have backup internal electric resistance and instead relies on more efficient reverse cycle defrost. • The unit rated efficiency is three times of gas-fired furnace or electric resistance heaters.

Equipment Cost

A single, retail PTAC unit with a rated cooling capacity of 12,000 Btu per hour and electric heating costs about $1,900 on average, not including freight. Meanwhile, a PTHP unit with equivalent cooling capacity costs about $2,500, not including freight (Grainger 2025). In comparison, a single DDPTHP unit with similar cooling capacity currently costs about $2,750, as quoted by a distributor to the project team. Items not included in this cost are startup, commissioning, spare parts, wired thermostats, condensate pump, and any additional in-wall plenums. DDPTHP final installed cost estimates range from $3,500 to $4,500 (BPA 2022). Assuming that these installation costs would all be roughly similar for typical PTHPs and the new DDPTHPs, the incremental cost derives mainly from differences in equipment cost—about $250 per unit.

Objectives

The goal of this study was to evaluate the in-field performance of a DDPTHP and make possible recommendations for utility incentive program inclusion and stakeholders:

- Perform a field demonstration of the DDPTHP at a low-income multifamily housing building.
- Measure system performance and estimate demand, energy, and greenhouse gas (GHG) savings.
- Compare costs, cost effectiveness, feasibility, and performance of DDPTHP to incumbent technology (e.g., PTHP).
- Acquire feedback from occupants, building management, and installer as it relates to installation and operation of DDPTHP.
- Document the complexity of DDPTHP integration and lessons learned for future installations.
- Evaluate market barriers and provide recommendations for utility programs and pathways to support broader market adoption.
- Recommend technology pathway for incentives or other utility program support.

To accomplish these objectives, the team developed a testing plan adhering to International Performance Measurement and Verification Protocol (IPMVP) principles. The methodology is outlined in the following sections and was designed to directly measure technology performance, as well as other relevant factors.

Methodology and Approach

The team conducted a field test in a newly constructed multifamily building in Pacific Gas and Electric Company (PG&E)'s territory to evaluate the DDPTHP performance. The following sections detail the specifics of the field assessment.

Test Site

The project site was an affordable housing multifamily building in Daly City, which is in California Climate Zone 3. The building has 147 housing units, totaling approximately 113,000 square feet of conditioned living space. The housing units are studios and one-, two-, and three-bedroom apartments, with approximately 360, 580, 800, 1,080, and 1,420 square feet, respectively. The new construction building was ready for occupancy in 2024; it included DDPTHP equipment installed in each residence's living room as the primary source for heating and cooling. Some residences also had supplemental electric resistance wall heaters in some bedrooms. This building provided a convenient opportunity to observe the performance of DDPTHP technology in situ without any influence on building design or equipment selection.

Figure 8: Host site building with dual duct exterior grills.

While the DDPTHP technology was installed in all 147 housing units, the team worked with the host site property manager to select four apartments as the test homes for this study, the characteristics of which are summarized in Table 4.

Table 4: Test site characteristics.

Characteristics	Apartment 1	Apartment 2	Apartment 3	Apartment 4
Bed/Bath	2/1	1/1	2/1	2/1
Floor Area (ft2)	800	580	800	800
Number of residents	2	1	2	2
Occupied during the day?	Yes	Yes	No	Yes

Each DDPTHP unit is manually controlled by a wall-mounted, unlocked thermostat; therefore, the setpoints can be manually changed by the occupant at any time. The DDPTHP specifications are listed in Table 5.

Table 5: DDPTHP rated specifications.

Specification	Value
Cooling capacity range (Btu/h)	6,600–11,600
Rated capacity at 95°F (Btu/h)	8,300
Combined energy efficiency ratio (CEER)	9.7
Heating capacity range (Btu/h)	6,200–10,600
Rated capacity at 47°F (Btu/h)	8,450
COP	3.0
Defrost method	Reverse cycle
Indoor sound level (dB)	32–43

Source: Manufacturer specification documentation.

Test Plan

The project team developed a test plan for measuring the use and performance of the technology under real-world use conditions at the four apartments. The measurement boundary was drawn around each DDPTHP with selected measurement points to satisfy the guidelines of IPMVP Option B Retrofit Isolation: All Parameter Measurement.

After host site recruitment, the team installed monitoring instrumentation at each unit for six months—from August 2025 through January 2026—to capture the DDPTHP operation across both heating and cooling. This length of time ensured the team could collect enough performance data to assess apartment loads, efficiency, and annualization. Data was monitored remotely with regular confirmation of continued data quality over the six-month period.

Using the collected data, the team analyzed the heating and cooling performance of the DDPTHP relative to weather conditions and loads. This performance data is crucial in validating the new product type, especially in comparison to the manufacturer specifications and a baseline code-alternative PTHP. Since the application is a new construction building, baseline monitoring was not possible. However, the performance was compared to a PTHP with similar capacity as an assumed code-efficiency baseline.

PTHP baseline calculations were based on standard heat pump performance curves; the team took steps indicated in the Appendix to calculate cooling and heating energy for an assumed code-efficiency PTHP baseline. The team used energy input ratio (EIR) as the method for efficiency, converting the rated COP and EER from Table 2 to EIR—which can be adjusted to instantaneous load and weather conditions for any given interval during the measurement period. The team then used EIR to calculate baseline power (represented as QE) using the formula:

$$QE = CAP_T * EIR_T$$

The PTHP performance curves were adjusted to measured field variables—including outside air temperature, return air temperature, average loads in Btu per hour, and capacity equivalent to the DDPTHP—to find comparable code EIR and baseline energy input. PTHP baseline energy results and field monitoring energy data were compared with respect to the site's part load ratio (PLR)—i.e., the ratio of actual load output to full load output at the operating point. The team annualized the energy impacts results using a ratio of monitored time to annual hours. Finally, we calculated other impacts using Total System Benefit (TSB) hourly avoided cost factors (CPUC 2024), avoided GHG using emissions factors (CEC 2022), energy costs from PG&E's E-1 rate schedule, and simple payback based on the incremental cost of $250 per unit.

Instrumentation Plan

The key measurement points and logging instrumentation are listed in Table 6; some parameters were continuously monitored while others were spot measurements. The instruments recorded electrical current at one-minute intervals to capture any compressor or fan cycling, but they continuously monitored temperature and logged it in five-minute intervals.

Table 6: Instrumentation plan.

Variable	Measurement	Logger	Accuracy	Frequency
DDPTHP power	V, A, PF, kW	DENT ElitePro	±1%	Spot measurement across heating, cooling, and fan modes
DDPTHP, condenser fan, and compressor currents	A	Monnit MNS2-9-W2-CM-020	±2%	1-minute
SAT	T, RH	Monnit MNS2-9-W1-TS-ST-L03	±0.45 °F	5-minute
RAT	T, RH	Monnit MNS2-9-W1-TS-ST-L03	±0.45° F	5-minute
OAT	T	NOAA weather station	n/a	1-hour
Supply fan airflow	cfm	Kestrel 4200	±3%	Spot measurement across fan speeds
Sound level	dB	Extech 407730	±2 dB	Spot measurement across cooling, heating, and fan modes

Figure 9 shows examples of logger placement within the DDPTHP unit.

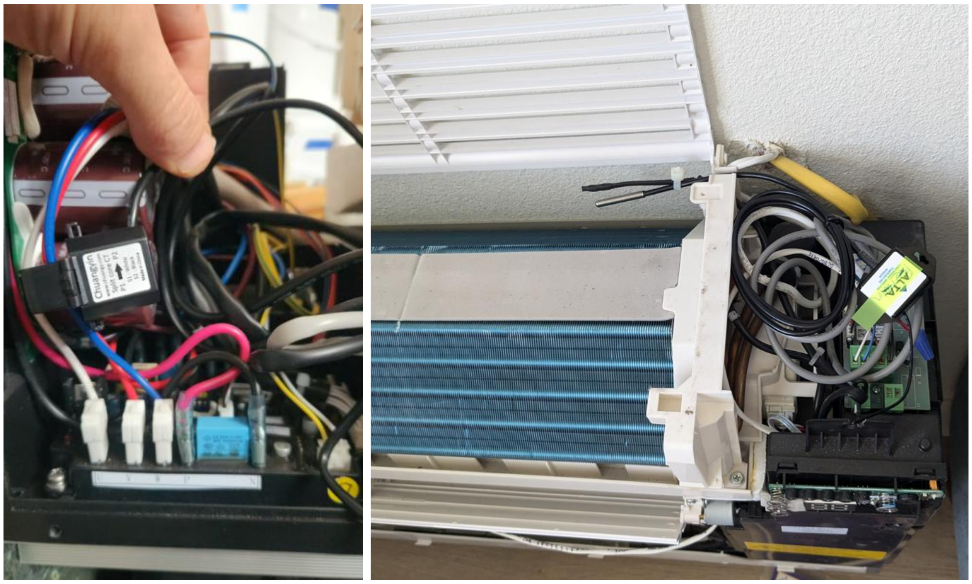

Figure 9: Example placement of compressor current sensor (left) and supply temperature sensor (right).

Bench Testing

Additionally, the team conducted bench testing to inform processing and use of the field monitored data by observing the operation in a controlled setting. This bench testing included:

- Evaluation of how the DDPTHP performs in off, fan-only, heating, and cooling mode, using HOBO, muiltimeter, and DENT ELITEpro loggers to compare current values with monitoring data.
- Establishing a relationship between current and real power across fan, heating, and cooling modes. These equipment curves enabled the team to calculate the in-situ DDPTHP power levels using the monitored current values.
- Infering airflow at the four host sites using the monitored supply fan current.
- Noting current values when the equipment is in low-fan, medium-fan, or high-fan mode to establish fan speed patterns with the field data and relate airflow values based on results from previous bullet point.

The team also measured the DDPTHP’s sound across different fan, heating, and cooling modes to quantify possible noise disturbance of the unit without any uncontrolled background noise that would be present at the host sites.

Findings

Overview

The monitored dataset spans August 2025 through January 2026 for a full capture of summer, shoulder, and winter season weather conditions. Based on occupant feedback, the host sites experience frequent cold winds coming from the bay, resulting in high heating uses. The microclimate at the host site location prevented a fair representation of typical weather and load patterns for California or any particular climate zone. As such, the results should be viewed as a snapshot for a unique and unusual microclimate. The team monitored data quality and maintained data collection at the four host sites without any gaps. With this data, the team calculated DDPTHP cooling and heating output in Btu per hour, as well as the associated energy consumption. Energy savings and impacts on GHG emissions, TSB, and energy cost were calculated for the monitoring period, as compared to a code-minimum efficiency PTHP. The team also annualized energy savings and impacts for each site.

Results

Over the monitoring period, the team found the DDPTHP to use less energy than the PTHP baseline, on average. For the observed loads, three of the sites saw the DDPTHP use 5 percent to 43 percent less energy than the baseline, while one site had a slight increase in energy usage due to an abnormal and unexpected load profile that did not align with the other three. Table 7 lists the energy usage, energy savings, TSB, avoided GHG, and energy cost savings over the six-month monitoring period.

Table 7: Results summary over 6-month monitoring period.

Site	PTHP Baseline Energy Usage (kWh)	DDPTHP Energy Usage (kWh)	Energy Savings (kWh and %)	TSB ($)	Avoided GHG (tons CO2e)	Energy Cost Savings ($)
Site 1	529	576	-47 (-9%)	-20	-0.004	-16
Site 2	974	926	48 (5%)	6	0.004	16
Site 3	397	231	165 (42%)	32	0.024	55
Site 4	251	143	108 (43%)	17	0.016	36

Table 8 lists the annualized impacts of energy savings, TSB, avoided GHG, energy cost savings for each site. For the three sites that saw net benefits, average annualized energy savings were 184 kilowatt-hours (kWh) per year, $25 per year in TSB, 0.02 tons carbon dioxide equivalent (CO2e) per year avoided GHG, and $61 energy cost savings per year. It also shows the simple payback based on incremental cost and energy savings to be well below the expected useful life of 15 years, which is assumed to be equivalent to a typical PTHP. The average impacts across all four sites resulted in 118 energy savings kWh per year, $12 per year in TSB, 0.014 tons CO2e per year avoided GHG, and $39 energy cost savings per year.

Table 8: Annualized impact results summary.

Site	Energy Savings (kWh/yr)	TSB ($/yr)	Avoided GHG (tons CO2e/yr)	Energy Cost Savings ($/yr)	Simple Payback (yrs)
Site 1	-81	-28	-0.006	-27	N/A
Site 2	82	8	0.005	27	9.2
Site 3	284	45	0.033	94	2.7
Site 4	186	23	0.023	61	4.1
Average Impacts	**118**	**12**	**0.014**	**39**	**5.3**

Bench testing also confirmed airflow and sound levels similar to the reported rated values in the equipment documentation, as shown in Table 9 below.

Table 9: Bench testing airflow results.

Mode	Airflow (CFM)	Sound Levels from Six Feet (dB)
Low fan	175	<40
Medium fan	195	42
High Fan	265	48
Max cooling	265	53
Max heating	265	50

Site 1

As a result of occupant comfort preferences, Site 1 was dominated by cooling loads over the monitoring period, the only such site of the four. Cooling loads persisted until late in the year, after which the DDPTHP was rarely used. Figure 10 shows the minutes of each hour spent in heating and cooling mode over the monitoring period.

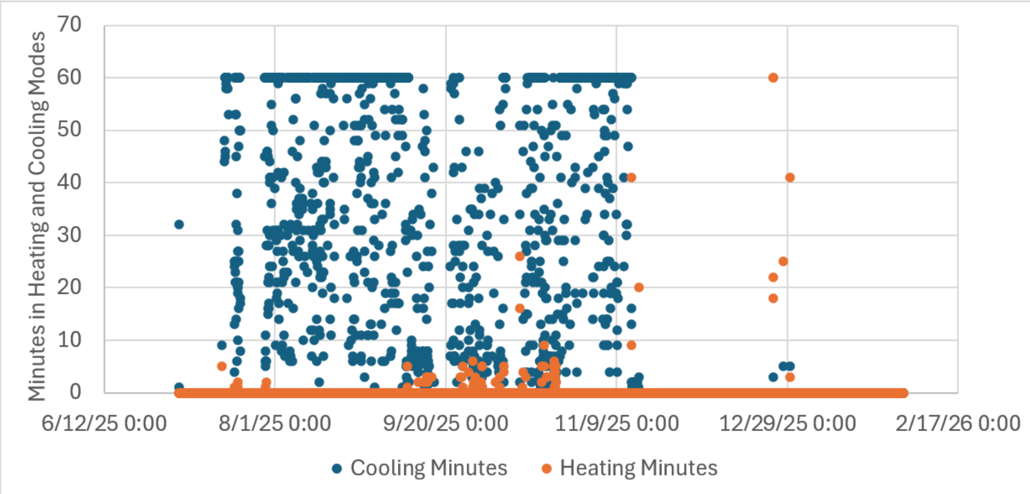

Figure 10: Site 1 monitoring time in heating and cooling modes.

Figure 11 demonstrates the DDPTHP at Site 1 performing at a lower demand in kilowatts (kW) than the PTHP baseline when the PLR is under 0.5. When PLR begins to increase above about 0.6, the DDPTHP draws more power to perform at a higher load compared to baseline. Figure 12 also shows significant instances operating at higher loads, between 0.5 PLR and 0.8 PLR. As a result, out of the four sites, Site 1 is the only site to conclude with an energy increase and net penalty impacts across the monitoring period.

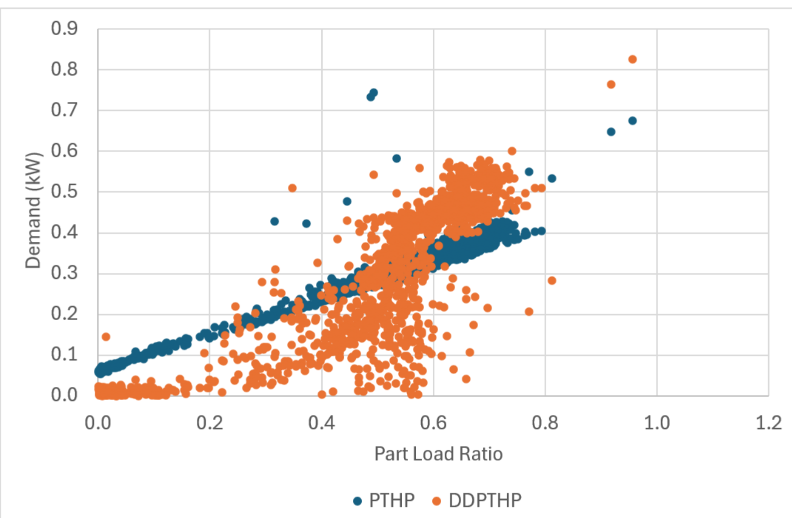

Figure 11: Site 1 PTHP vs DDPTHP power across site part load ratio.

Figure 12 shows the plot OAT vs demand (kW) where OAT ranged between 55 to 80 degrees Fahrenheit.

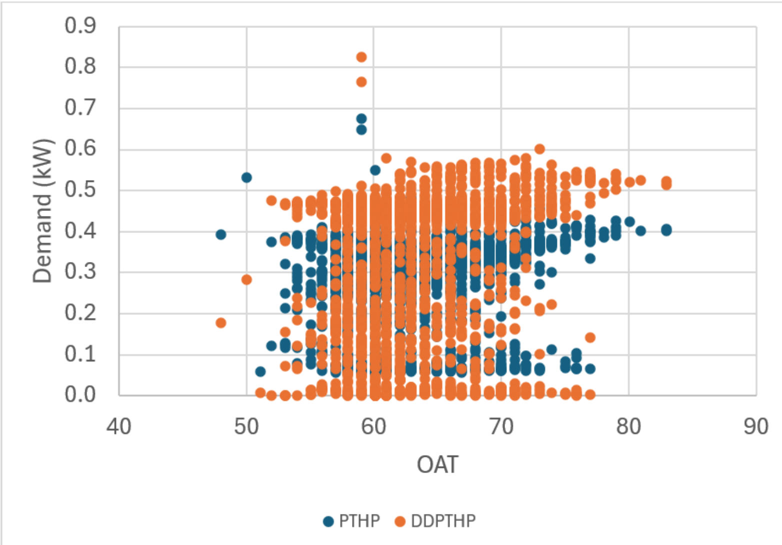

Figure 12: Site 1 OAT vs demand (kW) plot.

Site 2

In contrast to Site 1, Site 2 was dominated by heating loads over the monitoring period, as seen in Figure 13.

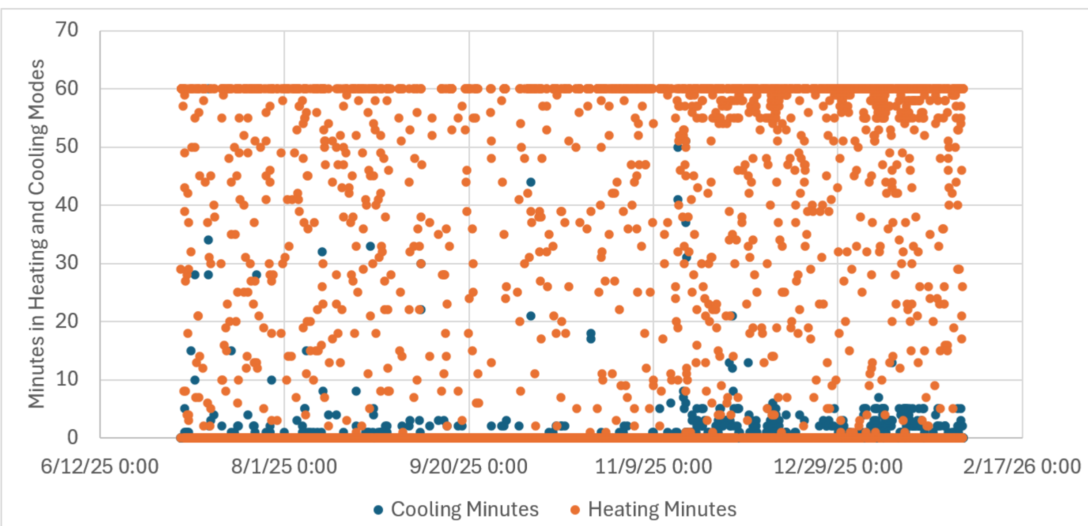

Figure 13: Site 2 monitoring time in heating and cooling modes.

Figure 14 demonstrates the DDPTHP at Site 2 performing at a lower demand and power than the PTHP baseline when the PLR is under 0.6. When PLR begins to increase above about 0.7, DDPTHP draws more power to perform at a higher load compared to baseline. Similar to Site 1, there are multiple instances where the unit operates at higher loads, between 0.7 and 1.0 PLR. Compared to Site 1, the DDPTHP shows about 5 percent in savings due to its efficiency at lower loads and the load profile matching expectations.

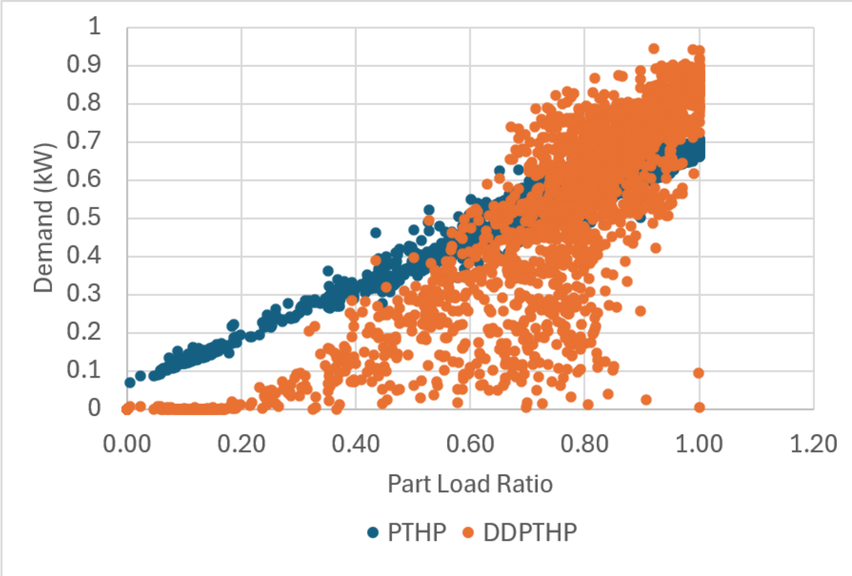

Figure 14: Site 2 PTHP vs. DDPTHP power across site part load ratio.

Figure 15 shows the OAT vs demand (kW) for site 2 where OAT ranged between 42 to 73 degrees Fahrenheit.

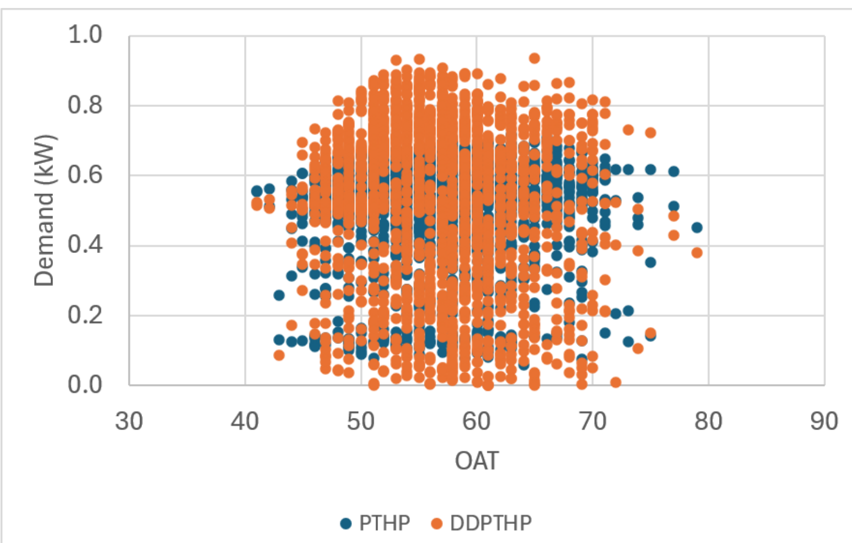

Figure 15: Site 2 OAT vs demand (kW) plot.

Site 3

Similar to Site 2, Site 3 was dominated by heating loads over the monitoring period, as seen in Figure 16.

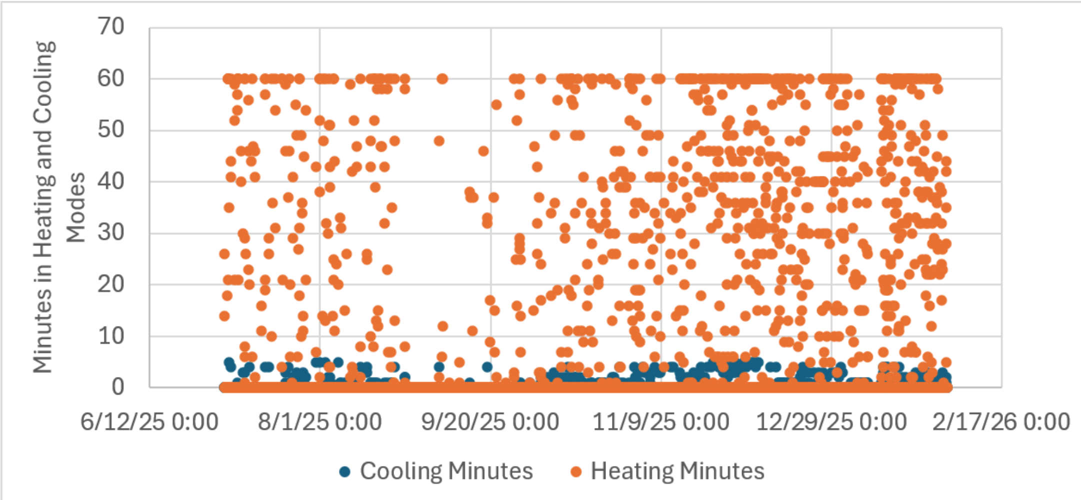

Figure 16: Site 3 monitoring time in heating and cooling modes.

Figure 17 shows the DDPTHP at Site 3 performing at significantly lower demand (in kW) than the PTHP baseline, when the PLR is under 0.6. Between 0.3 PLR and 0.5 PLR, the difference in power used between baseline and DDPTHP is more noticeable. Figure 17 displays fewer instances where the unit operates at higher loads between 0.8 PLR and 1 PLR. Compared to Site 2, the DDPTHP shows about 42 percent in savings.

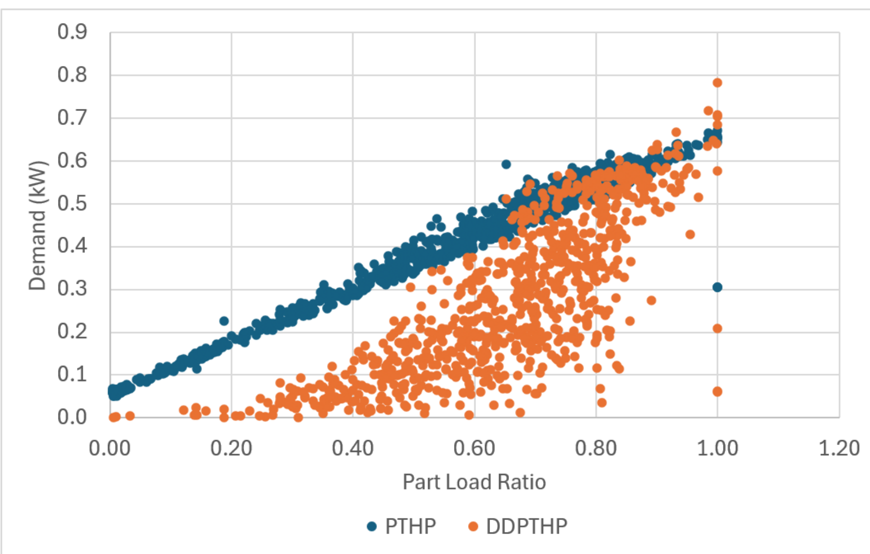

Figure 17: Site 3 PTHP vs. DDPTHP power across site PLR.

Figure 18 shows the OAT vs demand (kW) for Site 3 where OAT ranged between 45 to 70 degrees Fahrenheit. Compared to Site 1 and Site 2, the decrease in demand from DDPTHP is noticeable at these temperatures.

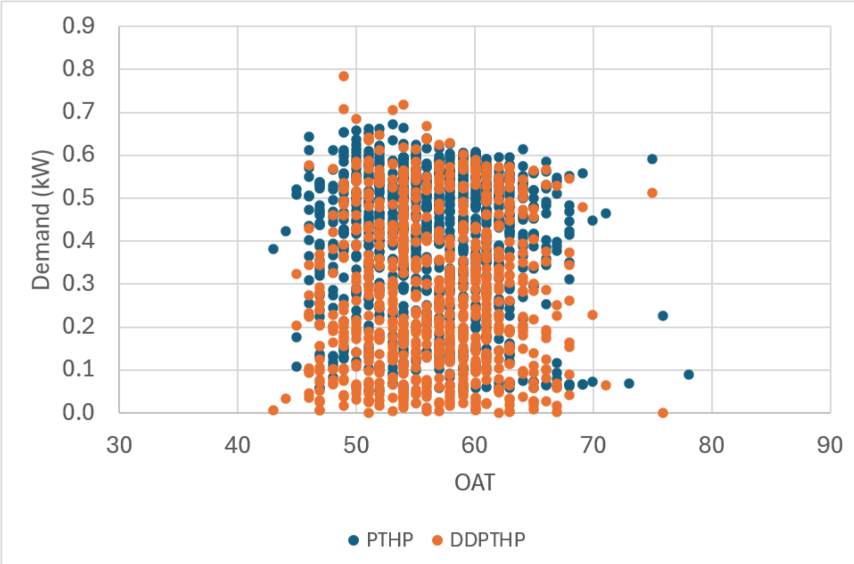

Figure 18: Site 3 OAT vs demand (kW) plot.

Site 4

Similar to Sites 2 and 3, Site 4 was dominated by heating loads over the monitoring period, as seen in Figure 19.

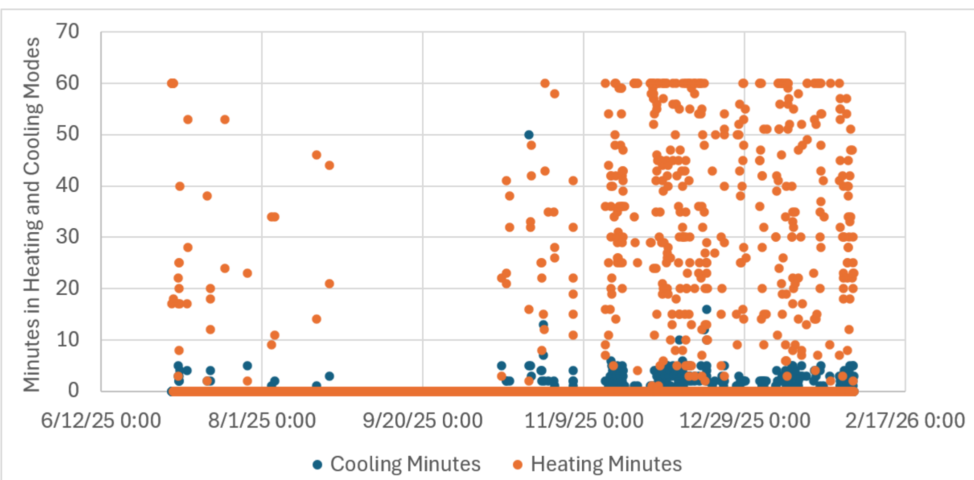

Figure 19: Site 4 monitoring time in heating and cooling modes.

Figure 20 shows the DDPTHP at Site 4 performing at significantly lower demand (in kW) than the PTHP baseline, when the PLR is under 0.6. Site 4 performs more efficiently than its baseline throughout its monitoring period, including at higher PLR of 0.8. Between a PLR of 0.3 and 0.6, the difference in power used between the baseline and DDPTHP is apparent. Figure 20 also presents considerably fewer occurrences where the unit operates at a higher load between 0.8 PLR and 1 PLR. Compared to Site 2 and Site 3, the DDPTHP at Site 4 demonstrated its highest savings of about 43 percent.

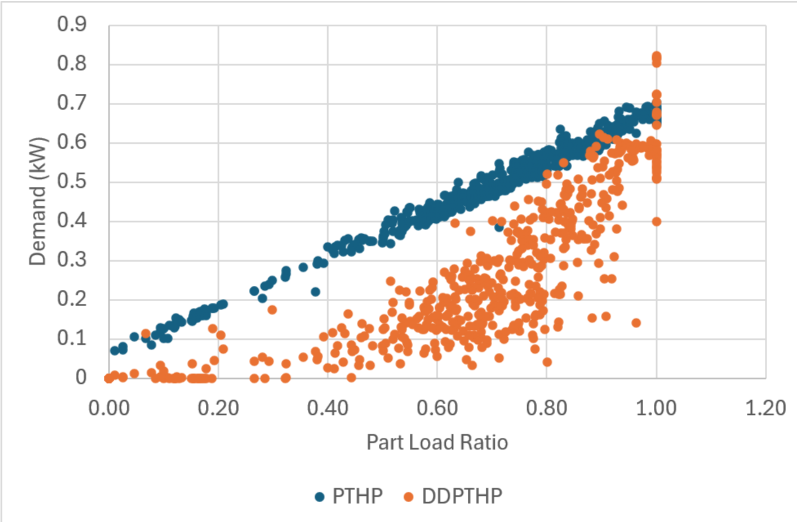

Figure 20: Site 4 PTHP vs. DDPTHP power across site PLR.

Figure 21 shows the OAT vs demand (kW) for Site 4 where OAT ranged between 43 to 65 degrees Fahrenheit. Compared to Site 3, the decrease in demand from DDPTHP is more noticeable at these temperatures where there is a clear load difference between PTHP and DDPTHP.

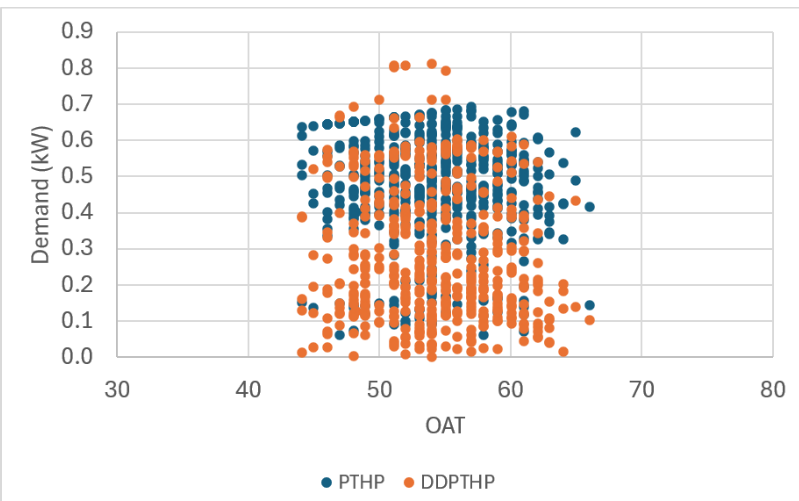

Figure 21: Site 4 OAT vs demand (kW) plot.

Stakeholder Feedback

As a final step in the project, an exit survey was conducted with some of the residents about their experience with the new technology, which they reported various levels of satisfaction about. The following charts show some qualitative results of the survey for households where there were no changes in the number of occupants living in the homes for the duration of the study.

The occupants from the four monitored dwelling units had mixed feedback on whether the DDPTHP had enough capacity to satisfy their comfort needs. One respondent noted they used a supplemental, portable heater during the study. One stakeholder shared that “given the poor reported satisfaction recorded from occupants, a lesson learned is that there should be some air temperature sensors within the apartment to better understand temperatures within the living space and whether or not tenants are using the units in a typical fashion.”

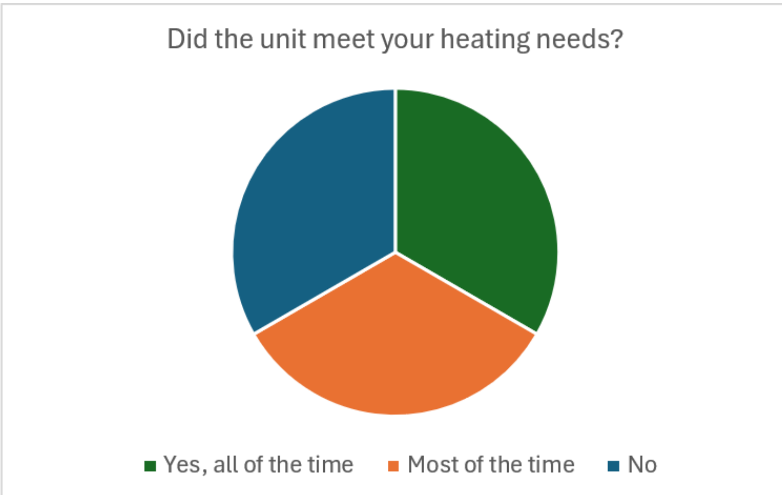

Figure 22: Resident feedback on heating needs.

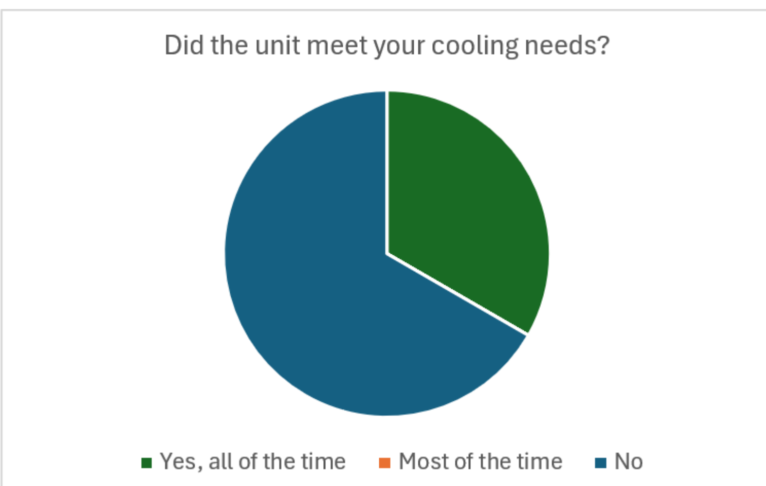

Figure 23: Resident feedback on cooling needs.

Noise levels were mostly not noticeable, as was expected given the equipment specifications and sounds measurements during bench testing.

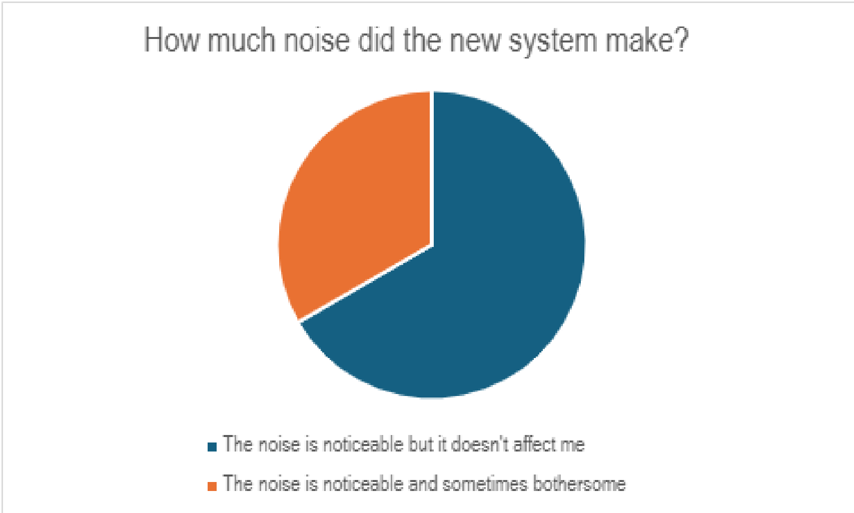

Figure 24: Resident feedback on system noise levels.

Overall, participants' reported levels of satisfaction with the new equipment were mixed, with respondents noting that on certain days, the system did not meet all their heating or cooling needs or did not bring temperatures to their comfort zone as quickly as they would have liked.

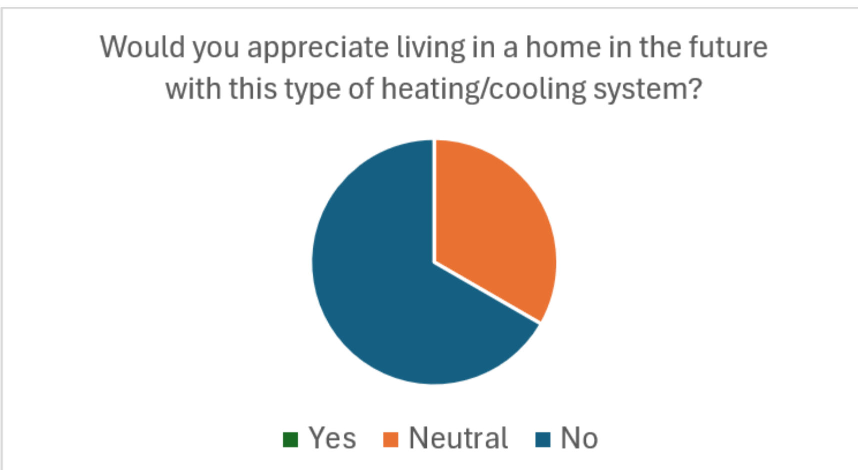

Figure 25: Overall resident system satisfaction feedback.

Discussion and Recommendations

The field results generally indicate that the new type of PTHP has clear and dependable energy benefits over incumbent PTHP options. The part-load performance of the equipment resulting from the variable speed components yields cost-effective impacts, as was hypothesized at the project onset. The team assessed the performance and impacts of four very specific load profiles unique to the participating host sites. These in situ assessments showed a payback of just over five years over an equivalently sized code-minimum efficiency PTHP installation. While the new product type may not necessarily provide efficiency benefits beyond more expensive and complicated VRF or DHP options, it does provide a convenient, affordable alternative for electrification and heat pump usage that does not have the downsides of a large, obtrusive through-the-wall PTHP or a temporary, inefficient window unit.

The observed data showed that the emerging technology is particularly efficient under part-load conditions, as would be expected for equipment with variable speed features. However, there is also evidence that the equipment may be slightly less efficient than incumbent technology at full-load conditions, perhaps due to variable speed drive penalties or the smaller heat exchangers that are necessary for fitting into the packaged form factor designed to be fully located inside the building's conditioned space.

User experience feedback was mixed. No respondents expressed concerns about usability, and sound levels were not a reported issue for three of the four participants. This feedback and the low measured sound levels should alleviate any concerns of noise due to the inside, living space location of all the equipment components. However, the occupants did express that the equipment tended not to meet their comfort needs, which could perhaps be more of a sizing issue rather than performance of the product itself. The new construction building was in a particularly windy location, with higher infiltration and space conditioning loads than the designers or typical sizing practices may have accounted for.

Due to the small sample size and variability in observations, performance and impacts were not extrapolated to any larger population beyond the measured host sites. Furthermore, the measured data was also not sufficient to confirm any equipment ratings or test methods that are in development and early adoption stages for variable speed micro heat pumps (Bansal, et al. 2024). Additional work is warranted and recommended.

Recommendations for future application and study include:

- Laboratory testing should establish performance curves for variable speed PTHPs under standard test conditions, like those referenced in ongoing work in "ET25SWE0014 Performance Metrics of Micro Heat Pumps Through Laboratory Testing," "ET25SWE0063 Multifamily Micro Heat Pump Focused Pilot," and "Emerging 'Micro' Heat Pumps: Testing and Heating Performance Metrics" (Bansal, et al. 2024). These performance curves should then be used in subsequent modeling efforts.
- Modeling across standard California building types and climate zones using confirmed performance curves can serve as a basis for workpaper development now that the field demonstration and ongoing pilot study has confirmed benefits and function in the field. Based on the observations in this study, there may be some load profiles that are counter-indicative and result in energy penalties. Modeling across standard conditions and profiles can further evaluate this possibility and avoid misapplication of the technology.
- Minimum workpaper requirements should include: variable speed compressors and fans, reverse cycle defrost, elimination of any interior electric resistance heating or defrost, weatherproofing at the envelope penetrations, and no particular building type restrictions outside of any counter-indicative load profiles. For example, although the obvious application may be multifamily, hotel, or other light-commercial buildings at scale, the product can certainly function well and with similar benefits in a single-family home. Similarly, this emerging technology is equally well-suited to both new construction and existing buildings. It makes sense for retrofit scenarios where unitary equipment needs to be replaced, especially where

existing gas heating equipment—such as a wall furnace or electric resistance wall heaters—can be replaced with a single heat pump product.

- Exterior grilles included with the unit are weak plastic discs that do not provide weatherproofing or integrate with an engineered envelope or weather-resistive barrier. Third-party louvers that integrate with the exterior finish and maintain the building's weatherproofing would better meet these needs, but the manufacturer does not support custom louvers or grilles, citing free-area limitations. Manufacturers could work to improve this aspect of the product.
- Plumbing code prohibits routing one apartment's condensate to a drain line into another, so condensate must be managed within each dwelling. In new construction, designers can plan for this upfront, albeit with added costs; in retrofits, condensate management is a primary constraint on adoption. There are four options for managing condensate: using condensate pumps to route from the unit to drain into a sewage connection in the associated apartment (such as the washer or bathroom sink drain), a condensate riser in the wall with an indirect drain to sewage at the bottom, a condensate riser in the wall routed to exterior landscape, or an added drain near the unit within the living space. Condensate pumps inside the unit could help manage this design constraint.
- Given the equipment's efficiency gains come largely at part-load conditions due to the internal variable speed and multi-speed components, proper sizing is a crucial factor. Proper sizing to a site or zone's peak design load will help ensure that savings can be realized over the part-load conditions that will constitute most of the annual runtime. This thinking assumes a similarly sized baseline option, matching the peak, design point load. Savings will decrease with increased time spent at full capacity for any given application and load profile.

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Appendix: Curve-Fit for Baseline Equipment Performance Methodology

Equipment operating characteristics are specified in two parts. First, the Air-Conditioning, Heating, and Refrigeration Institute standards for the design, fabrication, and installation of heating, ventilating, and air conditioning equipment] capacity and consumption are given. Second, the off-design to design functional relationship is specified. For example, the hourly available cooling capacity from a unit is:

$$CAP_T = \text{available total cooling capacity}$$
$$= CAP_{ARI} * CAP(WBT,DBT)$$

where CAP(WBT, DBT) is the modifier function to account for off-design WBT and DBT. In keyword form, the equation is expressed as

$$CAP_T = \text{COOLING-CAPACITY} * \text{COOL-CAP-FT}(WBT,DBT),$$

where WBT and DBT are the wet- and dry-bulb temperatures of air entering the coil for water coils and entering air wet-bulb and outdoor dry-bulb for direct expansion units.

To calculate the energy input to produce the available output, a similar rated value and modifier function is used.

$$EIR_T = \text{ratio of electric input to cooling output}$$

$$EIR_T = EIR_{ARI} * EIR(WBT,DBT) * EIR(PLR),$$

or in keyword form,

$$EIR_T = \text{COOLING-EIR} * \text{COOL-EIR-FT}(WBT,DBT) * \text{COOL-EIR-FPLR}(PLR).$$

The PLR is the ratio of actual load output to full load output at the operating point. Thus, the electrical input to the unit is

$$QE = CAP_T * EIR_T$$

or

$$QE = CAP_{ARI} * CAP(WBT,DBT) * EIR_{ARI} * EIR(WBT,DBT) * EIR(PLR)$$

In the case for heat pumps for cooling and heating calculations, dry-bulb temperature inputs are the same as outdoor dry-bulb temperature. Therefore, the dry-bult temperature variable from the above formulas is the same as outdoor dry-bulb variable in the following heating formulas:

$$CAP_T = \text{HEATING-CAPACITY} * \text{HEAT-CAP-FT}(ODB,EDB)$$

$$EIR_T = \text{HEATING-EIR} * \text{HEAT-EIR-FT}(ODB,EDB) * \text{HEAT-EIR-FPLR}(PLR)$$

$$QE = CAP_T = EIR_T$$

Source: (James J. Hirsch & Associates 2018).