

FUTURE FOCUS
AIR-TO-WATER HEAT PUMP FIELD STUDY

Air-to-Water Heat Pumps in Practice: Findings from Real-World Installations

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TABLE OF CONTENTS

Table of Contents 2
Acknowledgements 3
Executive Summary 3
Introduction 5
Research Overview 9
Results 15
Key Findings and Recommendations 63
Conclusion 69
References 70
Appendices 72

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EXECUTIVE SUMMARY

Domestic hot water (DHW), space heating, and space cooling account for the majority of residential energy use, making these systems key targets for efficiency improvements. Air-to-water heat pumps (AWHPs) provide an efficient and flexible pathway for installing or retrofitting hydronic systems that serve these end uses. This Focus on Energy 2023-2026 field study evaluates the performance of five AWHP systems across four residential buildings in Wisconsin. Projects consisted of one multifamily retrofit, two single-family retrofits, and one single-family new construction. Site recruitment began in 2023, and equipment installation

occurred between November 2024 and August 2025. Performance monitoring continued through August 2026.

Key Findings

Contractor experience and design support influenced system design decisions and commissioning practices, and ultimately, system functionality. Installations led by an experienced contractor quickly achieved reliable operation. Early design involvement from a manufacturer helped guide a less experienced installer, while the less experienced installer without early support encountered persistent challenges.

System design varied, with the simplest AWHP installation at the new construction project site. The three retrofit projects required careful load assessments, targeted re-piping, and the use of multi-stage controls. Resulting system performance varied widely and was influenced by control strategies. Heat pump and boiler controls should be integrated to minimize reliance on auxiliary heat, and outdoor reset controls should be set on the supply water to improve efficiency. For systems serving both space heating and DHW loads, control strategies should be informed by resident hot water consumption patterns.
AWHPs improved the heating efficiency of all systems. At the site with significant design troubles, these improvements were marginal, with energy savings of about six percent. The other three sites saw savings of 40, 48, and 53 percent. These savings are similar in magnitude despite differences among the three sites in baseline fuel type (gas or electric), building type (new construction or retrofit), and scale (single- or multifamily). At these sites, space heating efficiency averaged at a Coefficient of Performance (COP) of 2.7 to 3.2. DHW efficiency was lower, averaging a COP of 1.2 to 1.5, due in part to higher required DHW supply temperatures.

Economic outcomes depended on local rate structures. Electricity cost nearly five times more per unit of energy than natural gas at dual fuel sites, so AWHPs reduced annual operating costs when replacing electric resistance systems, but not when displacing natural gas, even when retrofits resulted in similar percentage energy savings. Accordingly, in dual-fuel applications, designing for partial heating displacement could improve cost outcomes.

Program Implications

The findings indicate that broader adoption of AWHPs will depend on greater standardization of design, controls, and troubleshooting practices in the region. This process can be accelerated with programmatic support.

For both single- and multifamily buildings, programs should prioritize new construction and electric boiler retrofit applications to build installer familiarity with AWHPs. New construction applications generally involve simpler system designs, while electric boiler retrofits offer better cost outcomes than systems displacing natural gas. For retrofit projects, site screening should demonstrate a feasible path to providing adequate heat with low-temperature supply water. This criterion is likely to favor projects with radiant floor heating, although projects with oversized boilers or proposed emitter retrofits could also qualify.

Programs should require contractors to complete AWHP-specific training and, when design expertise is not available in-house, obtain design and commissioning support from qualified providers. Program materials should provide best practices for backup heat controls, outdoor reset controls, and DHW sizing and controls, and programs should consider requiring projects to follow these best practices. Additionally, funding for post-installation performance monitoring could help identify and resolve issues quickly, and basic customer education initiatives could help customers recognize abnormal system operation and communicate problems to installers.

By addressing key barriers, these measures can reduce perceived installation risk and associated cost premiums, improve system performance and customer experience, and build the contractor knowledge needed to support broader AWHP deployment in Wisconsin.

INTRODUCTION

Technology Overview

An AWHP is an all-electric HVAC system able to provide space heating, space cooling, and/or DHW. AWHPs extract heat from the outside air and transfer it to water via a compressor-driven, refrigerant-based system, reversing this process for chilled water. For space heating, the heated water is pumped to various emitters like radiators, fan-coils, and in-floor radiant systems. AWHPs can reach a coefficient of performance (COP) of more than five, delivering over five units of heat for every unit of electricity consumed, equivalent to efficiencies over 500 percent (LG 2020-2021, Enertech 2025, Arctic 2024). This efficient operation can save substantial amounts of energy.

AWHP technology has been deployed in parts of Europe and Asia since the mid-2000s (Hashimoto 2006, Daikin 2024). Early applications in colder climates were often limited to domestic hot water, partial space heating displacement, and/or space heating displacement with substantial electric resistance backup. Over the past decade, advances in cold-climate performance have expanded the feasibility of AWHPs to serve as primary heating systems in a wider range of conditions (Daikin 2012).

In December 2022, Focus on Energy researched the state of AWHP technology in Wisconsin for residential applications. This research found that there are 228,000 single-family and 168,000 multifamily boiler heating systems in Wisconsin, equating to 15 percent of the residential units in the state. The ideal candidates for AWHP retrofits are an unknown subset of this stock: AWHPs require distribution systems that can accommodate low temperature supply water, and high temperature boiler retrofits would introduce additional complexity and expense. Within this subset of buildings, the research outlined that the opportunity for energy efficiency and reduced utility costs within the market is high.

In terms of product offerings, the residential AWHP market has gained traction in recent years in the United States. Table 1 shows manufacturers selling residential AWHPs in the United States as of September 2026, as well as the Midwestern distributor for each, when that information could be located by the research team.[1] There is currently no federal residential AWHP performance standard, but manufacturers and programs typically report laboratory rated COP for delivering 110°F supply water at a 5°F outdoor temperature as an indication of cold-climate performance. This metric is also provided in the table.

Table 1: Residential AWHP products available in the United States

Manufacturer	Sales Contact / Dealer Network (Midwest-specific when information available, national otherwise)	Product Line	COP @ A5W110 (ranges due to differences amongst models and/or equipment sizes)
Apollo / MBTEK	MBTEK (U.S. online supplier)	APOLLO EVI DC	2.2 to 2.3
Arctic Heat Pumps	Dean Long (Midwest manufacturer rep)	R32 DC Inverter EVI	2.2 to 2.5
Chiltrix	A to Z Sales & Marketing via Unico (Midwest manufacturer rep)	CX Series	2.2 to 2.5
Daikin	Williams Distributing (Midwest distributor)	Altherma 3 H HT	2.2[2]
Ecoer	F.W. Webb (U.S. distributor)	Smart Green One	2.3
Enertech Global	Enertech installer-referral network[3]	Advantage	2.3 to 2.6
Gree	Wells HVAC Supply (Midwest distributor)	Wells by Gree AWHP	1.9
IBC Technologies	FourMation Sales (Midwest manufacturer rep)	HPX Series	2.0 to 2.4

[1] Products that surfaced during an initial review were cross-checked with Efficiency Vermont's Qualified Products List (qualifiedproducts.efficiencyvermont.com) for comprehensiveness.
[2] Daikin has not released a COP @ A5W110, specifically. This value is interpolated efficiencies at other conditions.
[3] https://enertechusa.com/find-an-installer

LG Electronics	K&E Distributing (Midwest distributor)	R32 Air-to-Water Monobloc	2.4 to 2.5
Lochinvar	Porter Pipe & Supply (Midwest distributor)	CENTRUS	1.9
Midea	The House Supplier (U.S. online supplier)	M-Thermal Split	2.1
Mitsubishi Electric	Got Ductless (U.S. online supplier)	ecodan	1.9 to 2.0
Nordic	Nordic dealer network[4]	ATW Series	1.8 to 1.9
NTI	Emerson Swan (Midwest manufacturer rep)	Verta Series	1.9 to 2.0
Samsung HVAC	Samsung U.S. dealer network[5]	EHS Mono HT	2.2
SpacePak	Gustave A. Larson (Midwest distributor)	Solstice R32 Series	1.5 to 2.8
U.S. Boiler Company	F.W. Webb (U.S. distributor)	AMBIENT HPS	1.9
Viessmann	FourMation Sales (Midwest manufacturer rep)	Vitocal 100-AW	1.3 to 2.2
Weil-McLain	Weil-Mclain distributor network[6]	ECO HP / ECO Hybrid	2.1

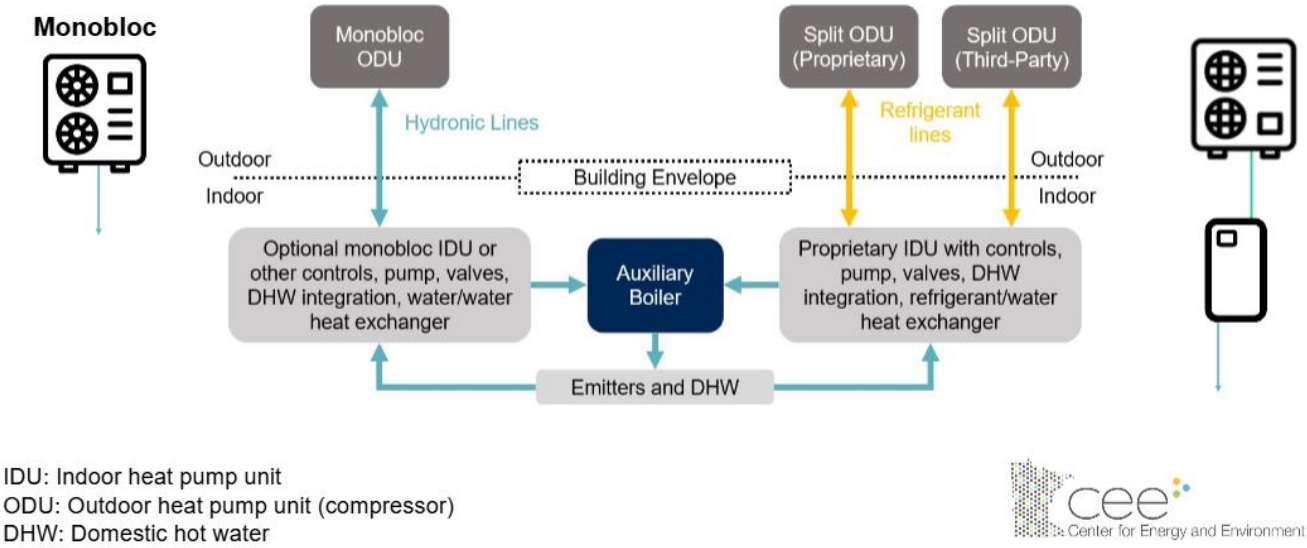
Contractor familiarity with residential AWHPs remains low in many United States regions. Residential contractors and distributors are often reliant on manufacturers for information and guidance. There is greater familiarity with commercial AWHPs, especially amongst commercial HVAC designers and engineers, but these teams are currently not often brought onto smaller residential projects.

System Design

AWHPs can be manufactured as a split system, like traditional air-source heat pumps (ASHPs), or as a monobloc system in which all refrigerant-containing components are located in the outdoor unit (ODU). Monobloc pumping and DHW controls may also be located in the ODU or housed in an indoor unit (IDU). Since no refrigerant lines extend into the home, monobloc configurations can accommodate low-global-warming-potential refrigerants that may be restricted from use inside because of their flammability; as refrigerant regulations become more stringent, monobloc systems are therefore expected to become increasingly common. Additionally, monobloc setups eliminate direct refrigerant handling during installation. However, the hydronic lines connecting the outdoor and indoor portions of the system must be protected against freezing, typically with glycol and piping insulation. Glycol can be expensive, so monobloc systems often use separate outdoor and indoor hydronic loops, with heat transferred through a buffer tank. All sites in this pilot used monobloc AWHPs.

Figure 1: Monobloc versus split system configuration

[4] https://www.nordicghp.com/find-a-dealer/
[5] https://www.samsunghvac.com/about-a2w-hp
[6] https://www.weil-mclain.com/distributor-locator/



Both split system and monobloc AWHP systems are comprised of several components, including buffer tanks, backup heating sources, and control schemes. Systems can include indirect buffer tanks that transfer heat between a heat pump loop and a distribution loop, direct buffer tanks that increase volume in the heat pump loop, and/or dynamically controlled thermal storage tanks to optimize the time of energy use. They can also be designed to work without a buffer tank at all.

Regardless of system configuration, AWHP controls and auxiliary heat controls should be coordinated so that heating is provided through one set of coherent system logic. For electric backup systems, an integrated boiler can be installed as part of the AWHP IDU. If backup heat is provided by natural gas or an external electric boiler, boiler controls should be integrated with the IDU controller or a standalone Wi-Fi-enabled controller on a buffer tank. Less optimally, external backup boilers can remain controlled primarily by their own internal controller (i.e., aquastat controller or other electric onboard on/off and water temperature controller) with call-for-heat connections to the broader system sent through relay devices. Boilers can be triggered to run on a time delay (i.e., turning on after the heat pump has attempted to heat the system to the target supply water temperature for a certain number of minutes) or based on an outdoor switchover temperature, among other possible but not commonly used control strategies.

Ideally, for space heating, the leaving water temperature (LWT) from an AWHP decreases when loads are low at warmer outdoor temperatures. This is accomplished through LWT outdoor reset controls. DHW efficiencies are typically lower than space heating efficiencies in combined AWHP systems because this dynamic cannot be leveraged for DHW.

Figure 2: Summary of key design components



Buffer tanks

Indirect to transfer heat between a heat pump loop and a distribution loop

Direct to increase volume in the heat pump loop

Dynamically controlled thermal storage tanks to optimize the time of energy use



Backup boilers

Electric "boost" or gas backup

Controlled by:

- Integration with IDU
- Integration with Wi-Fi enabled device on buffer tank
- On-board controller and relay devices

Triggered by:

- Time delay (HP has tried to heat to supply water temperature for x minutes)
- Outdoor switchover temperature



Supply water temperature

Outdoor reset to optimize space heating delivery temperature

Higher delivery temperature for DHW than space heating

= higher COPs for space heating in most combi systems

More detailed AWHP mechanics and best operational practices have been laid out in several prior reports, including an American Council for Energy Efficiency Economy GTI Energy paper titled "Best Practices from the Field: Air-to-Water Heat Pump Combi Systems" (LaFleur 2022) and a Minnesota Conservation Applied Research and Development report titled "A Cold Climate Solution for High-Efficiency Cooling, Space Heating, and Water Heating" (Hill 2023). These two studies reached common conclusions about hydronic system design, some of which are outlined above. In addition, these studies stress that AWHPs often require higher mass emitters than many existing boiler systems in order to provide adequate heat output at lower LWTs. Retrofitting boiler systems with lower mass emitters therefore requires careful design to ensure an AWHP does not become capacity-constrained by the distribution system. In general, improperly sized AWHP distribution systems (i.e. emitters, buffer tanks, and zone controls) can lead to heat pump issues such as short cycling. Careful load assessment and system design are thus critical. This is especially important for cooling applications, where longer heat-pump cycle times are needed to support effective dehumidification and existing radiant infrastructure may lack condensation control.

RESEARCH OVERVIEW

Previous Focus on Energy research, detailed in the Technology Overview section, suggested that a field study would be beneficial to better understand AWHP feasibility and energy savings potential in the field. This section outlines the objectives and methods of this real-world pilot.

Objectives

Through outreach to manufacturers, field demonstrations, and system monitoring, this study sought to:

- Conduct outreach to air-to-water manufacturers with a presence and capability for design support in Wisconsin.
- Demonstrate AWHP in three single-family buildings and one multifamily building in Wisconsin. Recruit a mix of retrofit and new construction sites. Recruit at least one site with AWHP domestic hot water and AWHP hydronic cooling.
- Identify key characteristics (i.e. climate zones, age, fuel type, level of weatherization, hydronic distribution emitter type and size) making a home a promising candidate for an air-to-water heat pump.
- Document barriers to installation, system failures, changes to operating parameters, and adjustments that were required throughout the monitoring of the system.
- Quantify costs associated with AWHP systems and retrofits, including product, installation, and operating and maintenance costs.
- Quantify AWHP system performance, including electricity consumption, backup fuel use, heating and cooling efficiencies, operating costs, and maintenance requirements, and compare performance to conventional heating systems where applicable.
- Examine the performance of integrated domestic hot water and space heating systems to determine whether they provide adequate heating and hot water under real-world operating conditions.
- Understand the perspective of AWHP users and installers through surveys and interviews.
- Draft a TRM workpaper to support eligibility of AWHP as a prescriptive measure within the Focus on Energy portfolio.

Recruitment

This study was open to customers of utilities participating in Focus on Energy. Participants were required to own their homes (or properties) and use a hydronic system as the primary heating source or be willing to install an AWHP in their new construction home. To minimize changes to the distribution system, existing systems needed to be able to supply sufficient heat with supply water temperature of 130ºF or below. As a result, all recruited sites had in-floor radiant heating systems.[7]

Outreach to multifamily participants began in September 2023 and was conducted through existing building owner relationships in Wisconsin. Early on, West Central Wisconsin

[7] As mentioned in the Background/Introduction, traditional radiator systems typically deliver water at much higher temperatures than AWHPs, requiring alterations to the distribution system and heat emitters to ensure sufficient distribution capacity when supply temperatures are lowered. For the study, radiator systems that could be feasibly upsized to serve the heating load with 130ºF water or were oversized for the building envelope (e.g. in recently weatherized buildings), were eligible alongside in-floor radiant systems, but only in-floor radiant systems were recruited.

Community Action Agency (West CAP) expressed interest in participating in the study. West CAP operates approximately 15 affordable housing properties in West Central Wisconsin. All their properties are weatherized, and several have in-floor radiant heat, making them ideal candidates for AWHP retrofits.

Outreach to single-family participants began in February 2024. The research team created a one-pager (shown in Appendix A), a webpage, and a pre-survey questionnaire to recruit single-family retrofit sites. Communications were sent out to customers via the Focus on Energy newsletter. Focus on Energy also reached out to contacts at electric municipal utilities and co-ops separately. A total of 31 complete and partial responses were received from the pre-survey questionnaire posted on the study webpage. Of the 13 complete pre-survey questionnaire responses, five were from eligible sites. After further screening, including talking with customers, virtual walkthroughs, and site visits where necessary, this process resulted in the recruitment of two single-family retrofit sites.

To recruit installers for the multifamily and single-family retrofit sites, the research team reached out to highly active Focus on Energy Trade Ally contractors who received incentives for previous boiler and air source heat pump (ASHP) installations, as well as other contractors in Wisconsin who had worked with the research team previously. The installer outreach one-pager is shown in Appendix B.

This process highlighted the nascent Wisconsin AWHP market. More than thirty installers were contacted. Many of the installers expressed interest but had difficulty identifying participants in their service territory. Some of these installers wanted to install AWHPs in furnace buildings, highlighting their lack of familiarity with the technology. Other installers expressed that since they were not familiar with AWHP, they were hesitant to mention this study as an option for their customers. Ultimately, two installers were recruited for the three retrofit sites, with one installer performing installation at both the multifamily retrofit site and one of the single-family retrofit sites.

The research team targeted builders, beginning with an email blast which led to six builders showing interest. None of the builders had an eligible site or could align construction with the timeline of the study which resulted in the research team leveraging manufacturer outreach to recruit the new construction site. One AWHP manufacturer connected the research team with a homeowner and installer who planned to install an AWHP. This home fit all eligibility requirements and was selected for the study.

The four sites ultimately selected in the recruitment period were:

- **Site 1:** a four-unit multifamily retrofit using two AWHPs paired with natural gas back-up boilers to provide combined space heating and domestic hot water.

- **Site 2:** an all-electric single-family retrofit using an AWHP paired with the existing electric boiler integrated to provide space heating and domestic hot water.
- **Site 3:** a single-family retrofit using an AWHP paired with the existing natural gas boiler as back-up to provide space heating and cooling.
- **Site 4:** an all-electric single-family new construction installation using an AWHP paired with an integrated electric boiler to provide space heating and cooling.

Incentives

Participating customers received the following incentives:

- Single-Family Retrofits: 100% of total equipment and installation costs up to $45,000.
- New Construction: $8,000 plus any incentives available through Focus on Energy's New Homes program.[8]
- Multifamily Retrofit: 100% of total design, equipment, and installation costs up to $100,000.

Methodology

Monitoring and Verification

Sensors were installed at the time of AWHP installation to monitor system performance. The set of installed sensors was slightly different at each site depending on the type of loads served (i.e., heating, cooling, DHW), the presence of a buffer tank, and the type of backup heating. The diagrams of each system design and associated temperature and flow measurements are shown in the Site Information sections.

Sensors informed the following calculations:

- Pre- and post-period efficiency as COP.
    - COPs reported in this paper are the energy delivered by the heat pump (calculated from water temperature and flow measurements) divided by the energy that the heat pump consumed (monitored with power meters). This metric does not include backup heat contributions or distribution losses, which are reported in other metrics.
- Primary and backup system utilization and runtime by outdoor temperature.
- Domestic hot water demand and impact on system operations (at applicable sites).
- Indoor space temperature and any spatial changes to delivered heat.

Table 2 lists each monitoring sensor and its primary use(s) in analysis.

[8] The incentive payment to the participant was ultimately $8,372.68, since there was extra incentive budget.

Table 2: Type of monitoring equipment installed

Sensor	Measurement	Used in calculation of:
Honeywell AC-250 with IMAC pulse relay	Natural gas flow volume[a]	Backup energy/efficiency, backup utilization
JD JS 16mm/0.63" 100A CT	Boiler circuit power[b]	Backup energy/efficiency, backup utilization
SA1-TH-44006-40-T Surface Mount Thermistor	Hydronic supply temp	Energy/efficiency, backup utilization
SA1-TH-44006-40-T Surface Mount Thermistor	Hydronic return temp	Energy/efficiency, backup utilization
Prosense FMM100-1002	Hydronic flow	Energy/efficiency, backup utilization
JD JS 10mm/0.39" 50A	Circulator pump power	Energy/efficiency, backup utilization
SA1-TH-44006-40-T Surface Mount Thermistor	Radiator branch supply temp	Comfort, system performance
MX1101 Hobo Temp/RH Sensor	Room temperature	Comfort, system performance
JD JS 10mm/0.39" 50A	AWHP circuit power	Energy/efficiency, AWHP utilization
JD JS 10mm/0.39" 50A	Secondary pump power	Energy/efficiency, AWHP utilization
SA1-TH-44006-40-T Surface Mount Thermistor	AWHP thermocouple	Energy/efficiency, performance
Badger Meter PFT-2E	DHW water flow[c]	DHW energy/efficiency
SA1-TH-44006-40-T Surface Mount Thermistor	DHW inlet temp[c]	DHW energy/efficiency
SA1-TH-44006-40-T Surface Mount Thermistor	DHW outlet temp[c]	DHW energy/efficiency
H300 Current Switch	Radiant zone calls	

a. *Gas flow meter only installed for natural gas boilers. At Site 1, this meter did not report correctly, and the rated boiler efficiency was used in analysis.*
b. *Boiler circuit power meter only installed for electric boilers*
c. *DHW monitoring only if AWHP also provides heat for domestic hot water*

As M&V equipment was installed at the time of AWHP installation, no direct monitoring of the pre-period exists for these sites. The research team operated the system in "back-up only" mode for three one-week windows spaced across the winter monitoring period. These one-week windows were treated as our counterfactual (pre-period) data, while the remainder of the monitoring period was considered the post-period.

Normalization Analysis

Results are calculated using various normalization methods depending on the end use (i.e. space or water heat). Weather normalized values use a TMY3 file from the weather station closest to each site.

When space heat input energy is plotted, monitored heat pump input energy at all sites has a linear relationship with outdoor temperature. Boiler input energy is zero up until a certain temperature, where a linear relationship begins. Piecewise linear regressions on daily data were thus used to estimate energy consumption of each equipment type per outdoor temperature in the TMY dataframe. For sites where the AWHP provides just space conditioning (Site 3, Site 4, and the space-heat only system at Site 1), these normalized values were used in the final savings calculations, but not daily COP or backup contribution results.

For AWHPs providing both space heating and water heating, both energy input and energy output were normalized. Space heating values were normalized as above. Water heating values were normalized using a generalized additive model (GAM) fit to a Gaussian error distribution for heat pump and boiler energy. This model estimated daily energy consumption and production for DHW as a function of daily DHW consumption and outdoor air temperature. Separate smooth functions for DHW volume consumed and outdoor temperature were included alongside an interaction term, allowing for potentially nonlinear relationships between these variables and energy use. In normalized values, DHW consumption was held constant at the mean daily demand over the study period, while the modeled dependence of both AWHP and boiler energy use on outdoor temperature was retained. For sites with the AWHP providing both space conditioning and DHW (Site 2 and the space and DHW system at Site 1), normalized energy values were used in the final savings calculations, as well as in daily COP and backup-contribution results, to isolate the effects of outdoor temperature from day-to-day variation in DHW demand. Hourly COP results and results presented in the DHW Characterization sections are not normalized, allowing the relationship between DHW consumption and system performance to be evaluated directly.

Due to a lack of data on the baseline cooling systems at these sites, cooling energy usage is not included in final savings results.

Utility Cost Data Collection

The research team obtained energy cost data from the residents for single-family sites, and from the building owner for the multifamily site. Rates varied across sites with each site receiving service from a different utility. These costs were used in the analysis of the economic impacts of each retrofit.

Pre-Retrofit Modeling

After site selection, building energy modeling software was used to model the heat load at each retrofit site, as well as the change in fuel consumption expected in the post-period. All modeling was done using Energy Plus with an AWHP add-on module. These modeling results

are provided in the Summary of All Sites for comparison to monitored results, but all reported savings results in this report are based on the “back-up only” periods described above.
one man job but noted that two installers would have made installation more efficient.

Installer and Building Owner Interviews

The research team conducted structured interviews with the building owner and installer for each site. Installer interviews focused on the existing equipment, perceptions of AWHPs, installation experiences and barriers, and maintenance. Resident interviews focused on satisfaction and comfort in operating the new equipment. The guides for these interviews are included in Appendix D.

RESULTS

Site 1: Multifamily Retrofit

Site Information

Existing System:

- Two condensing natural gas boilers with an in-floor radiant distribution system
  - The larger boiler serves space heating for two residential units, as well as a new 80-gallon indirect water heater for all four units.
  - The smaller boiler serves space heating in the other two residential units. Through-wall packaged terminal air conditioning sleeves (i.e. PTACs) for cooling.

Post-Retrofit System:

- One 5-ton and one 2.5-ton monobloc AWHP with IDUs, with original gas boilers as backup.
- One 80-gallon indirect water heater is heated with the larger AWHP system.
- There are no buffer tanks in the systems.
  Cooling was unchanged. The AWHP system was sized to fully replace gas heating.

Post-Retrofit System Controls:

- AWHP operation is triggered by a heat call from the radiant space heating system or the DHW system.
- The boiler “tops off” the system if the water passing through the IDU is not at the necessary delivered water temperature.
- The system cannot provide both space heating and domestic how water at the same time. DHW heat calls are prioritized when both uses require heat at the same time.

Contractor Experience Level: Prior experience with heat pump hydronic systems

Number of Troubleshooting Callbacks: 4

Figure 3: Site 1 property with site selected in red



Figure 3: Site 1 existing boiler, AWHP ODU and IDU installed, and indirect water heater




ENERTECH


ENERTECH


turbomax
THERMO 5000

Figure 4: 5-ton HP system with space heat and DHW at Site 1

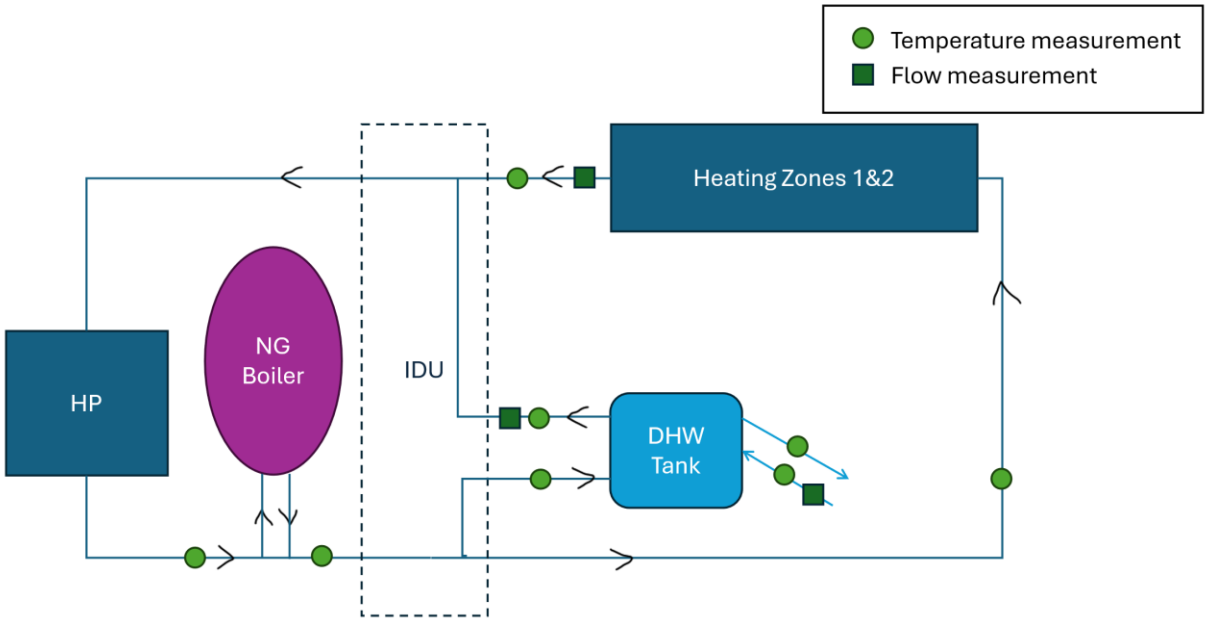


Figure 5: 2.5-ton HP system with just space heat at Site 1

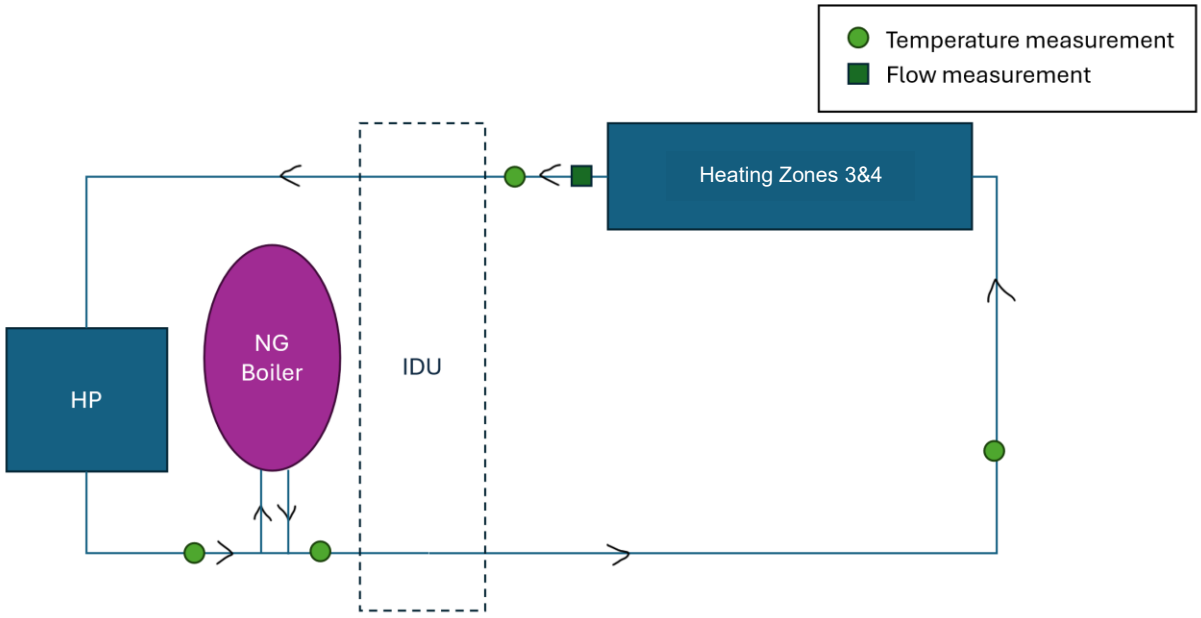


Table 3: Site 1 additional site details

Electric Utility	Gas Utility	Building Size	Monitored Design Load at -13°F	Installation Costs[9]	Incentives Provided
Xcel Energy	We Energies	3,360 sqft	49kBTU	$100,871	$100,871

Installation and Troubleshooting

The installation of the AWHP went smoothly due to the highly qualified contractor, who had experience installing geothermal heat pump systems (which have controls similar to those in an AWHP system). The installer re-piped the system in both mechanical rooms to place each natural gas boiler in parallel to its corresponding AWHP. The variable-speed pumps within the IDUs were leveraged to supply water to the two space heating and four DHW zones. The IDU control logic also managed zone valves, backup boilers, and temperature and flow for DHW. The contractor successfully programmed an outdoor reset curve for space heating at both systems.

After installation, this larger heat pump had a firmware issue preventing changes to controls. This was fixed by the installer upon consultation with the manufacturer. The installer also returned to site once to fine-tune the backup boiler.

At the outset of the monitoring period, the DHW target tank temperature was set to 125°F. In the following weeks, the building owner called the contractor reporting hot water runouts. The contractor adjusted the tank temperature to 135°F (with a mixing valve still decreasing the actual delivered water temperature to 120°F), which in effect increased the water tank storage capacity and provided satisfactory DHW for the residents.[10] However, this change increased backup heating energy consumption and decreased heat pump efficiency to maintain that higher temperature, as described in the DHW Characterization section below.

One major operational issue occurred at this site during the study. The outdoor temperature dropped to -20°F, which locked out the smaller space heat only heat pump. Snow accumulation inside the unit then prevented it from turning back on, and the system operated in boiler-only mode for several months. The issue was flagged by the research team while running quality assurance checks, which prompted the installer to return to site after some delay, returning the heat pump to full functionality in March 2026. Without the monitored data at this site, the boiler would likely have continued serving this system for longer. This issue highlights the need for some building owner or resident awareness of their AWHP system, which could enable them to flag abnormal function to the installer for service. In this case, that

[9] This building required electrical infrastructure upgrades, including an additional electrical meter and sub-panel. Installation costs include time and materials for these upgrades.
[10] This indicates that the previous boiler also had a setpoint higher than 125°F, though this was not confirmed.

abnormal function would consist of observed low heat pump runtime or high gas bills compared to electric.

Installer Experience

The installer brought substantial experience to this installation, having installed several hundred GSHP systems and three AWHP systems. The installer felt well prepared for this installation despite this being their first installation of this specific AWHP model. They credited this to their past similar installation experiences and recent completion of manufacturer-required training; the installer said that the training was especially useful since it went beyond the typical educational format of a high-level lunch and learn.

This site required additional prep work ahead of the installation, such as adding an electrical panel to one of the mechanical rooms and re-piping the boiler to serve as a secondary system instead of the original setup as a primary system. There was adequate space available in the ground level mechanical room and the layout allowed the ODU to be closely located to the mechanical room hosting the indoor equipment. The existing distribution piping layout worked well to accommodate changes required for the new piping design.

During start up, the installer sought clarification from the manufacturer regarding nuances identified in their instruction language related to programming the Human Interface Module (HIM), backup heat, and the indirect water heater. The installer mentioned that the manufacturer planned to clarify this language in future revisions to their setup instructions. The installer expressed that overcoming the learning curve from this first installation provided ease for the following installation at Site 2. The installer estimated an additional 10 unplanned labor hours for this learning curve, which is expected for the first time installing a new product. The installation was completed in approximately one week. He completed this installation as a one man job but noted that two installers would have made installation more efficient.

Resident and Owner Experience

Two West CAP representatives, the property maintenance manager and the property manager, provided feedback.

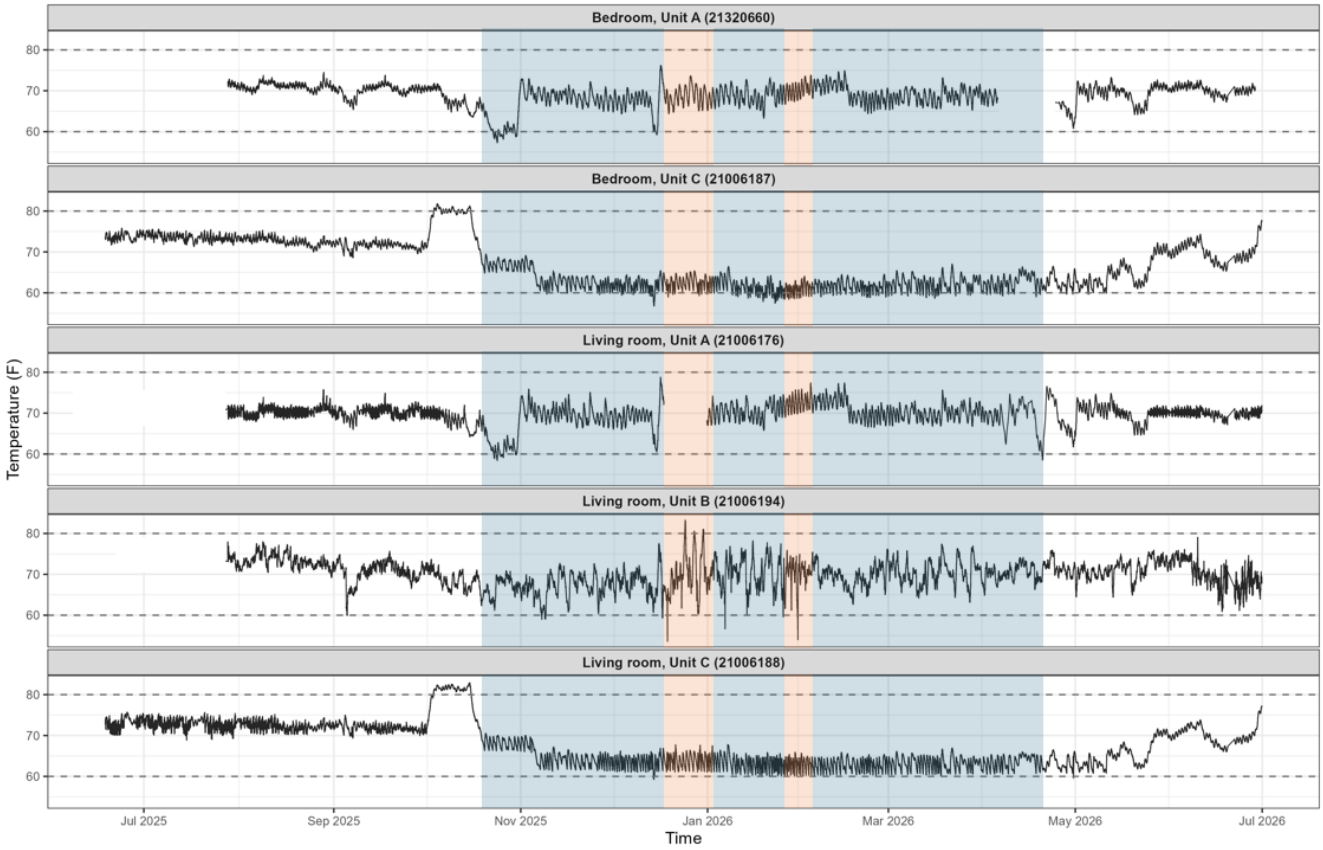
The property manager is confident in their understanding of the system and controls. They noted significant operational changes in terms of the backup boiler settings in the mechanical room controls, but said that the manual has been straightforward when questions arise. They are glad that tenants' day-to-day use of the in-unit thermostats remained essentially unchanged. The owner also noted that since radiant floor hydronic heating systems were in place before, long term tenants understand that raising the space temperature will not be instantaneous.

The owner was motivated to install AWHP systems by the anticipated energy savings and available funding. They also valued the opportunity to compare the building's performance with that of the five buildings that retained their original systems. The owner said they would recommend an AWHP to another property owner if it could be financially justified, rating their satisfaction with the new systems a four out of five. They reported initial boiler short-cycling, which was resolved upon a contractor return visit. They also noted the necessary DHW delivery temperature adjustment.

The property manager was satisfied with the backup heat control settings and did not want to modify the control logic because the systems provided adequate comfort. Therefore, the installer retained the existing configuration rather than adding an economic heat pump lockout control.

Since the final adjustments were made, the owner hasn't received any comfort or hot water runout complaints and confirmed that the systems provide a good level of comfort with consistent space temperatures, "even when it's less than 0°F outside." As shown in Figure 6, there is no discernable difference between backup-only and AWHP system setpoint behavior, indicating that the AWHP system was able to meet residence setpoint throughout. Temperatures in Unit B were the most variable of the monitored units, hitting values both below 60°F and above 80°F. The cause of this variation is unknown.

Figure 6: Monitored indoor temperatures at Site 1, heating season in blue, backup-only periods in orange



In the final interview, property representatives reported that one unit was vacant for approximately six months during the study, saying that the unit was initially occupied by one resident and, after the vacancy, by three new residents. The representatives did not provide more information about the specific details of the vacancy. It is unknown to what extent this affected the monitored space heating and water loads of the building.

Energy Use and Efficiency

Table 4 shows the weather-normalized impact of the two AWHP installations on annual energy use and costs. As energy consumption also varies with resident hot water demand, annual and daily values in this subsection are normalized to the site's monitored average daily hot water consumption of 79 gallons per day. The site saved 60 MMBTU per TMY year. Tenant utility costs were determined prospectively to not be affected by the retrofit, but it is notable that the (owner-paid) operational costs of the site's HVAC systems increased by $797 a year. The larger AWHP displaced 84 percent of annual boiler gas usage, with most boiler contributions happening during DHW calls. The smaller AWHP successfully displaced 91 percent of gas usage.

Table 4: Site 1 weather-normalized baseline and post-retrofit energy use and cost

	Electricity	Natural Gas	Net Energy	Estimated Annual Costs
Unit costs	$0.12/kWh	$0.88/therm		
Pre-retrofit Use (Baseline)	NA	1,262 therms	126 MMBTU	$1,111
Post-retrofit Use	14,715 kWh	161 therms	66 MMBTU	$1,908
Impact	**+14,715 kWh**	**-1,101 therms**	**-60 MMBTU 48 percent**	**-$797**

For the AWHP serving combined DHW and space heat, Figure 7 below shows the observed LWT curve across outdoor temperature for space heating in blue, as well as the average heat pump-supplied DHW temperature in green. The constant value of 125°F for the DHW supply demonstrates that the boiler consistently topped off delivered hot water to reach setpoint, due to the AWHP's space heating-targeted heat exchanger design and/or the heat pump's maximum allowed LWT. The returning water temperatures for these uses are also shown in dashed lines, indicating the temperature lift required of the heat pump. This temperature differential is lower for DHW, but there is a higher final delivered temperature, which resulted in more compressor work and likely contributed to the lower COPs detailed in coming figures.

Figure 7: Leaving and returning water temperatures for the AWHP supplying both DHW and space heat at Site 1

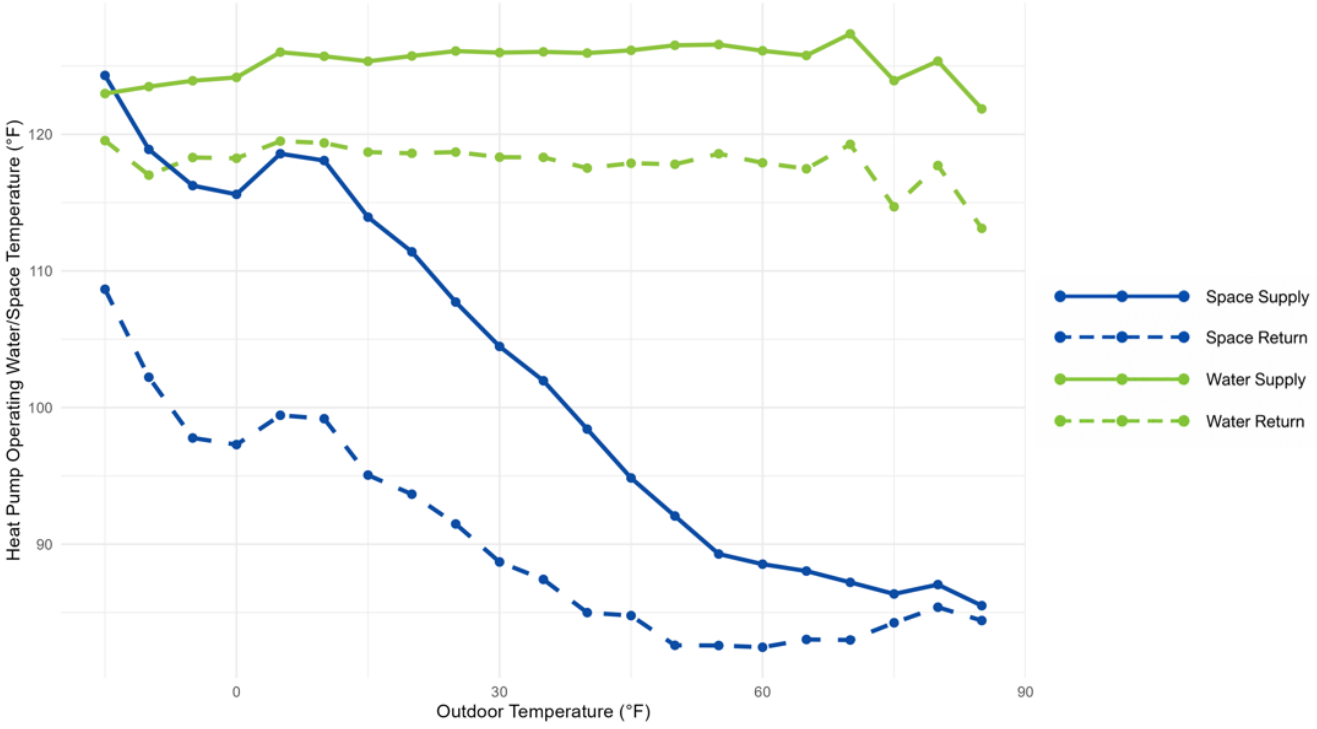


Figure 8 below shows hourly HP COP for the larger AWHP by type of heating and outdoor temperature.[11] Hourly COPs for both space and water heating correlate positively with outdoor temperature, with a more dramatic correlation for space heating. For both space and water heating, there is more heat available to the compressor at warmer outdoor temperatures, which increases specified and realized heat pump efficiency. Additionally, because of the outdoor reset controls (i.e. delivered hot water temperature decreasing at warmer outdoor air temperatures), space heating scales "doubly" with outdoor temperature. The hydronic DHW system, by contrast, must receive delivered hot water at or above the target tank temperature at all times.

The water heating COPs were noticeably lower than the space heating COPs. This is due to the higher LWT when heating the DHW to setpoint compared to space heating, combined with the short DHW cycles observed; the DHW tank would call for a small amount of total heat at a time, and since the boiler was not on a timer, it would help the heat pump meet the call's requirement before the heat pump could reach its optimal operating conditions. Accordingly, average daily COPs for this system were lower in the summer months, when there was no space heating needed.

Figure 8: Hourly HP COP per outdoor temperature for the Site 1 AWHP providing both space heat and DHW, for space versus water heating

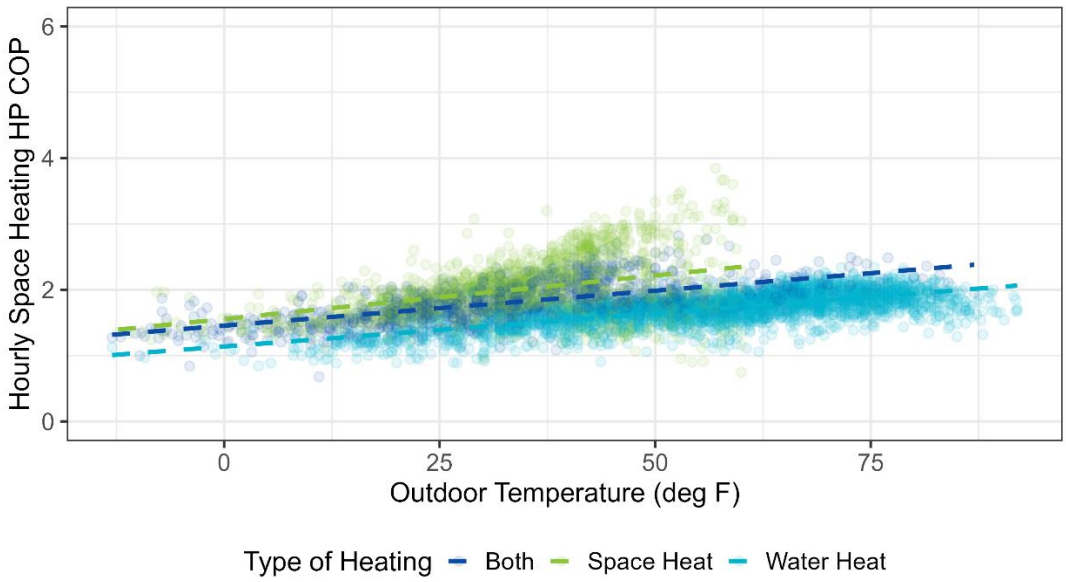
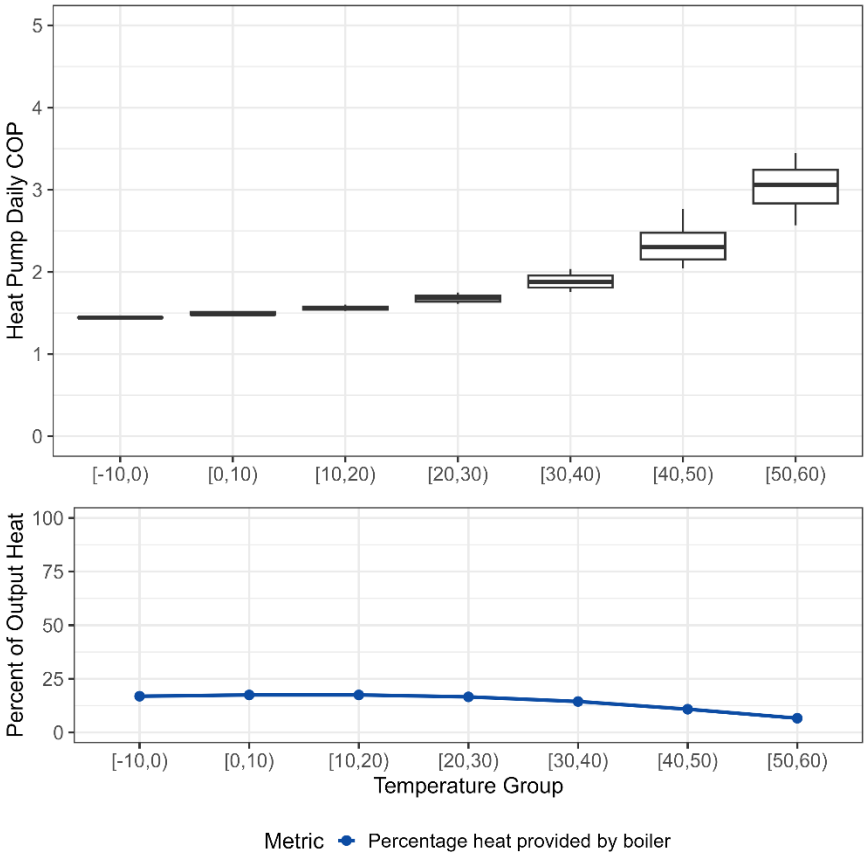


Figure 9 shows a box and whiskers plot of the daily average COPs of this larger HP (serving both space and normalized water heating) and the percentage of energy output provided by the boiler per outdoor temperature group. Heat pump COP ranged from 1.5 at colder

[11] Note that here and in the rest of the paper, COPs may not be reflective of total system performance because of buffer tanks, switching between DHW and space heat, and system thermal inertia.

temperatures to 3.5 at moderate temperatures. The boiler provided a relatively consistent amount of backup heating, covering about 18 percent of space heating load up to 40°F. At temperatures warmer than 50°F, the heat pump covered almost all of the space and water heating load.

Figure 9: Heat pump performance and boiler contribution per outdoor temperature for larger Site 1 AWHP



The research team ran the below linear model to disaggregate the impacts of supply water temperature versus outdoor temperature on COP. All terms are very significant, with the impact of a lower supply temperature being slightly higher than the impact of a higher outdoor temperature per degree change. Note that this was possible for this site since the heat pump is producing both space heat and DHW water at all temperatures, allowing for a model to capture changes in COP due to just supply temperature change. In the space heat-only systems with a constant LWT curve, since supply temperature for space heat is set based off of the outdoor temperature, the variables cannot be disaggregated in this way.

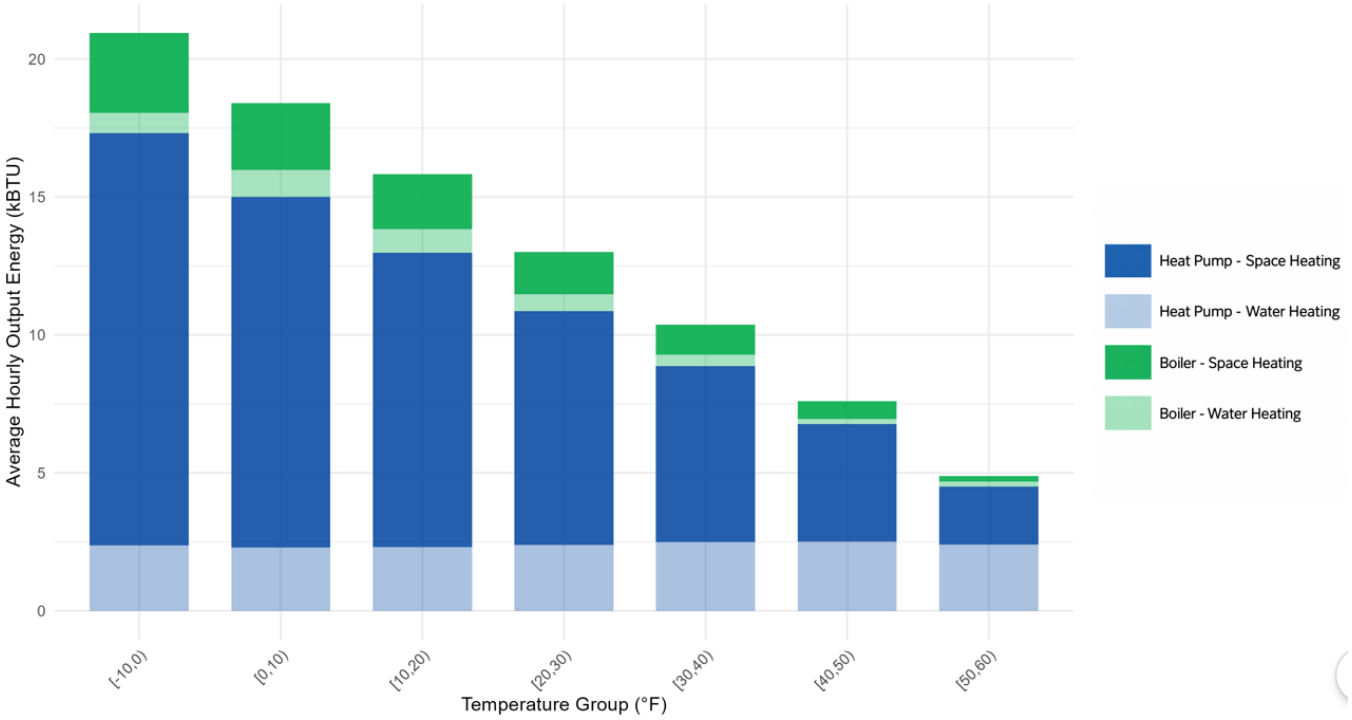
$$lm(COP \sim outdoor\ temperature + LWT)$$

Table 5: Model of outdoor temperature versus supply temperature for DHW and space heat AWHP at Site 1

Variable	Value	p Value
Intercept	3.379	<2e-16
Outdoor Temperature	0.006	<2e-16
Supply Water Temperature	-0.016	<2e-16

The relative loads for this AWHP can be seen in Figure 10. The heat pump provided a constant DHW load, with the boiler picking up the increase in DHW load at colder temperatures. The space heating output of both the AWHP and the boiler increases at colder temperatures. Notably, up until 60°F, the boiler is providing both space and water heating load, though its relative contributions to space heating load decrease at higher outdoor temperatures. This is due to a lack of time delay control in the system, with the boiler activating for the first few minutes while the heat pump increases its delivered water temperature to target.

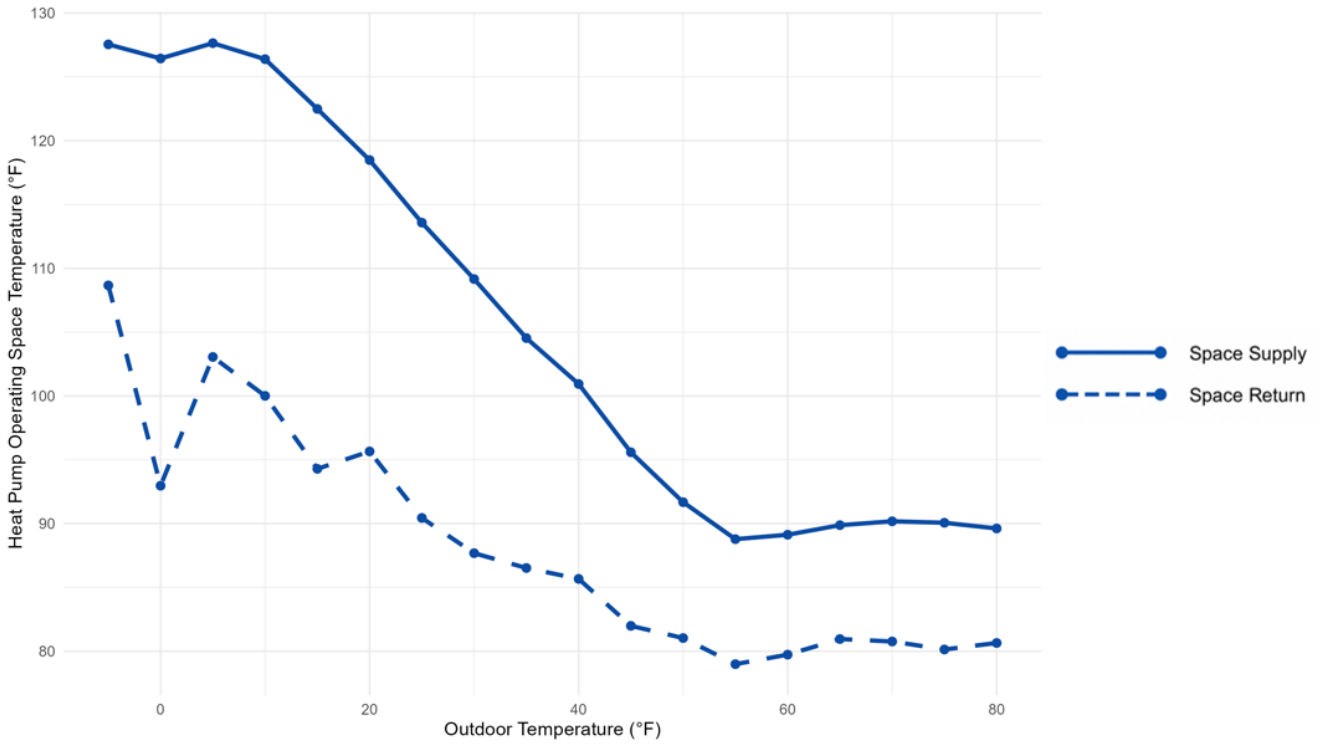
Figure 10: Average hourly output for the AWHP providing both DHW and space heat at Site 1



The smaller AWHP at Site 1, serving only space heating in another portion of the building, performed reasonably well during the heating season. The leaving water temperature curve and average returning water temperatures for this site are shown in Figure 11. This system

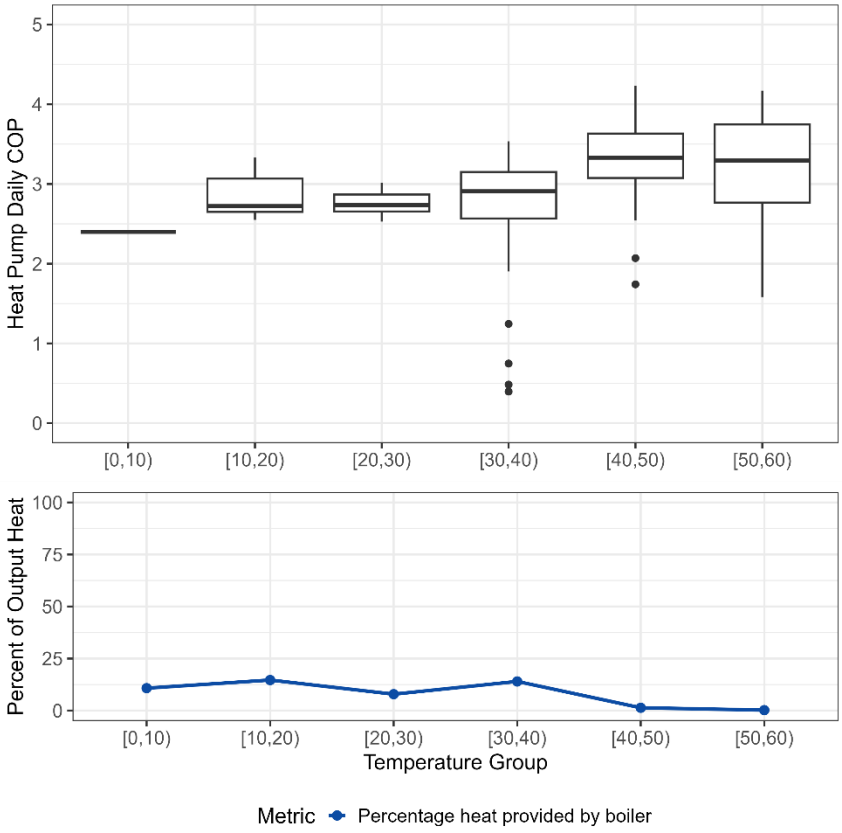
was set to a higher LWT at the coldest outdoor temperatures than the combined space and DHW system.

Figure 11: Leaving and returning water temperatures for the AWHP supplying only space heat at Site 1



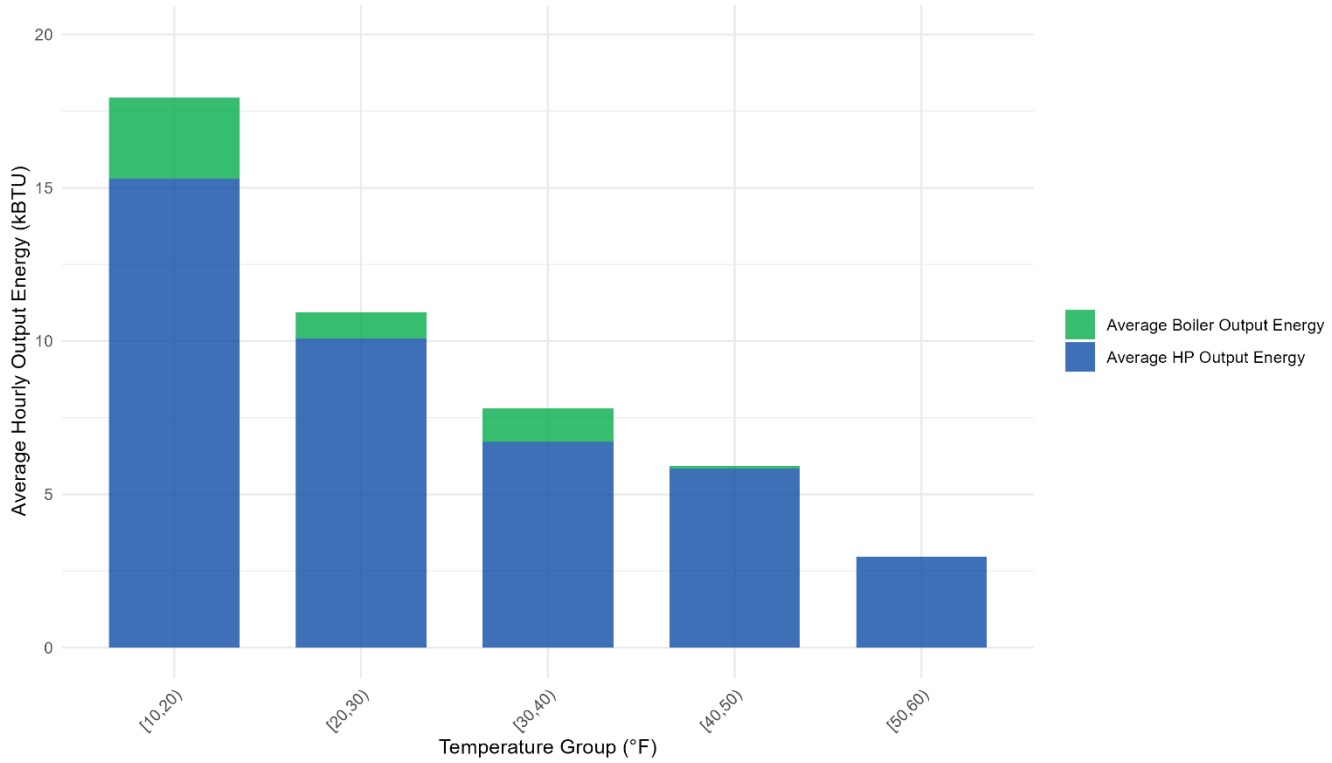
Daily COPs were the highest of the heat pumps monitored in this study and averaged at around 3.0. These increased with increasing outdoor temperature, as seen in Figure 12 below. Boiler contribution decreased with increasing outdoor temperature, remaining below 15 percent of boiler contribution across all temperatures. Like the larger system there was not a boiler time delay set, but unlike the larger system, this system did not depend on boiler heat at moderate temperatures. This indicates that there may have been a backup heat lockout at moderate temperatures set here that the installer did not set for the DHW-serving system.

Figure 12: Heat pump performance and boiler contribution per outdoor temperature for smaller Site 1 AWHP



The average hourly output energy for the space heat-only system is shown in Figure 13 below. This system was sized to be substantially smaller than the other system at this site, as the other system provides space heat to two apartments and DHW to the whole complex. In reality, the monitored load for these two systems was about equivalent, due to differences in resident DHW consumption and/or space heating behaviors compared to modeled assumptions.

Figure 13: Average hourly output for the AWHP providing just space heat at Site 1



The energy use and economic results above are based on controls that do not cut the heat pump off below a certain outside air temperature. With this site's utility rates and assuming rated boiler efficiency of 95 percent, the economic breakeven COP is 3.8. Based on the heat pump COPs and utility rates in the figures and table above, the building owner would have to switch to a 50ºF switchover temperature for the best operational economics. This building owner was satisfied with how the system was running and opted not to do that, allowing the AWHP to operate year-round going forward, and absorbing operational cost increases.

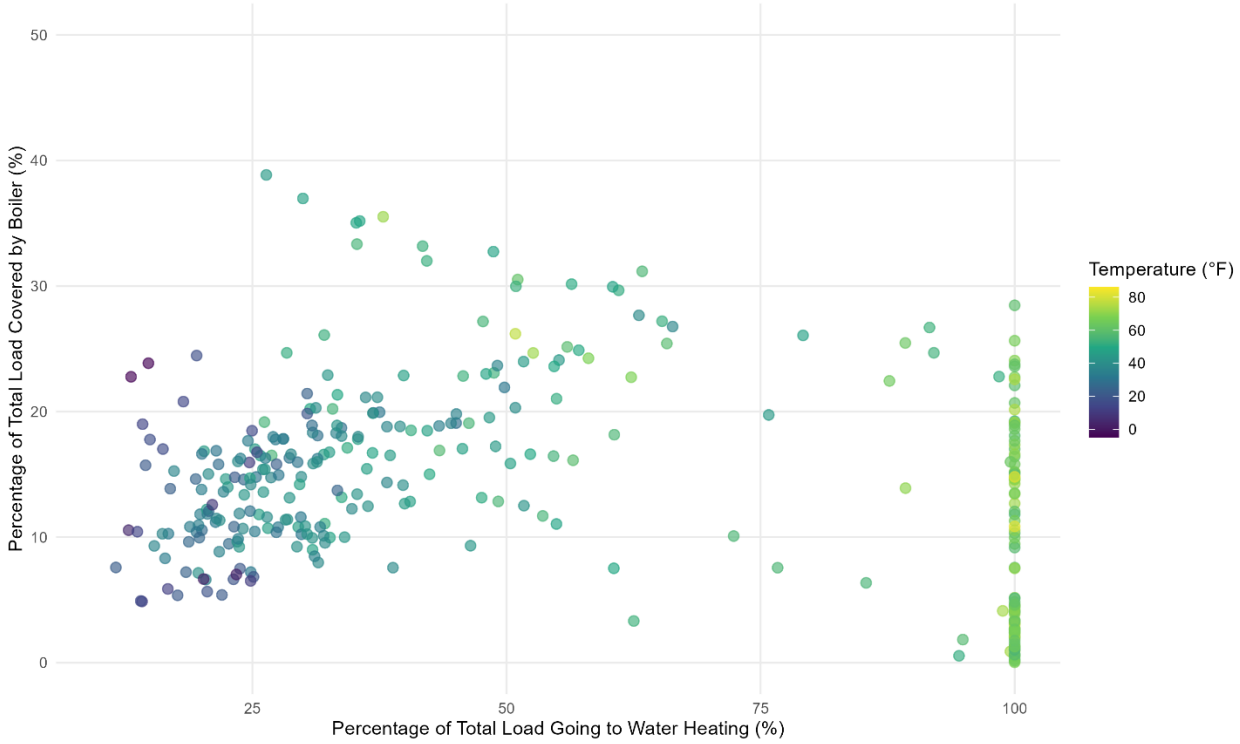
DHW Characterization

There are several dynamics at play between outdoor temperature, water consumption, and backup heating contribution that further affect the ultimate efficiency of the AWHP providing both space heat and DHW at this site. Note that numbers throughout this section are not normalized by water consumption.

Figure 14 shows the portion of total heating load contributed by the boiler compared to the amount of total load (both boiler and AWHP) going to DHW. When the portion of DHW load was higher, due to higher DHW demand and/or lower space heating needs in moderate outdoor temperatures, the boiler tended to contribute a higher percentage of the total load than when space heating took up more of the total load. This demonstrates that the bottleneck in

this system is due to the AWHP not being able to heat at the high required DHW delivered water temperature and/or the boiler helping the AWHP meet small DHW calls before the heat pump could begin steady-state operation, rather than the system being unable to provide the total amount of heat energy for both space heating and water heating on cold days.

Figure 14: Portion of load covered by boiler compared to portion of load comprised by water heating

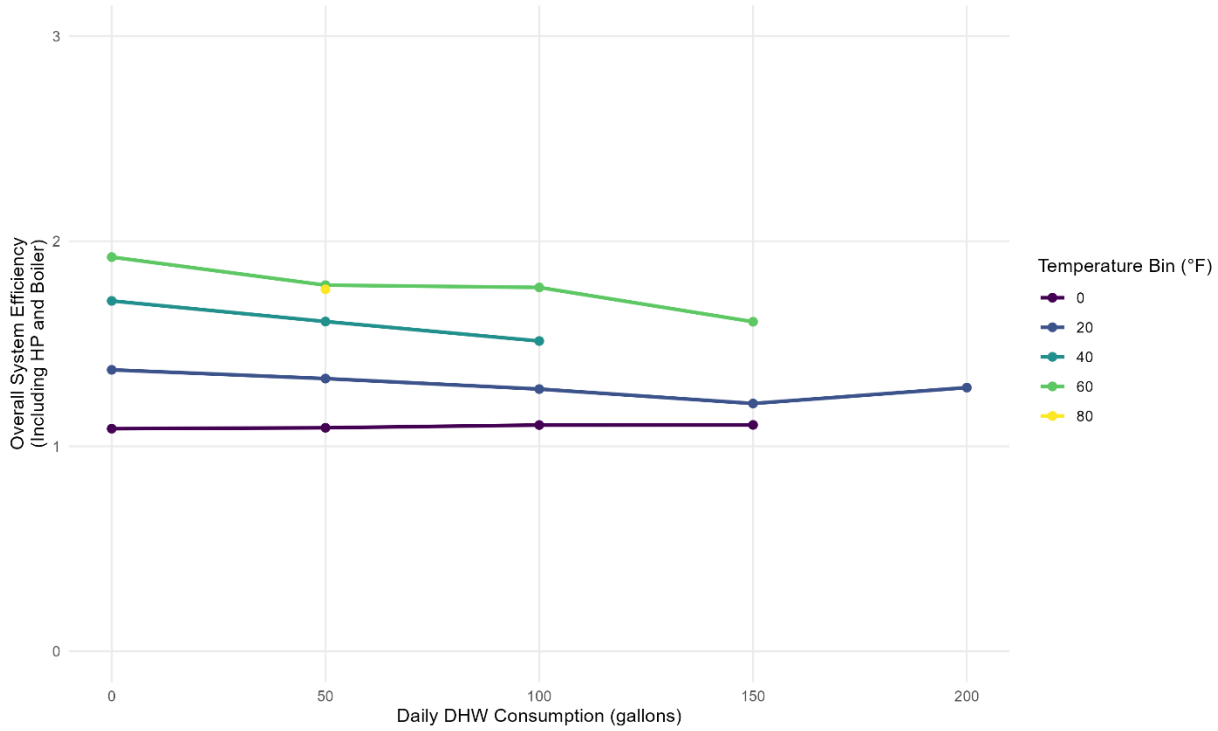


As described in the Site Information, the higher 135°F setpoint in the tank, combined with a mixing valve, increases total water storage capacity in the system and averts the hot water runout issues that were experienced at this site. This is very useful for a site with highly variable consumption (50 to 300 gallons a day) that is often much higher than the water tank volume. However, this higher setpoint likely also triggers more boiler contribution, as the AWHP struggles to raise the water temperature sufficiently. Setting a lower setpoint or increasing the amount of time before the boiler turns on to support the heat pump would decrease this phenomenon, but may risk resident dissatisfaction. If the DHW tank size were increased and the setpoint decreased, that could also improve heat pump efficiencies and decrease boiler contribution.

Figure 15 buckets days into 20 degree temperature bins and 50-gallon hot water consumption bins, combining both the heat pump and boiler contributions. At most outdoor temperatures, DHW heating efficiency decreases as water consumption increases, demonstrating a higher necessary boiler contribution when the tank is depleted more often, and the water returning

from the indirect heat exchanger is at a lower temperature. At the lowest outdoor temperatures, however, system efficiency remains flat at slightly above 1.0 across consumption levels, meaning that the heat pump compressor is unable to heat even a smaller amount of returning water to setpoint without significant boiler assistance.

Figure 15: DHW system efficiency compared to DHW consumption at various outdoor temperatures



Site 2: Single-Family Retrofit #1

Site Information

Existing System:

- 9 kW electric boiler serving five radiant in-floor space heating zones.
- One separate 80-gallon electric water heater.
- Two window air conditioning units for cooling.

Post-Retrofit System:

- One 2.5-ton monobloc AWHP with a new integrated 9 kW electric boiler as part of an IDU serving space heat.
- One 65-gallon indirect water heater.
- No buffer tanks in the system.
- Cooling is unchanged.

Post-Retrofit System Controls:

- AWHP operation is triggered by a heat call by the radiant space heating system or the DHW system.
- The boiler “tops off” the system if the water passing through the IDU is not at the necessary delivered water temperature.
  The system cannot provide space heating and domestic hot water heating at the same time. DHW heat calls are prioritized when both uses require heat at the same time.

Contractor Experience Level: Prior experience with heat pump hydronic systems (>20 geothermal installations). Same contractor as Site 1.

Number of Troubleshooting Callbacks: 4

Figure 16: Site 2 prior boiler serving space heating, AWHP ODU and IDU installed, and indirect water heater.



Figure 17: System diagram at Site 2

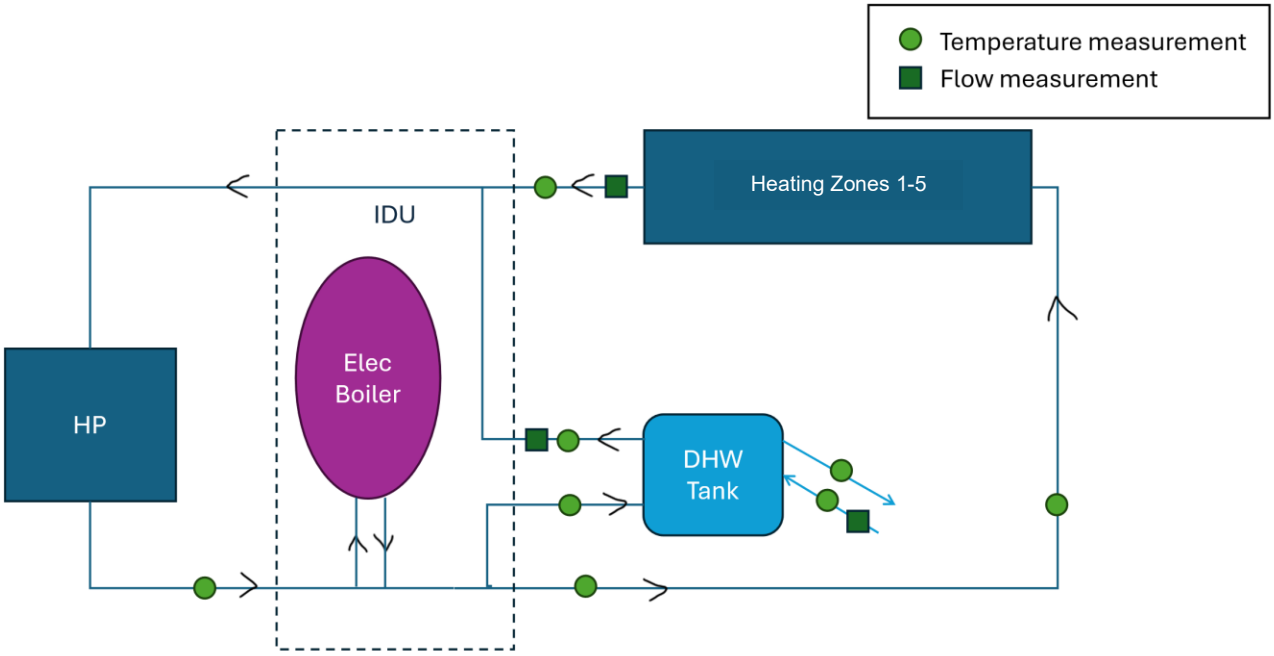


Table 6: Site 2 additional site details

Electric Utility	Gas Utility	Home Size	Monitored Design Load at -2°F	Installation Costs	Incentives Provided[12]
Xcel Energy	N/A; all-electric	1,600 sqft	18kBTU	$43,856	$43,856

Installation and Troubleshooting

Like Site 1, the installation at this site went smoothly. The system was re-piped as needed with an integrated electric boiler, DHW controls, and variable speed pumping integrated into the heat pump IDU. An outdoor reset curve was successfully set for space heating. Since this installer had recently raised the DHW tank temperature at Site 1 after runout complaints, Site 2 was similarly set to a DHW tank temperature of 135°F with a mixing valve lowering delivered water to 120°F. Decreasing this DHW tank temperature could decrease backup energy consumption without impacting resident satisfaction at this site, as described below.

[12] The total retrofit costs for this site exceeded the available per home incentives, and this customer was unwilling to pay the difference. The incentive cost for this site was expanded to accommodate the installation cost.

The contractor returned to site once shortly after installation to make tweaks to dial in the system controls. Based on error codes on the AWHP, the resident and the contractor coordinated two additional software-related return visits.

In October 2025, this site began operating only in electric resistance. The research team flagged this behavior. When available, the contractor visited the site and determined there had been a refrigerant leak in the outdoor unit. This was fixed in December 2025.

Similar to Site 1, these service visits highlight the importance of resident engagement. This resident was able to identify two needed contractor return visits by checking error controls on the AWHP, but did not notice the decreased AWHP runtime or increased electric bills caused by boiler-only operation.

Installer Experience

The installer brought substantial experience to this installation, including the Site 1 installation. From an installation standpoint, the installer described this site as fairly normal, and in some respects, simpler than a typical hydronic retrofit since the IDU arrived with pumps, control valves, and backup heat integration already built in. The installer noted that completing the multifamily site AWHP installation gave his team useful experience going into this installation.

On the support and training side, the installer felt well-prepared going in, crediting the manufacturer's requirement that dealer-direct contractors complete a three-day training program before being authorized to purchase and install the equipment. The main support the installer needed during the project involved the control module (the connectivity/app component of the AWHP), which required a new interface and app update. Since installation, the site required about four return visits, outlined above; the installer considered this a normal number of return visits for this type of system.

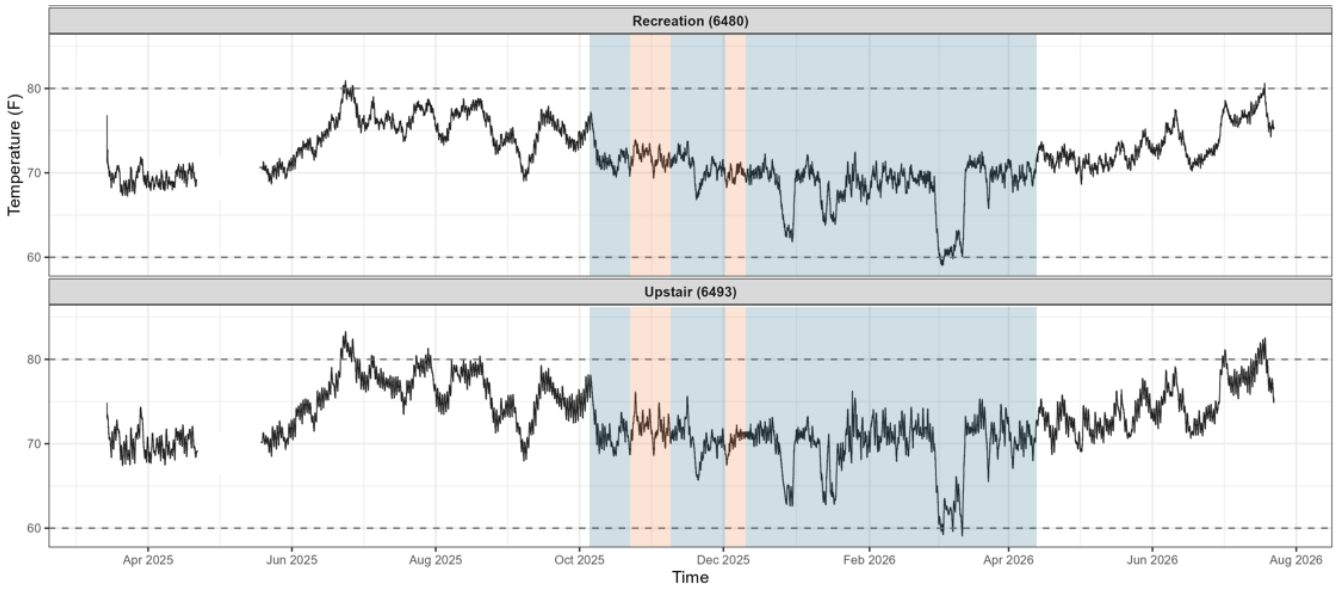
Homeowner Experience

The homeowner indicated high satisfaction with their AWHP system, rating it a five out of five, citing benefits such as energy efficiency, lower electric bills, and comfort. The homeowner also noted a positive overall impression on seasonal performance, reporting no problem keeping up on very cold days outside of the time when refrigerant was leaking. Comfort-wise, the homeowner states that there are no cold spots due to the in-floor radiant heat, no drafts with temperatures holding reliably at setpoint, and no hot water run-outs. The homeowner estimated a $20-30/month bill savings in the summer, and $40-50/month bill savings in winter compared to prior years.

As shown in Figure 18, monitored indoor temperatures remained around 70°F throughout most of the heating season, both during the backup-only periods and with the AWHP system. There

are a few dips in monitored indoor temperatures down to around 60°F in January and March. The cause of this dip (and whether they were intentional) is unknown.

Figure 18: Monitored indoor temperatures at Site 2, heating season in blue, backup-only periods in orange



Energy Use and Efficiency

The annual energy and cost impacts of the retrofit at Site 2 are shown in Table 7. As energy consumption also varies with resident hot water demand, these values are normalized to the site's monitored average daily hot water consumption of 13 gallons per day. This site experienced energy savings of 20 MMBTU per year. With an electric baseline (as opposed to gas), all efficiency increases were translated to cost savings, with about $525 saved annually. However, this would not be enough to pay back retrofit installation costs over the system's lifetime. These dollar savings would have been higher if the site were not on an electric heating rate in both the pre- and post-retrofit periods.

Table 7: Site 2 weather-normalized baseline and post-retrofit energy use and cost

	Electricity	Natural Gas	Net Energy	Estimated Annual Costs
Unit costs	$0.09/kWh (space heating rate)	NA	NA	NA
Pre-retrofit Use (Baseline)	14,599 kWh	NA	50 MMBTU	$1,314
Post-retrofit Use	8,787 kWh	NA	30 MMBTU	$791
Impact	**-5,812 kWh**	**NA**	**-20 MMBTU 40 percent**	**-$523**

Figure 19 depicts the monitored LWT curve across outdoor temperature for space heating in blue and the average heat pump-supplied DHW temperature in green. Similar to Site 1, the constant ~120°F DHW supply water demonstrates that the boiler consistently topped off delivered hot water to reach setpoint. The temperature differential between supply and return water is about equal for both uses at this site.

Figure 19: Leaving and returning water temperatures for Site 2

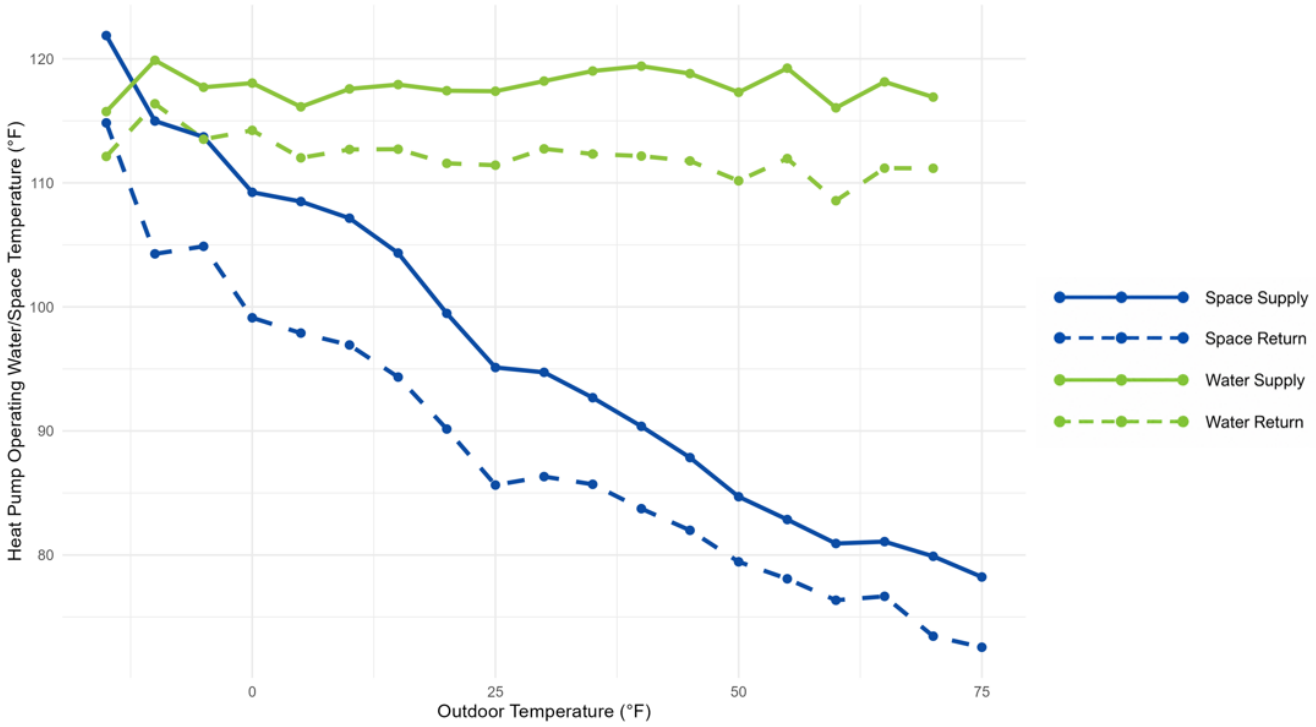


Figure 20 shows the AWHP's COP by type of heating and outdoor temperature. Similar to Site 1, both water and space heating COPs correlated positively with outdoor air temperature. Space heating COPs were significantly higher than water heating COPs on average, at least partially due to the high setpoint temperature of the DHW tank. There were lower overall COPs in the summer, when space heating was not needed; daily summer COPs averaged around 1.0, and winter COPs averaged around 2.5.

Figure 20: Hourly HP COP per outdoor temperature for larger Site 1 AWHP, for space versus water heating

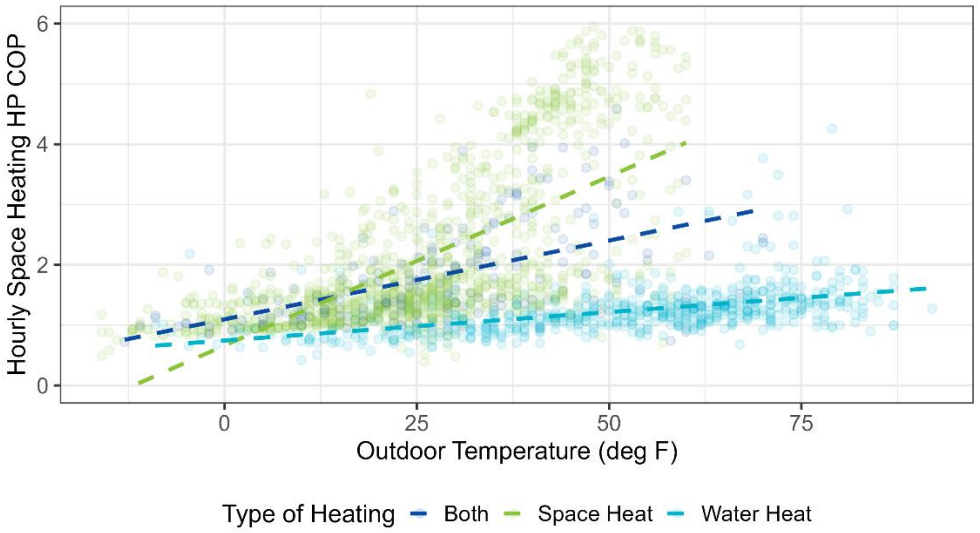
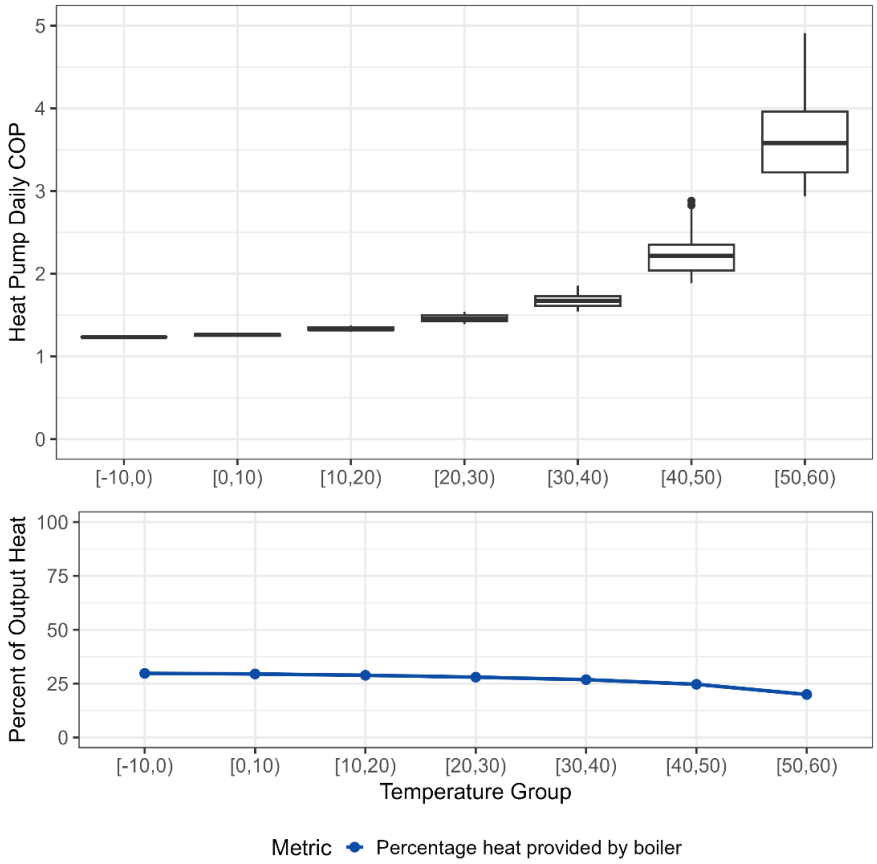


Figure 21 shows a box and whiskers plot of the daily average COPs of the heat pump (including both space and normalized water heating) and the percentage of energy output provided by backup heat per outdoor temperature group. Daily heat pump COP ranged from 1.2 at the coldest temperatures to 5.0 at moderate temperatures. Electric boiler contribution decreased with increasing outdoor temperature, but less dramatically than at Site 1, indicating that the boiler played a more constant role in DHW heating, perhaps due to the smaller AWHP size. On average when normalized, the integrated electric boiler provided around 25 percent of site heating load.

Figure 21: Heat pump performance and boiler contribution per outdoor temperature for Site 2



The research team ran a linear model to of supply water temperature and outdoor temperature versus COP. Similar to Site 1, all terms are very significant, with the impact of a lower supply temperature being slightly higher than the impact of a higher outdoor temperature per degree change.

$$lm(COP \sim outdoor\ temperature + LWT)$$

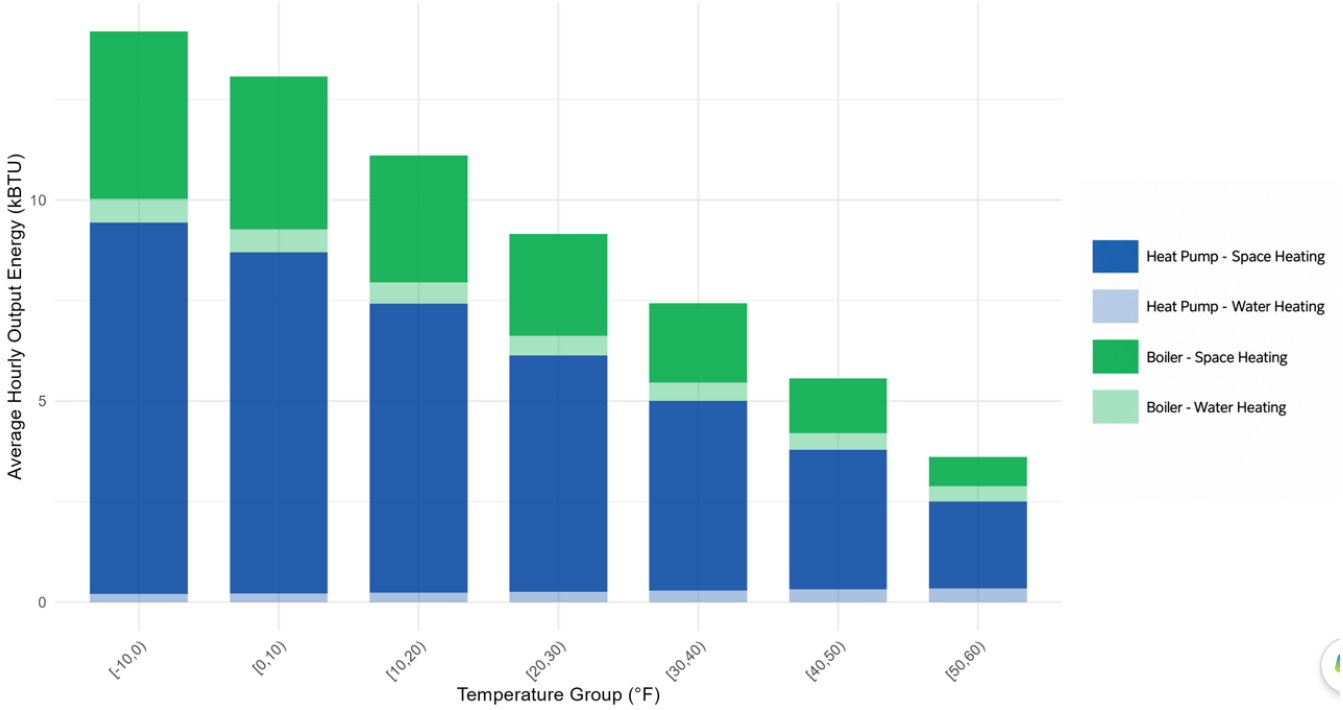
Table 8: Model of outdoor temperature versus supply temperature for DHW and space heat AWHP at Site 1

Variable	Value	p Value
Intercept	6.154	<2e-16
Outdoor Temperature	0.014	<2e-16
Supply Water Temperature	-0.046	<2e-16

The relative loads for this AWHP can be seen in Figure 22. The AWHP provided the majority of the space heating load. The boiler provided the majority of DHW load at all temperatures, with heat pump contribution increasing only slightly at more moderate outdoor temperatures. The space heating output of both the AWHP and the boiler increases at colder temperatures. The boiler provides a significant amount of the space heating load all the way up to 60°F, due to

the lack of timer delay at this site. Similar to Site 1, as the AWHP was ramping up, the boiler would come on to supply the targeted temperature in the meantime, and then ramp down once the AWHP reached the temperature.

Figure 22: Average hourly output for Site 2

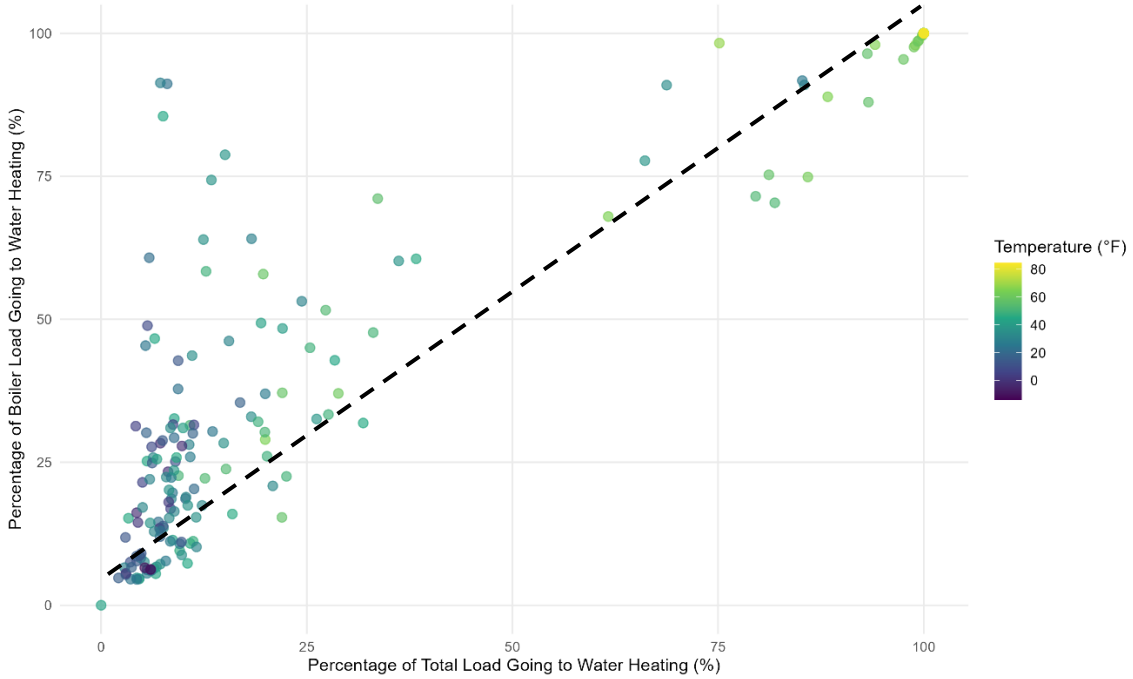


DHW Characterization

The DHW tank at this site was set to the same 135°F setpoint as Site 1. However, unlike Site 1, the 65-gallon DHW tank at this site is oversized for this site's hot water needs, with relatively uniform consumption around 13 gallons per day and on only one day during the study period was the tank depleted.

Additionally, the AWHP at this site was half the size of the DHW AWHP at Site 1, with half the compressor power available to raise returning water to the high DHW setpoint. This resulted in an even more substantial boiler contribution to water heating. Figure 23 shows the amount of boiler load versus total load that went towards DHW. Almost all points are on the left side of the diagonal line, meaning that the electric boiler was disproportionately serving the water heating load across all temperatures. Note that the axes on this graph are slightly different than those used in the Site 1 DHW Characterization. The daily numbers on this graph are not normalized by water consumption.

Figure 23: Percentage of total versus boiler load going to DHW



Together, the low DHW consumption levels and high DHW component of boiler load at Site 2 indicate that the higher setpoint temperature, set out of caution by the installer to increase DHW thermal storage, was likely not necessary. The setpoint could be decreased, or the time before the backup boiler activates increased, to enable the AWHP to carry more DHW load more efficiently.

Site 3: Single-Family Retrofit #2

Site Information

Existing System:

- One natural gas boiler serving six radiant in-floor space heating zones and one 80-gallon indirect water heater.
  Ducted split-system air conditioning for cooling.

Post-Retrofit System:

- One 4.5-ton monobloc AWHP without a separate IDU. The existing gas boiler provides backup space heating and all DHW.
- Space cooling through AWHP into existing ducting and a new air handler unit.
  The heat pump loop (with glycol) is separated from the heat distribution loop (without glycol). The heat pump loop has a 14-gallon direct buffer tank in the loop to increase water volume, and the two loops are separated with a 40-gallon indirect buffer tank for heat exchange and storage.

Post-Retrofit System Controls:

- AWHP operation is triggered by the temperature of the buffer tank, and a relay to the boiler has it kick in after 15 minutes if the temperature demand has not been met.
- The boiler heats to DHW setpoint upon DHW calls, and space heat setpoint otherwise. Relays prevent the boiler from supplying heat to the radiant zones when heating DHW.

Contractor Experience Level: No prior experience with hydronic heat pump systems.

Number of Troubleshooting Callbacks: 9

Figure 24: Site 3 prior boiler and AWHP installed, buffer tank, and post-retrofit boiler



Figure 25: Final system diagram at Site 3 (after fixes)

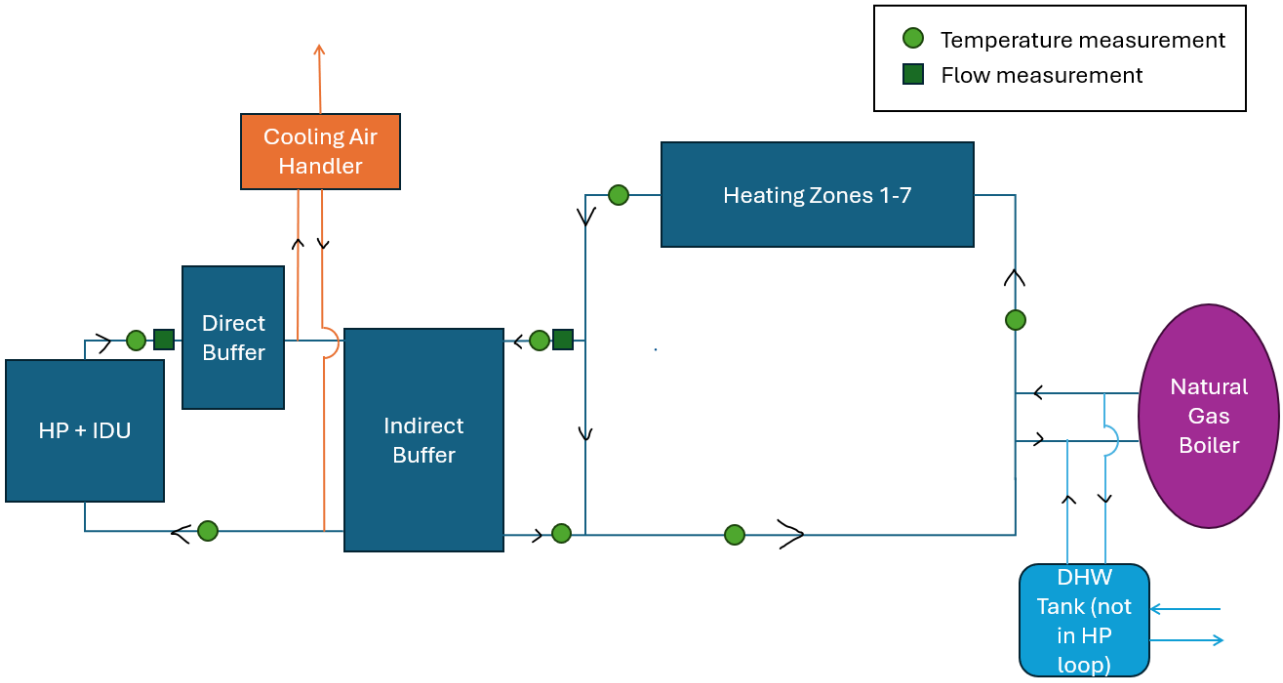


Table 9: Site 3 additional site details

Electric Utility	Gas Utility	Home Size	Monitored Design Load at -4°F	Installation Costs	Incentives Provided
Alliant Energy	Alliant Energy	1,900 sqft	13kBTU	$41,900	$41,900

Installation and Troubleshooting

Site 3 experienced a significant number of installation issues due to an inexperienced contractor who did not receive early design support. Instead of requesting support beforehand, the installer thought it would be sufficient to bring the regional product distributor to the installation with them for assistance. At that time, materials had already been purchased and only minimal design changes could be made. There were several system revisions and callbacks, summarized in this section; the full troubleshooting timeline for this site is provided in Appendix C.

At first, the boiler remained within the primary heating loop, as the installer wanted to avoid re-piping the previous system and minimize system control alterations. This required the heat pump to heat the indirect buffer tank to the 135ºF DHW tank temperature at all times, leading to a major degradation of space heating efficiency, with the system operating below a COP of 1.0 the majority of the time.

The installer returned to the site to improve the system configuration. The boiler was re-piped to a secondary loop to allow for separate DHW heating, with the heat pump no longer supplying any DHW heating. This meant, however, that the system (originally sized for both space and DHW) was very oversized for what it ultimately heated. Additionally, a Wi-Fi-enabled standalone controller was installed on the buffer tank, allowing for improved AWHP zoning and controls. This setup delivered some efficiency gains for heating. However, the boiler and its pumps remained controlled by a series of improvised “relay in a box” devices, a cause of confusion and a likely cause of continued performance issues.

During the first post-retrofit cooling season, the system operated at very low efficiency and with poor dehumidification. The research team determined that the heat exchanger in the buffer tank was too small to properly cool by reviewing monitoring data. When the installer went on-site to fix this issue, the heat pump control board “fried,” and became unresponsive. A few weeks later, the installer returned with the distributor and manufacturer to install a new control board and configure both the control board and the standalone controller. However, they determined it was not feasible to redo the boiler integration controls, which remained suboptimal. At this time, it was also determined that the volume of water-glycol mixture in the heat pump loop was lower than the minimum system volume specified by the manufacturer. The contractor had not known there was a minimum system volume. The manufacturer suggested adding a small direct buffer tank to remedy the situation, which the installer implemented a few weeks later.

The following cooling season, the LWTs in the system were too high to effectively dehumidify. After correspondence with the distributor and a visit to the site, the installer determined that the controls had reset to Celsius and reset the controls (likely due to a power outage). However, the drainage pan was cracked, and the resident had to mop condensate until the installer could return for this additional fix. The AWHP is now satisfactorily cooling the home, but there is very little monitored data at warm temperatures, so cooling efficiencies are not reported here.

The space heat zones in this system remain controlled by manual mixing valves from the pre-retrofit system, which are set to supply a constant water temperature that can adequately heat the relevant zone at design temperature. Because of this, the manufacturer recommended that the buffer tank remain at a constant temperature of 105°F (with the boiler receiving a call for heat when this temperature dips). The system is thus unable to significantly benefit from outdoor reset LWT controls, and efficiency gains at warmer temperatures are primarily due to typical heat pump dynamics (i.e. more heat in the outdoor air makes for more efficient heat transfer from that air), rather than the added LWT dynamic referenced throughout this report.

Installer Experience

The interviewed Site 3 installer had substantial experience with conventional boilers and air-source heat pumps, but no prior experience installing hydronic heat pump systems; he reported that knowing about these two similar system types transferred reasonably well to the individual components of the AWHP system, but not to their integration. The installer described the AWHP equipment itself as high quality but said the overall experience was a "nightmare" because of the complexity of the system and the level of support required. The installation took substantially more effort than a typical boiler replacement, with many subsequent site visits for troubleshooting and adjustment. At these later troubleshooting visits, he reported that the distributor and manufacturer ultimately provided important troubleshooting assistance.

Several of the installation difficulties were associated with insufficient early design and training support. The installer became involved only shortly before installation, after the original installer responsible for the project had left the company, and had not participated in the initial site visit or design process. Much of the system information was provided through printed materials, and the installer reported that the training he accessed focused more on what could be sold than on the technical details required to install and commission the system.

The installer identified the controls as an area where additional hands-on training would have been valuable. Although the installation manual was reasonably useful, he described that it provided information without clearly guiding the installer through the system configuration.

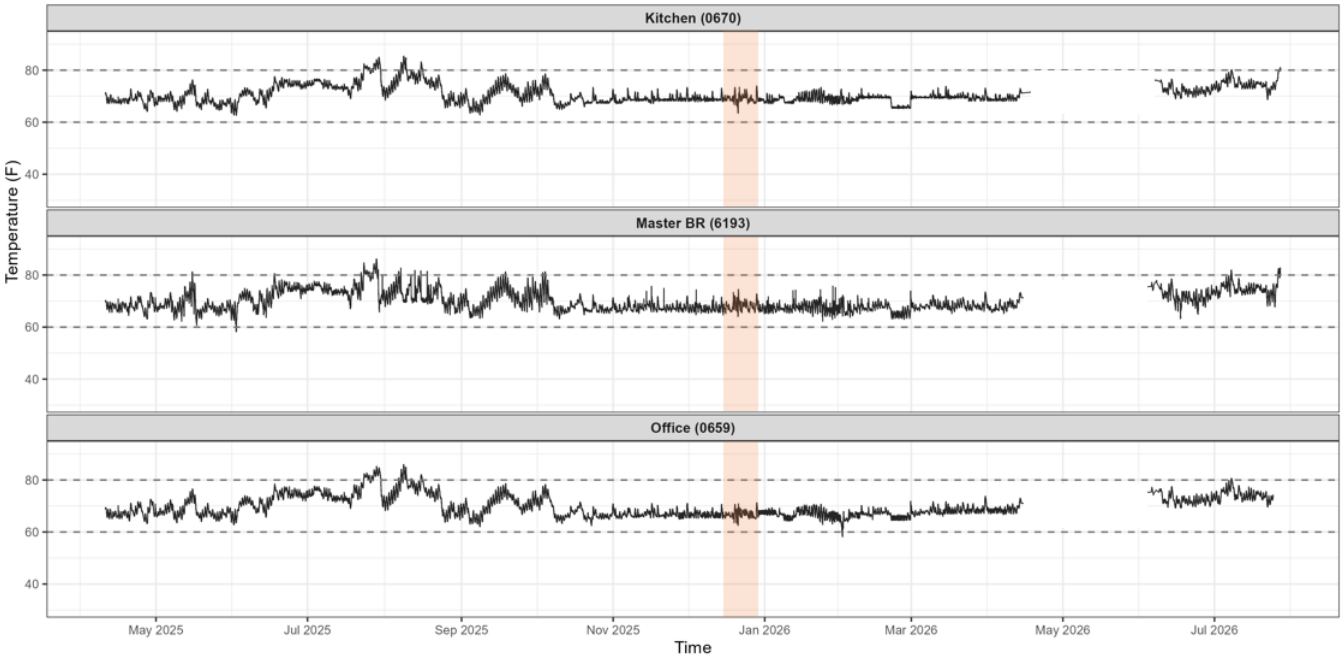
Despite these challenges, the installer reported that his understanding of AWHP installation improved substantially through the project and indicated that a similar installation could be completed much more effectively in the future. He estimated that a comparable system could ultimately require approximately three days for two skilled installers, compared with the substantially longer duration and repeated callbacks experienced at this site. The installer remained supportive of AWHP technology in principle, but considered this particular application a poor fit because of the interaction between the DHW-based sizing and existing distribution controls.

Homeowner Experience

In the final interview, the Site 3 resident rated overall satisfaction as 3 out of 5, describing the system as functional but not sufficiently straightforward or reliable to recommend to others. In particular, he said that he found it difficult to understand the system's operation and controls; the thermostat itself functioned normally, but the underlying system controls caused confusion, especially after multiple system fixes. He expects to rely on the installer for future controls adjustments. The resident also questioned the value proposition of an expensive system that still requires a gas boiler for backup and increases overall utility costs.

The resident described winter thermal comfort as generally good, with no major temperature swings. Summer/cooling performance, especially dehumidification, was a significant source of dissatisfaction. Although the home uses cooling relatively infrequently, these limitations were noticeable when returning home and turning the system on after being away. At the time of the interview, the resident indicated that cooling had improved after the most recent site visits, but remained an important consideration in his overall assessment. These trends are visible in the monitored indoor temperature measurements in Figure 26, where temperatures are consistent throughout the winter during both baseline and AWHP system time periods, but jump higher than 80°F at points during the summer months.

Figure 26: Monitored indoor temperatures at Site 3, backup-only period in orange



Energy Use and Efficiency

The weather-normalized heating energy use and cost impact of the ultimate AWHP system is shown in Table 10. Marginal energy was saved by the system, and costs increased by around $370 annually. The AWHP displaced 35 percent of annual boiler gas usage. This is substantially less than the planned 100 percent heating displacement, despite the system's annual heating load being less than assumed during system sizing. This discrepancy is likely a symptom of the backup integration controls issues described above.

Table 10: Site 3 weather-normalized baseline and post-retrofit energy use and cost

	Electricity	Natural Gas	Net Energy	Estimated Annual Costs
Unit costs	$0.17/kWh	$1.07/therm		
Pre-retrofit Use (Baseline)	NA	353 therms	35 MMBTU	$951
Post-retrofit Use	2,956 kWh	228 therms	33 MMBTU	$1,584
Impact	**+2,956 kWh**	**-125 therms**	**-2 MMBTU 6 percent**	**+$369**

Figure 27 shows a box and whiskers plot of the daily average COPs of the heat pump per outdoor temperature group. Below, the percentage of space heating provided by backup heat and the percentage of heat lost in the distribution loop (i.e., buffer tanks) are given per outdoor temperature group. Distribution heat loss was calculated by subtracting the heat delivered across the heating zones from the total heat delivered by the heat pump into the distribution system.

Heat pump COPs rarely exceeded 2.0 and hovered below 1.0 at temperatures lower than 20ºF. Backup heat consistently provided the bulk of system heat, even though the heat pump was likely oversized for the heating load. The system did not experience substantial buffer tank losses, further indicating that suboptimal performance stemmed from overreliance on backup heat caused by suboptimal controls.

With this site's utility rates and the observed boiler efficiency of 75 percent, the breakeven COP is 3.4. The heat pump at this site never performed above this efficiency, and thus there is not a switchover temperature that would break even with the pre-retrofit system under current system configurations. However, a switchover of 42ºF was set at the end of the study period to improve system economics.

Figure 27: Heat pump performance and boiler contribution per outdoor temperature for Site 3

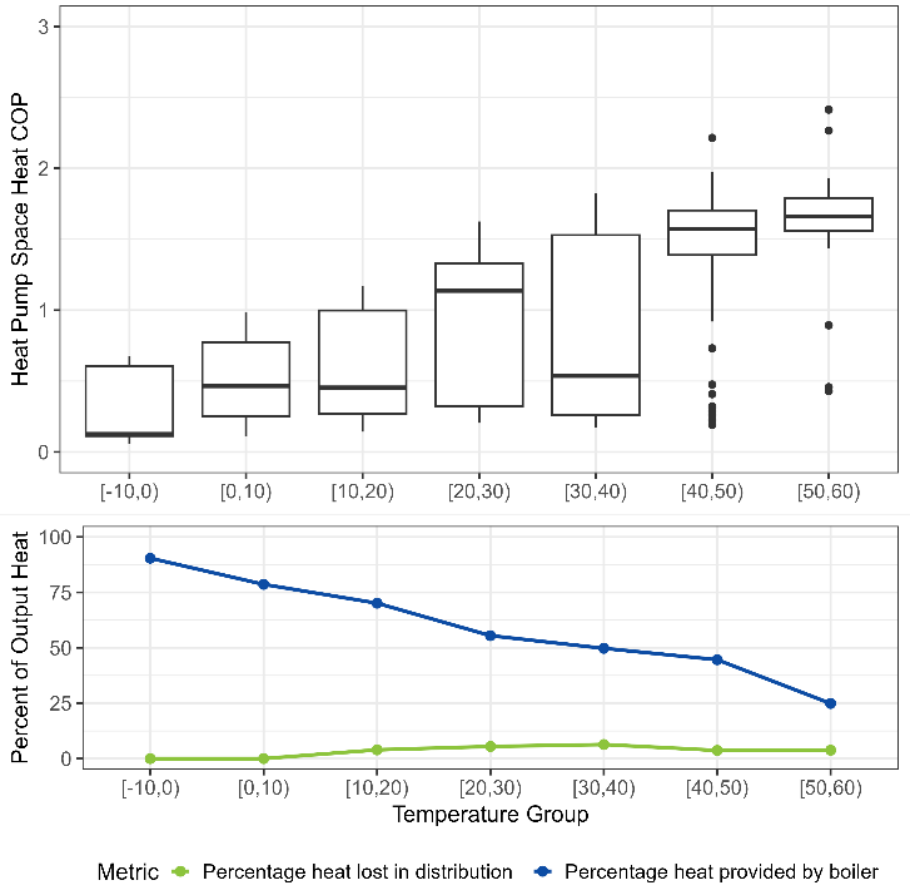
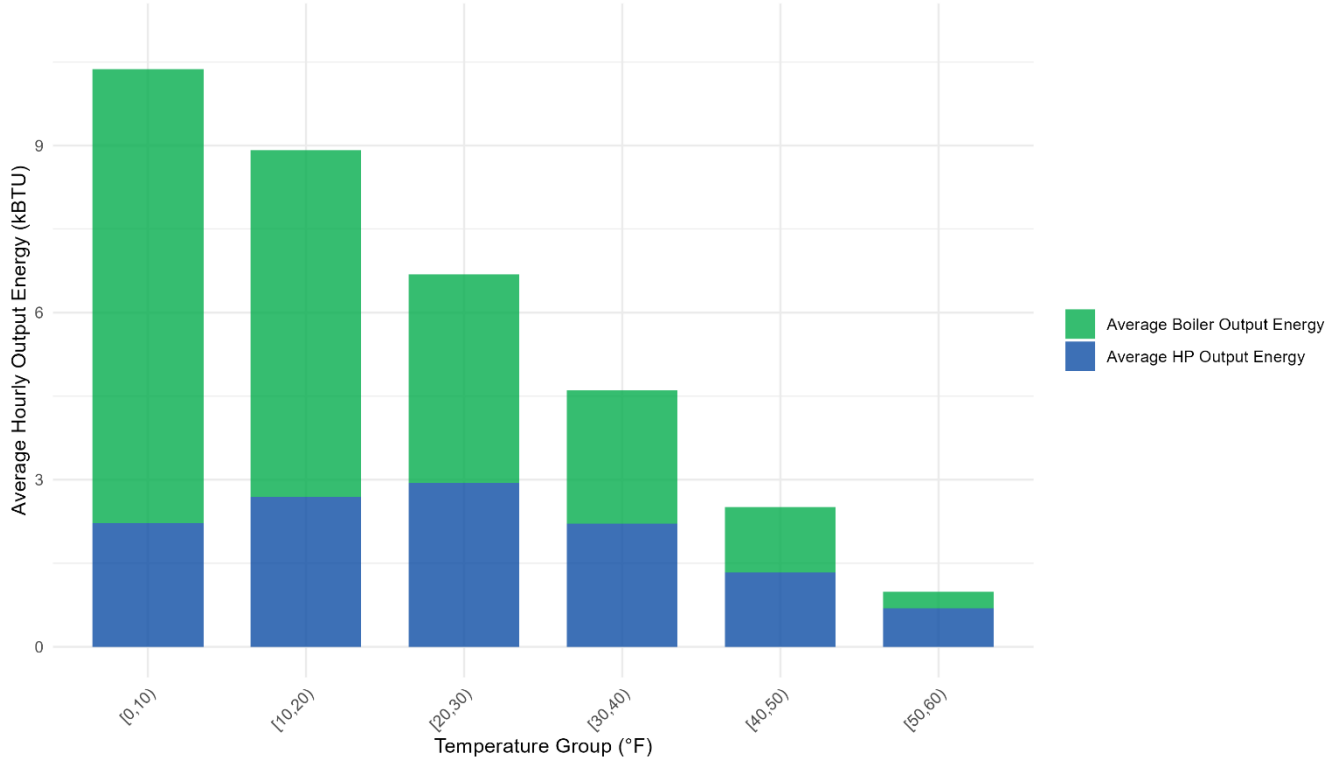


Figure 28 shows the relative loads for this AWHP. The boiler provided the majority of load at all temperatures, with heat pump contribution decreasing at the lowest temperatures despite it being oversized for the space heating load.

Figure 28: Average hourly output for Site 3



Site 4: Single-Family New Construction

Site Information

Installed System:

- A 4.25-ton monobloc AWHP with a 15 kW integrated electric boiler; no separate IDU.
- System includes a 55-gallon buffer tank and serves a single zone in-floor radiant heating loop on the lower floor.
- Three fan-coil units upstairs for cooling.

Installed System Controls:

- AWHP operation is triggered by the temperature of the buffer tank, and the boiler kicks in after 45 minutes if the temperature demand has not been met.

Contractor Experience Level: No prior experience with hydronic heat pump systems.

Number of Troubleshooting Callbacks: 0 – the homeowner diagnosed two controls issues with the manufacturer remotely.

Figure 29: Site 4 equipment



Figure 30: System diagram at Site 4

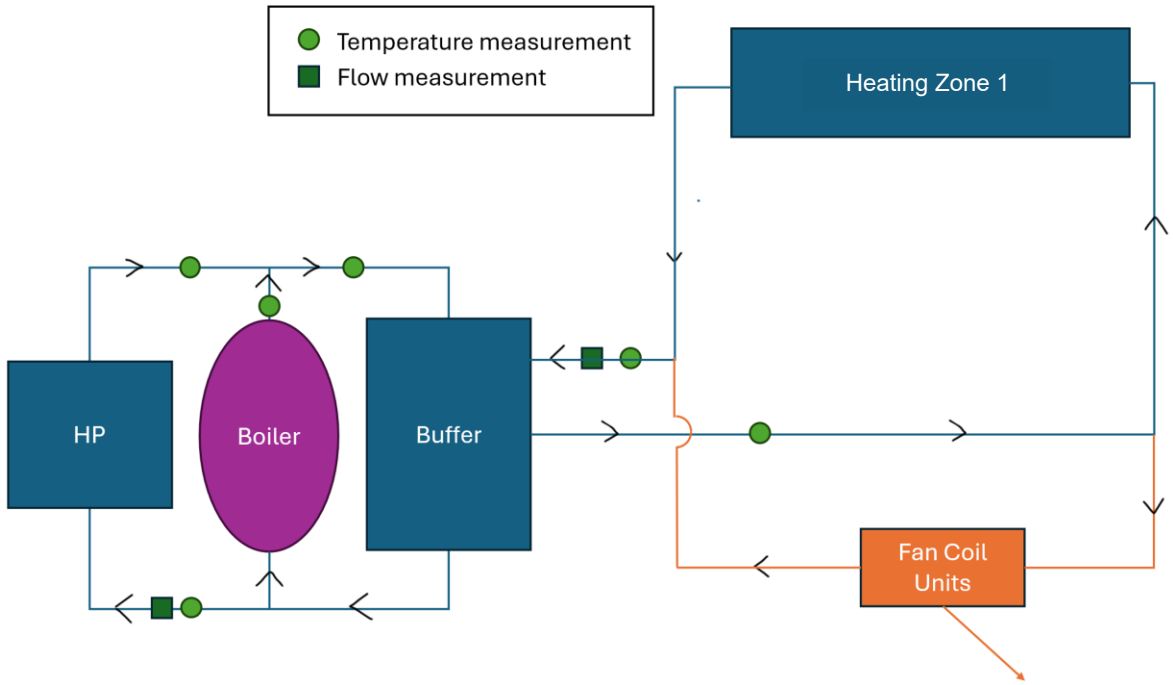


Table 11: Site 4 additional site details

Electric Utility	Gas Utility	Home Size	Monitored Design Load at -13°F	Installation Costs	Incentives Provided
Xcel Energy	N/A; all electric	2,392 sqft	25kBTU	$13,440[13]	$ 8,373

Installation and Troubleshooting

The manufacturer provided materials on system design, and since this was new construction, the system could be installed exactly as specified. Installation went relatively smoothly at this site, though it took longer than expected. Because of the installer's lack of familiarity with the controls for the system, once the heat pump control system connected to Wi-Fi, the manufacturer offered to remotely access these controls and bring the system up to operation, which the installer indicated worked well.

The site did not have any comfort issues during the cooling season.

[13] Cost for new construction is cost of heat pump materials to contractor. The new construction scoping was unable to break out distribution system installation costs.

When the heating season began, the homeowner noticed the backup boiler was not activating. They met remotely with the manufacturer and were able to diagnose a loose thermostat wire that prevented a signal from reaching the electric boiler. The manufacturer walked the homeowner through removing a jumper on the electric boiler, which resolved the issue.

Mid-winter, the research team notified the homeowner that the outdoor reset controls did not appear to be functioning. In February 2026, the homeowner and manufacturer worked together to successfully implement these controls, and performance improved.

Installer Experience

This installer had no prior experience with GSHP or AWHP installations, noting that this job was more advanced than a typical job for their team. The most difficult part was the control wiring and sequencing (making sure components energized in the correct order), while the piping itself was straightforward and comparable to a normal boiler installation. The installer noted that space was the most limiting factor that shared the overall design, though the building plans proved spot on.

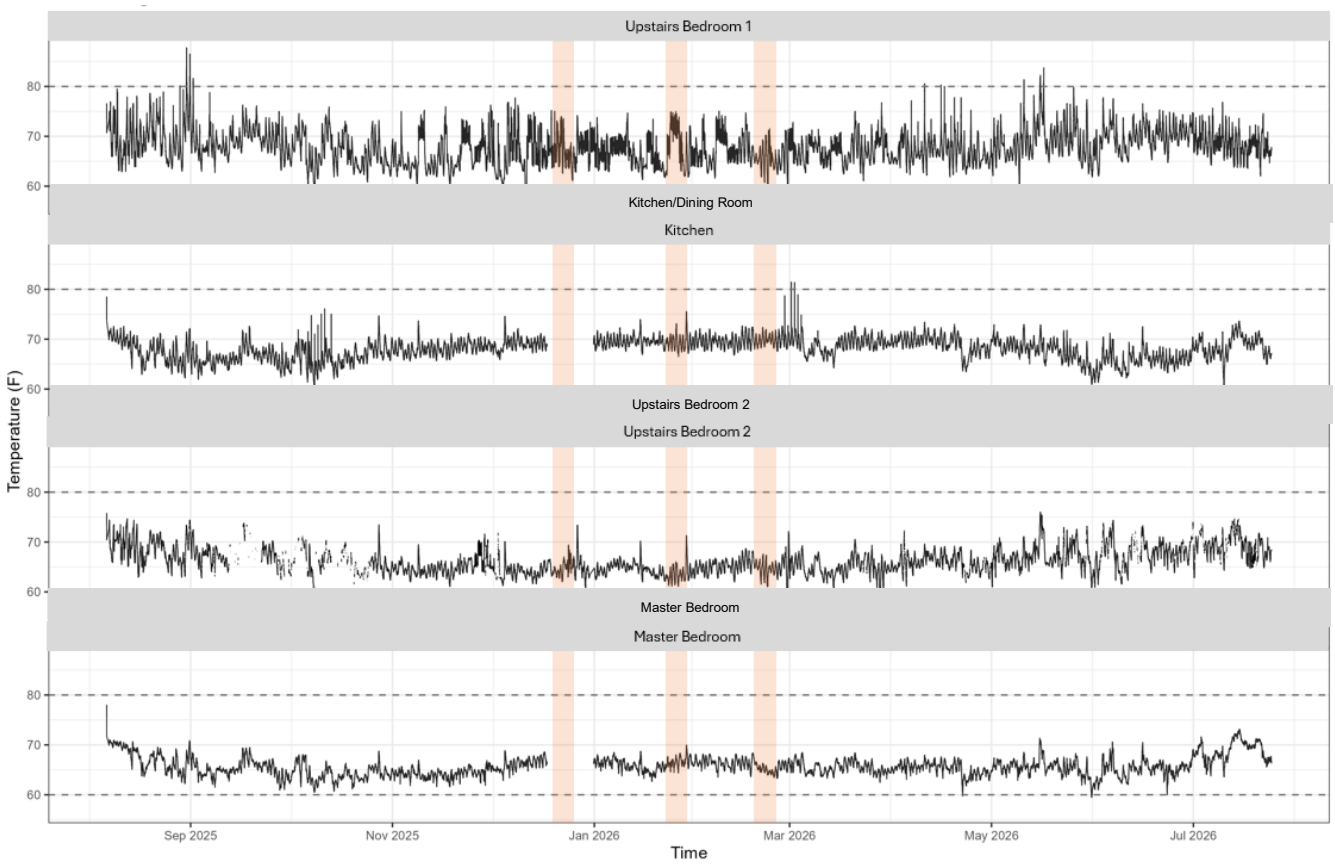
The installer did not complete any training prior to this installation, and integrating the buffer tank with the ODU was a new experience for them. Despite that, the job took 12 hours start to finish, matching the estimated time exactly. The manufacturer was helpful with troubleshooting throughout this time. The installer noted that their original outreach to the manufacturer had resulted in little information on unit specifications, but once the equipment arrived on site and installation was underway, the manufacturer was much more responsive.

Homeowner Experieince

The homeowners reported that at first they had a general frustration with the AWHP controls as they learned how the system worked. Once past the initial adjustment period, however, the homeowners reported feeling confident in operating the thermostat and controls day to day. The homeowner rated their overall satisfaction between four and five out of five. They noted that the air didn’t feel as dry as it does with forced air systems, and in the summer, the home stayed cool and comfortable without feeling humid or sticky.

The homeowners described the indoor temperature as generally very reliable, responsive, and quick to adjust to temperature change. They stated they were never uncomfortable, even during very cold and very hot conditions. In Figure 31, as at all other sites, there is no discernable difference in thermal comfort in the times with the system operating with the baseline system (boiler-only) versus the AWHP system. The homeowners did describe minor warming in the afternoon on the west side of the house due to direct sun exposure, which is visible in the top row of the figure.

Figure 31: Monitored indoor temperatures at Site 4, backup-only period in orange.



Energy Use and Efficiency

The heating energy and cost differences between the boiler-only baseline periods and the full AWHP system are shown in Table 12. This site had the most favorable economic outcomes and the most favorable energy savings outcomes due to a combination of an electric boiler baseline, high system efficiency, and a regular electric rate (i.e., not a discounted electric space heating rate, as no electric heating rate was available in this region).

Table 12: Site 4 weather-normalized baseline and post-retrofit energy use and cost

	Electricity	Natural Gas	Net Energy	Estimated Annual Costs
Unit costs	$0.15/kWh	NA		
Electric Boiler Use(Baseline)	16,223 kWh	NA	55 MMBTU	$2,770
AWHP System Use	7,578 kWh	NA	26 MMBTU	$1,240
Impact	**-8,645 kWh**	**NA**	**-29 MMBTU 53 percent**	**-$1,530**

Figure 32 shows the monitored LWT for space heating at Site 4. The blue line shows the originally-commissioned constant delivered water temperature, and the green line shows the ultimate outdoor reset curve. Cooling supply and return temperatures are visible in the bottom right. The differential between supply and return temperatures was the highest at this site.

Figure 32: Leaving and returning water temperatures at Site 4, with and without outdoor reset applied

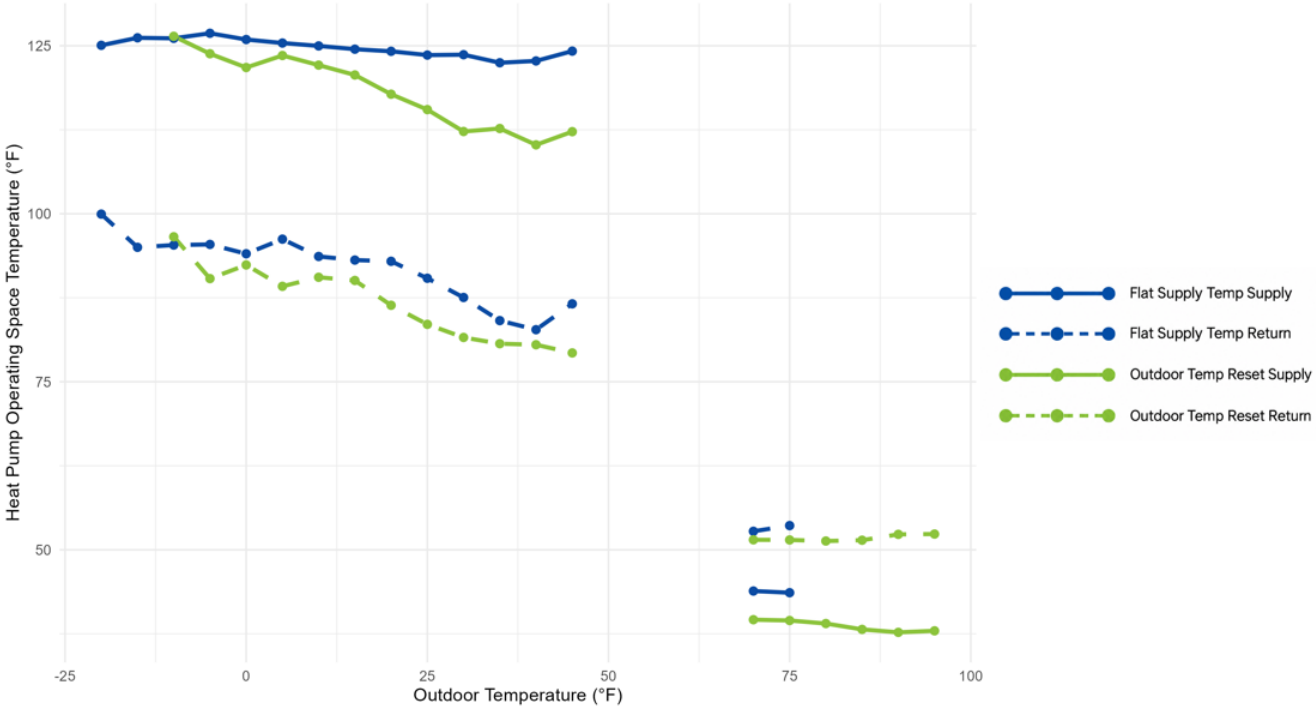
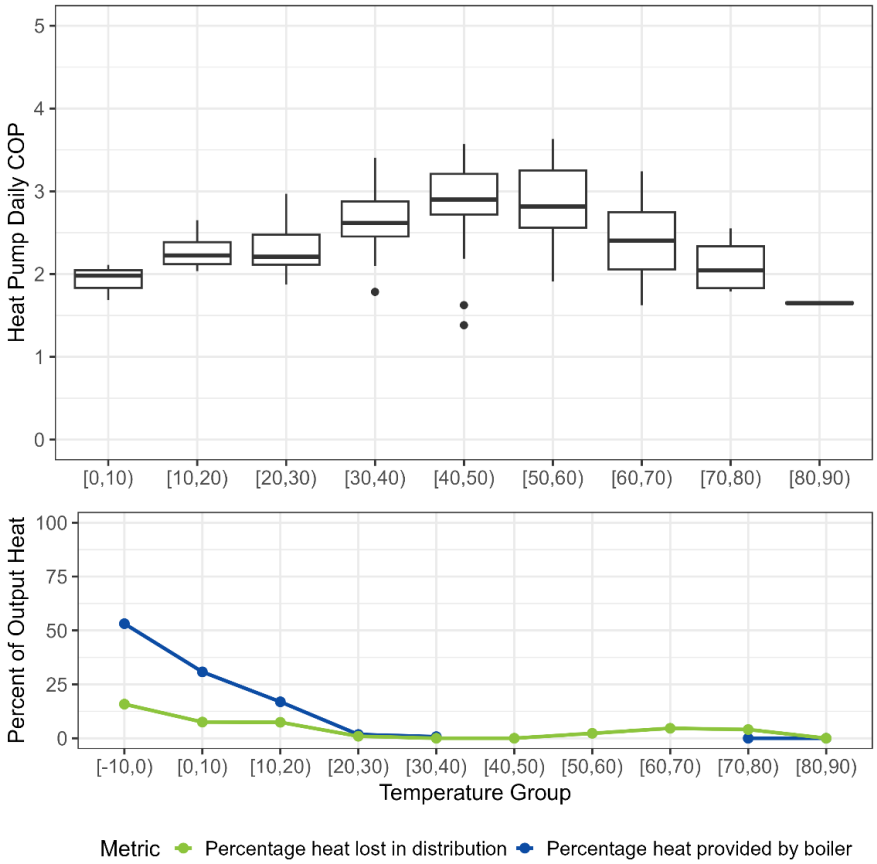


Figure 33 shows a box and whiskers plot of daily average COPs of the heat pump, the percentage of space heating provided by backup heat, and the percentage of heat loss in the distribution loop (i.e., buffer tank) per outdoor temperature group. Distribution heat loss was calculated by subtracting the heat delivered across the heating zones from the total heat delivered by the heat pump into the distribution system.

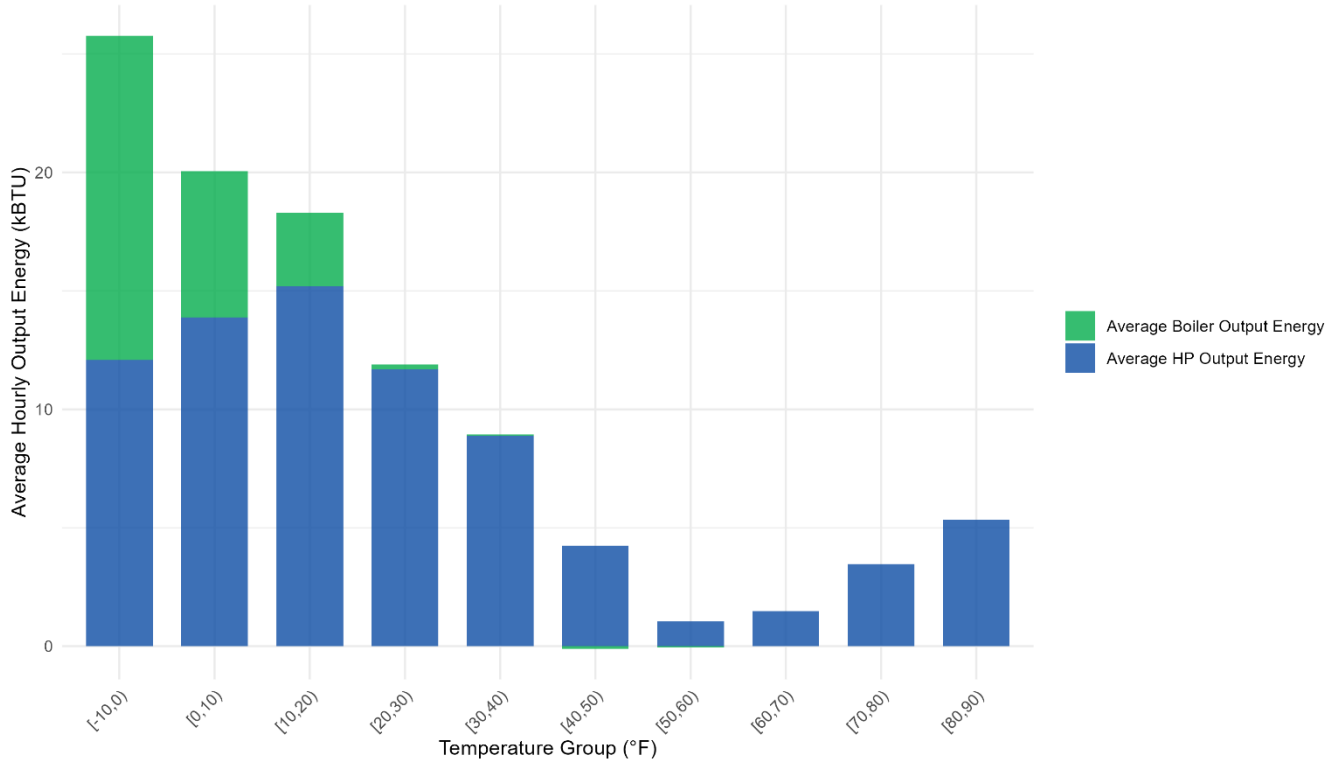
COPs at this site remained between 2.0 and 3.0 most days, increasing slightly with outdoor air temperature for space heating up to 60ºF and decreasing slightly for space cooling above 60ºF. Due to the timer on the boiler controls, this site was the least reliant than the others on backup heating at moderate temperatures, though electric backup heat provided 50 percent of heat output below 0ºF. Daily heat losses from the buffer tank ranged from zero to 10 percent.

Figure 33: Heat pump performance and boiler contribution per outdoor temperature for Site 4



The average loads that the boiler and heat pump carried at this site at each outdoor temperature bucket are shown in Figure 34. Below 10ºF, the heat pump contribution decreases with temperature, as the AWHP requires backup assistance to meet the required LWT.

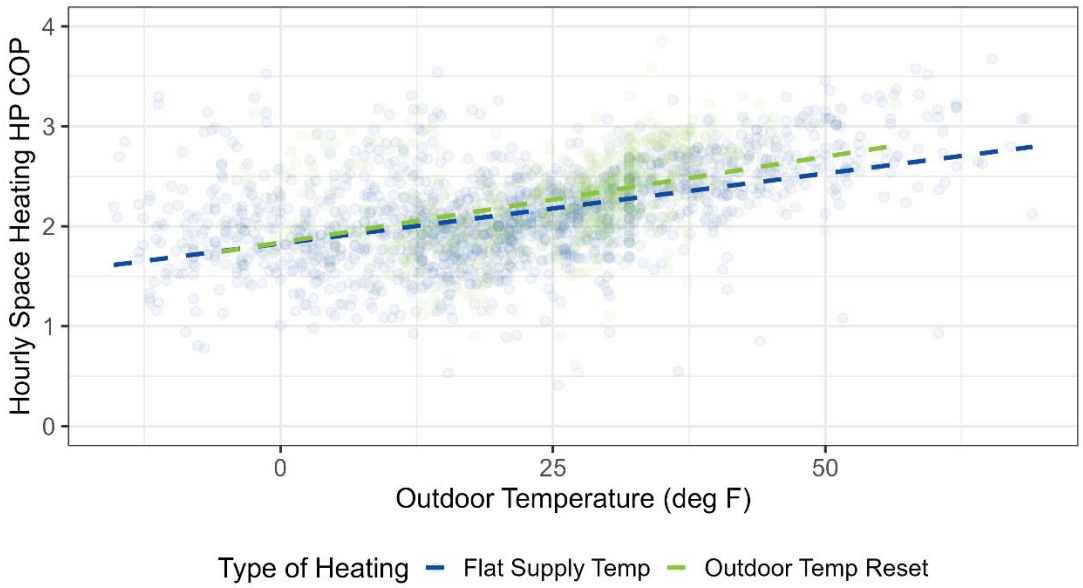
Figure 34: Average hourly output at Site 4



Impact of LWT Outdoor Reset

The fix of the LWT controls partway through the post-retrofit period provides a case-study of the impact of these controls on heat pump efficiency across outdoor temperatures. Figure 35 plots hourly space heating COPs as they were originally configured, and as they were configured during the second half of the heating season. The linear models for these conditions are almost exactly aligned at low outdoor temperatures, when maximum LWT is needed. However, the benefit of the outdoor reset controls can be seen during moderate shoulder season temperatures as the LWT outdoor reset modulates downward, with a 0.25 increase in COP at 50ºF.

Figure 35: Site 4 space heating COPs with and without outdoor temperature LWT reset



Similar to the models done for Site 1 and Site 2, the change in outdoor reset controls at this site allowed the research team to model the impact of leaving water temperature versus outdoor temperature on COP for heating. Outputs are shown in Table 13. The same effect can be seen as in the figure above, with decreasing lower water temperature increasing the efficiency of the heat pump. The magnitude of these effects per temperature change are about equal in this model.

$$lm(COP \sim outdoor\ temperature + LWT)$$

Table 13: Model of outdoor temperature versus supply temperature for DHW and space heat AWHP at Site 1

Variable	Value	p Value
Intercept	3.425	<2e-16
Outdoor Temperature	0.013	<2e-16
Supply Water Temperature	-0.013	<2e-16

Energy Use, Efficiency, and Cost Summary of All Sites

The site-by-site performance results presented above are collated in Table 14 to facilitate comparison across sites and highlight broader trends in system performance, energy savings, costs, and sizing.

Table 14: Summarized site information

	1: MF Retro		2: SF Retro #1	3: SF Retro #2	4: SF New
	AWHP 1	AWHP 2			
AWHP Loads	Space heat and DHW	Space heat only	Space heat and DHW	Space heating and cooling (modeled load assumed DHW, but ultimate system was just space heat)	Space heating and cooling
AWHP Size (Tons)	5.5	2.5	2.5	5	4.5
Space Heat COP @ 40°F	2.9	3.1	3.2	1.1	2.7
DHW COP @ 40°F	1.5	N/A	1.2	N/A	N/A
Cooling COP @ 70°F	N/A	N/A	N/A	N/A	2.1
Annual MMBTU Savings	60 (48%)		20 (40%)	2 (6%)	29 (53%)
Annual Operating Cost Change	+$797 (72% increase)		–$523 (40% saved)	+$369 (39% increase)	–$1,297 (53% saved)
Installation Cost	$100,871 $13k/ton $30/sqft		$43,856 $18k/ton $27/sqft	$41,900 $8k/ton $22/sqft	$13,440[14] $3k/ton $6/sqft
Monitored Load at Design Temp (kBTU)[15]	21	28	18	13	25
Modeled Load at Design Temp (kBTU)	38	32	31	34	No modeling, as contractor sized AWHP to estimated load of new home

[14] Cost for new construction is cost of heat pump materials to contractor. This unit was installed as part of a larger system installation

[15] For sites with both space heat and DHW (Site 1 and Site 2), this load calculation includes both end uses, with DHW normalized to average consumption.

With the exception of Site 3 (with its design flaws detailed in the previous section), improved efficiency levels in the post-retrofit period led to annual energy savings of 40 to 53 percent. Space heating COPs were about 3.0 at 40ºF, and were higher than DHW COPs, which hovered between 1.0 and 1.5.

Sites with a gas baseline experienced increased utility cost because of the fuel spark gap in Wisconsin, with natural gas being nearly five times cheaper than electricity per unit of energy. Sites with an electric resistance baseline are saving money on utility bills, with greater annual savings at the new construction site with the higher electricity rate.

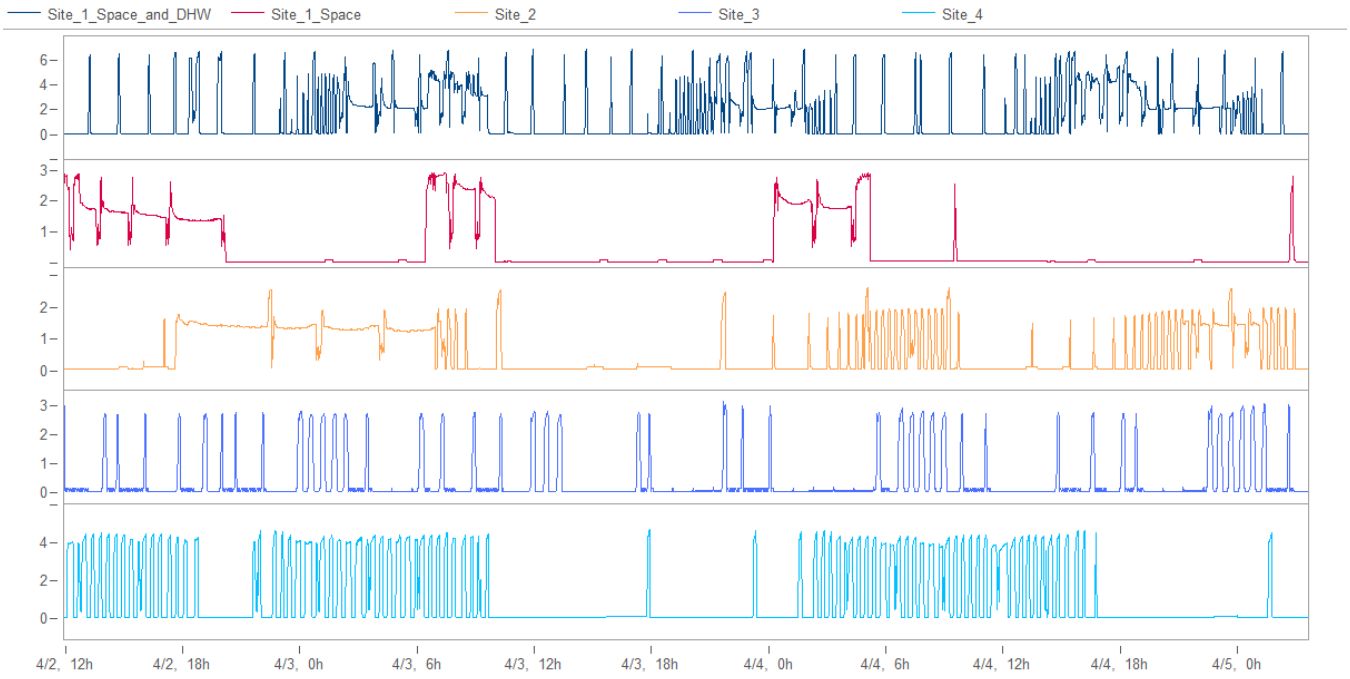
The reported new construction installation costs appears the lowest in the table. However, this datapoint only includes the cost of the heat pump itself, and therefore is lower than the true cost of the system, as the contractor was unable to separate the cost of the distribution system installation from other construction work on the new home. For the retrofit sites, installed costs are more consistent when given per square foot of the building (ranging from $22 to $30) than when given per ton of the installed system (ranging from $8,000 to $18,000).

Typical power cycling behaviors for each site are shown in Figure 37 for a set of days with temperatures in the mid-30s to mid-40s. Comparing this figure to the system sizes and monitored loads in the table above provides insight into the relative sizing of each AWHP.

The space heat only system at Site 1 was the heat pump able to maintain the longest cycle times, an indicator of satisfactory system sizing. This aligns with the fact that the monitored load of this site was the closest to its modeled/expected load. The space heat and DHW system at Site 1 and the system at Site 2 both had higher modeled/expected loads than monitored, and may have been able to be installed at a smaller size for this partial displacement context.[16] However, these systems maintained long cycle times for space heat much of the time, with most cycling occurring during DHW calls. A timer on the boiler for DHW calls could decrease this cycling, as described in the site-specific sections above. Site 3 and Site 4 appear oversized for their monitored loads, with constant cycling at mild temperatures. These were the sites with the lowest space heating COPs, but Site 4 was able to reach much more satisfactory COPs than Site 3. Recall that Site 3 was designed for DHW and space heating, and only ended up providing space heating, with a monitored load almost three times lower than expected. This, alongside the controls issues described in the previous section, likely contributed to the suboptimal performance at this site.

[16] Modeled loads were based off of pre-period utility bill data. Overestimated modeled loads indicate that modeled assumptions for the pre-period boiler and distribution systems were more efficient than in reality, that modeled assumptions for AWHP distribution efficiency were less efficient than reality, that space heating or DHW resident behavior changed post-retrofit, and/or that a relevant home characteristic was not correctly captured in the home walkthrough or model assumptions.

Figure 37: Timeseries showing typical power usage patterns of each AWHP (in kW)



The following section draws on these findings, as well as installer and resident experiences, to identify overarching conclusions and recommendations.

KEY FINDINGS AND RECOMMENDATIONS

This section synthesizes key findings and recommendations across four major themes: installation and design, controls, maintenance and troubleshooting, and economics and resident priorities.

Installation and Design

Finding: HVAC contractors in Wisconsin are unfamiliar with AWHP technology, but some are open to offering and installing them.
More than thirty installers were contacted during installer recruitment. Many HVAC installers expressed interest in the study, but had difficulty identifying relevant retrofit candidates, indicating low levels of AWHP system knowledge.

> **Recommendation: Expand contractor-focused AWHP training programs.**
> AWHP focused training should share guidance on characteristics that make a building a good fit for AWHP installation, along with hydronic system fundamentals and AWHP-specific design and control strategies. As detailed below, the importance of manufacturer and/or designer support should be emphasized.

Finding: AWHP installations were more seamless when installers had access to significant design and troubleshooting support or had experience with hydronic heat pump systems

Inexperienced installers were more successful when engaging manufacturer design support before system installation. Site 4 (single family new construction) demonstrates the value of early system design support – the inexperienced installer was able to lean on the manufacturer to optimize system controls and think through AWHP-specific nuances prior to installation and during commissioning. In contrast, at Site 3 (single family retrofit #2), a less experienced contractor who didn't have initial design support returned nine times over 18 months to re-pipe the system and adjust controls. Despite repeated revisions and input from the manufacturer, distributor, and research team, the system was never fully optimized.

> **Recommendation: Require installer training and design/commissioning support as conditions for future AWHP incentives.**
> Programs should require installers receiving incentives to complete AWHP-specific training. Manufacturer or qualified system designer involvement also should be required during system design, especially for less experienced installers. Program administrators could establish a tiered approach in which contractors with demonstrated AWHP experience have streamlined requirements, while first-time or inexperienced installers receive additional design review and commissioning support.

Finding: New construction installations were more streamlined, while retrofit installations were more complex, presenting a greater risk of suboptimal performance.

The new construction AWHP at Site 4 (single family new construction) saved design and troubleshooting time and expense compared to retrofit sites, resulting in 53 percent energy savings. Retrofits to boiler-based systems require integration with distribution systems originally designed around high, fixed-temperature boiler operation, presenting a myriad of choices surrounding distribution system modifications.

> **Recommendation: Prioritize new construction and electric boiler replacements as near-term AWHP deployment opportunities.**
> Disseminating results from these "easy win" deployments can increase contractor and customer awareness of and familiarity with AWHP technology. This could boost installer interest and lower both actual and perceived installation risk, which is often a contributor to high installation costs.

Finding: Successful retrofits carefully assessed heating loads and existing hydronic components, re-piped the mechanical room as necessary, and installed new variable-

speed pumping and controls to balance the system, for more than 40 percent energy savings.

The experienced contractor at Site 1 (multifamily retrofit) and Site 2 (single family retrofit #1) made the necessary informed changes to the existing distribution system, with satisfactory results. In contrast, the less experienced contractor at Site 3 (single family retrofit #2) was not aware of these best practices and attempted to integrate new equipment with existing components through improvised staging controls to save on costs. This led to AWHP performance issues and extensive troubleshooting.

> **Recommendation: Establish retrofit design requirements for existing hydronic systems.**
>
> Future programmatic best practice resources should include protocols for assessing building heating loads and existing emitters, evaluating whether existing piping and pumps are appropriate for lower-temperature AWHP operation, determining when re-piping or hydraulic separation is needed, and selecting appropriate variable-speed pumping and controls.

Finding: DHW system sizing and setpoints can materially affect AWHP performance. The AWHPs providing both DHW and space heating were less efficient for DHW, with an average DHW COP of 1.2 to 1.5, compared to space heating COPs around 3.0.

Site 1 (multifamily retrofit) has a water tank significantly smaller than what residents consume on high hot water consumption days. After Site 1 residents complained about hot water runouts, the contractor increased the DHW setpoint to 135°F, enabling a greater thermal capacity for the tank, but increasing the temperature lift required from the system and thus decreasing AWHP efficiency and increasing boiler heating contribution. The contractor set this same setpoint at Site 2 (single family retrofit #1), despite the water consumption of the site being significantly lower and the AWHP compressor being half the size of Site 1. The boiler contribution to DHW heating load at this site was even more significant due to these DHW contributions, and likely needlessly so.

> **Recommendation: Integrate expected DHW consumption, tank sizing, setpoints, and backup-heating strategy into AWHP system design materials. Emphasize the need for careful thought during the design phase about whether integrated space heat and DHW is the best route forward.**
>
> Training tools and resources should cover the impact of hot water consumption relative to DHW tank size on AWHP performance. To make more informed decisions on tank size, setpoint, and backup heat timer settings, installers would ideally ask a few survey questions and/or assess the base DHW load on summer gas bills to get a sense of DHW consumption before installation of an AWHP that does both space and water heating. Additionally, separate heat pump water heaters should be considered; in some

cases, this could lead to a heat pump with its compressor and controls better targeted to DHW temperature lift requirements. Note that space heat interaction effects due to the HPWH indoor compressor would need to be mitigated in this case, potentially by isolating the HPWH and/or insulating the space heat distribution system piping.

Controls

Finding: Backup boiler controls strongly influenced system performance.
AWHP system controls at sites with substantial energy savings were integrated so the heat pump or standalone controller managed backup operation. These sites performed predictably and allowed the heat pump to lead operation. In contrast, the boiler at Site 3 (single family retrofit #2) was initially piped in series and controlled by relays to its pre-retrofit onboard controller, which increased loop temperatures and led to excessive reliance on backup heating (65 percent of total heat).[17] At Site 4 (single family new construction), a successful backup heat timer was implemented that allowed the heat pump to raise supply temperatures before activating the boiler and for both systems to operate together down to the switchover temperature. At Sites 1 (multifamily retrofit) and 2 (single family retrofit #1), the boiler was not on a timer, contributing to heat at all temperatures at the beginning of the heat pump cycles, which allowed the systems to reach target LWT quickly at all times but decreased overall system efficiency and gas displacement.

> **Recommendation: Design standards should require backup boilers to be controlled through the AWHP's integrated controls or an appropriately designed standalone controller. A timer should be set to delay boiler contribution until after the heat pump has ramped up to full capacity if gas displacement is a priority.**
> A list of acceptable AWHP-compatible controllers or controller types could be included in incentive applications. Future programs should also require documentation of the intended control sequence, including heat-pump-first operation, backup-heat staging, and switchover conditions.

Finding: Appropriate outdoor-reset LWT controls improved AWHP efficiency.
It is important for installers to set an appropriate LWT curve for space heating, with lower LWTs at warmer outdoor temperatures. Lower LWTs result in higher hourly COPs, so a system with a constant maximum LWT operates less efficiently than one with an outdoor reset control. At Site 4 (single family new construction), the system initially operated without effective reset control, and the manufacturer remotely fixed these controls, resulting in improved performance and raising COP during the shoulder season. Modeling conducted for Site 1

[17] In integrating backup heating, related nuances regarding buffer tank settings and system water volume should also be kept in mind. The original Site 3 design did not properly integrate manufacturer requirements for either of these factors.

(multifamily site), Site 2 (single family retrofit #1), and Site 4 quantified the relative impacts of LWT and outdoor temperature on increasing heat pump COP. LWT was significantly related to COP at each site. For sites with the AWHP providing DHW, this finding also highlights the potential benefits of decoupling space heating and DHW, as detailed in previous recommendations, so that the AWHP only operates on this outdoor-reset LWT curve.

> **Recommendation: Require commissioning and verification of appropriate LWT curves.**
> Installers should establish LWT curves that reduce supply temperatures as outdoor temperatures rise and verify their operation during commissioning. Program requirements could include documentation of control settings and functional testing to confirm that the AWHP is not unnecessarily operating at elevated LWTs.

Maintenance and Troubleshooting

Finding: Rapid identification and resolution of operating issues is an important determinant of AWHP performance and customer experience.
Some AWHP issues during this study, such as snow accumulation at Site 1 (multifamily retrofit) and cooling control changes at Site 3 (single family retrofit #2), were relatively straightforward to correct but took substantial time to identify and service. Delays in troubleshooting can extend periods of inefficient operation, increase reliance on backup heat, and create frustration for residents.

> **Recommendation: Future programs should consider combining upfront incentives with a smaller performance-based component tied to verified operation or energy performance.**
> Where practical, projects should collect standardized operating data during an initial post-installation period. This information can be used at the site level to flag underperforming systems, optimize controls, incentivize quick installer troubleshooting, and help residents learn to identify when their system is malfunctioning. At scale, this data would be useful in validating claimed energy savings under TRM equations and characterizing the performance variability associated with equipment sizing, distribution-system design, DHW configuration, and controls. Post-installation data could also inform updates to program training materials and design requirements.

Finding: Resident engagement and remote servicing can lead to quicker issue resolution.
At Site 2 (single family retrofit #1) and Site 4 (single family new construction), controls issues were successfully identified by the resident, who then was able to contact the manufacturer to

remotely reset the system. In some of these cases, error messages sent by the manufacturer prompted residents to reach out.

> **Recommendation: Distribute AWHP resources to residents at the time of installation, and encourage manufacturers to incorporate error codes for abnormal system operation (in addition to full system malfunction).**
> Simple guidance on the basic AWHP controls interface, signs of unusual boiler operation and/or inadequate or excessive heating, and typical DHW recovery expectations can help identify problems earlier and improve resident experience. Residents do not need to understand the underlying hydronics or control logic but could find value in knowing how the system is intended to operate and which symptoms warrant contacting the installer (e.g. higher gas bills and lower electric bills for dual fuel systems, higher electric bills for electric systems, low observed AWHP runtime). Manufacturer error codes could be incorporated to assist residents in identifying these abnormal functions.

Economics and Resident Priorities

Finding: AWHP economic performance depended strongly on electricity and natural gas price differentials.
Compared against electric resistance boilers, the AWHPs provided cost savings of up to $1,300 annually and could recover incremental installation costs under high electricity rates. However, when displacing natural gas systems, operating costs increased by up to $800 annually due to relatively higher electricity prices in the region when compared to gas.

> **Recommendation: Prioritizing deploying AWHPs as electric boiler retrofits or as gas retrofits in utility territories with relative fuel economics more favorable to electricity. In territories with time-of-use electricity rates, encourage AWHP systems with thermal load shifting capabilities.**
> Electric boiler retrofits result in better cost outcomes than gas boiler retrofits within the rate structures seen in this study. Regardless of backup fuel, time-of-use rates that accurately capture the value added by demand-side thermal storage would improve the value proposition of AWHP systems with tank load-shifting capabilities. If deployed at scale, thermal storage (ideally with buffer tanks larger than those used in this pilot) could both lower customer costs and decrease grid peak demand by pre-charging tanks during times of low grid demand (GridWorks 2023).

Finding: AWHP sizing should reflect the customer's priorities; larger heat pump contributions maximize energy benefits but may increase upfront costs.

In dual-fuel systems with rate structures favoring natural gas, there are two system designs that can be considered "optimal." The system configuration with the largest heat pump heating load contribution will generally save the most energy and be the most environmentally beneficial. When energy or environment is the priority, the AWHP should be sized towards the full space heating load. However, residents with economic priorities may want to leverage cheaper gas prices by running only the backup system for space heating at colder outdoor temperatures (where AWHP efficiencies are lower). Preemptively accounting for these economic priorities during system sizing and design is most cost effective.[18] Partial heating displacement design results in a smaller AWHP with less drastic changes to the existing hydronic system, often decreasing costs. It also decreases the risk of issues caused by system oversizing.

> **Recommendation: Establish full and partial space heating displacement design pathways rather than treating one AWHP sizing strategy as universally optimal.** Future program materials and design tools should clearly distinguish between energy-optimized and cost-optimized system configurations. Installers should evaluate building load, utility rates, expected operating costs, and customer priorities before selecting equipment capacity and the desired heat pump contribution. Incentives could be structured to support both pathways while clearly communicating expected tradeoffs.

CONCLUSION

This pilot demonstrates AWHPs can successfully serve in the place of a boiler system in both retrofit and new construction scenarios where the distribution system is set up for a low supply water temperature. Energy savings of more than 40 percent were seen at three of the four pilot sites due to the increased efficiency of the AWHP system compared to baseline. For electric baseline sites, utility costs decreased with this increased efficiency, while gas baseline sites saw increased utility costs due to gas versus electric rate structures in the region.

AWHP performance depends heavily on system design, controls, and access to early and timely technical support. Energy efficiency programs in Wisconsin can accelerate reliable deployment moving forward by pairing upfront incentives with training and best practice guidance, design and commissioning support requirements, and performance monitoring. These measures can reduce installation risk, improve customer experience, and build the installer knowledge base needed to scale AWHP adoption.

[18] There is also flexibility to change backup heat contribution levels after installation through controls alterations (e.g. backup switchover temperature), as done in this pilot.

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APPENDICES

Appendix A: Customer Outreach One-Pager



OPPORTUNITY TO PARTICIPATE

AIR-TO-WATER HEAT PUMP FIELD STUDY

FOCUS ON ENERGY® is conducting a field study to evaluate the performance of air-to-water heat pumps in homes across Wisconsin.

We're looking for owners of single-family homes or multifamily properties in Wisconsin to participate in our study of this next-generation air-to-water heat pump technology, ready to perform in cold Midwest winters.

WHAT IS AN AIR-TO-WATER HEAT PUMP?

An air-to-water heat pump is an electric heating system that pulls heat from the outside air and transfers it to the water pipes that deliver heat to radiators and in-floor radiant systems, doing the work of a boiler or geothermal system. They can operate at up to 500% efficiency and can work in tandem with a backup boiler, saving substantial amounts of energy and potentially reducing energy costs. Air-to-water heat pump systems have been used in Europe for years and are already gaining traction in the Northeast of the U.S.

WHY PARTICIPATE?

Take the opportunity to heat your home with one of the first air-to-water heat pump systems deployed in Wisconsin, paid for in full by Focus on Energy. You will play a crucial role in this field study by giving feedback on your satisfaction with the system and allowing Focus on Energy to monitor the system as it heats your home. By participating, you contribute to advancing the understanding of air-to-water heat pump technology and its applications in Wisconsin's colder climates.

WHO IS FOCUS ON ENERGY?

Focus on Energy partners with Wisconsin's electric and natural gas utilities to provide resources, incentives, and rebates to benefit all Wisconsinites. By eliminating energy waste we reduce the need to purchase coal and natural gas from other states, keeping money in Wisconsin and supporting our energy independence.

focus on energy®
Partnering with Wisconsin utilities

OPPORTUNITY TO PARTICIPATE

Air-to-Water Heat Pump Field Study

Participating homeowner obligations:

- Complete a pre-installation survey to characterize existing equipment and household characteristics.
- Allow Focus on Energy staff to conduct an in-person or virtual walkthrough to verify the air-to-water heat pump will work well in your home.
- Sign a participation agreement with Focus on Energy.
- Allow Focus on Energy to add an air-to-water heat pump to your existing heating distribution system, and potentially make other changes such as replacing radiators.
- Allow Focus on Energy to install monitoring equipment to measure and verify the performance of the water heater for a 6-12 month period after the equipment is operational. Monitoring equipment will be removed after the study.
- Share your experience with the equipment through quarterly check-ins and a closing interview.

Any personally-identifying information will be handled securely. Field study data will be aggregated and anonymized prior to results publication.

Participating sites and customers must meet the following criteria:

- Participant must own the single-family or multifamily building where the heat pump is being installed.
- The building site must receive electricity from a participating Focus on Energy utility.

For either single-family or multifamily retrofit sites, the following are eligibility requirements:

- 75% or more of the heating load is currently delivered by a natural gas or electric boiler.
- A hydronic space heating distribution system capable of delivering sufficient heat from low temperature (<130°F) water, which will be either of:
  - An in-floor radiant heating system.
  - A radiator system in a building that has seen substantial envelope improvement from weatherization.
  - A radiator system in a building where rooms have sufficient space to upsize the radiators.

For single-family new construction, the air-to-water heat pump must be sized to supply the greater than 75% of heating load in a typical heating season.

INCENTIVES FOR HEAT PUMPS IN THE STUDY:

	RETROFIT	NEW CONSTRUCTION
Single-Family	Full cost with installation up to $35,000, paid to the homeowner	$10,000, paid to the builder
Multifamily	Full cost of design and installation up to $100,000, paid to the building owner	N/A



INTERESTED IN PARTICIPATING?

Take the pre-screening questionnaire to see if your home qualifies:
focusonenergy.com/awhp-field-study

Contact the Focus on Energy AWHP study team at:

Cynthia Segura, Researcher
cynthia.segura@focusonenergy.com

focusonenergy.com • 800.762.7077

REDUCING ENERGY WASTE ACROSS WISCONSIN

Focus on Energy, Wisconsin utilities' statewide program for energy efficiency and renewable energy, helps eligible residents and businesses save energy and money while protecting the environment. Focus on Energy information, resources, and financial incentives help to implement energy efficiency and renewable energy projects that otherwise would not be completed.

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Appendix B: Builder and Installer Outreach One-Pager



OPPORTUNITY TO PARTICIPATE

AIR-TO-WATER HEAT PUMP FIELD STUDY

FOCUS ON ENERGY® is conducting a field study to evaluate the performance of air-to-water heat pumps (AWHP) in homes across Wisconsin.

We're looking for home builders and HVAC installers in Wisconsin to participate in our study of this next-generation AWHP technology, ready to perform in cold Midwest winters.

WHAT IS AN AIR-TO-WATER HEAT PUMP?

An AWHP is an electric heating system that pulls heat from the outside air and transfers it to the water pipes that deliver heat to radiators and in-floor radiant systems, doing the work of a boiler or geothermal system. They can operate at up to 500% efficiency and can work in tandem with a backup boiler, saving substantial amounts of energy and potentially reducing energy costs. AWHP systems have been used in Europe for years and are already gaining traction in the Northeast of the U.S.

WHY PARTICIPATE?

Home Builders: As a home builder, you will be one of the first to gain experience with high efficiency, cutting-edge technology that will see greater market presence in the coming years. You will also be eligible for a $10,000 incentive for eligible single-family home projects.

You will play a crucial role in our field study by becoming one of the identified Trade Allies tasked with installing AWHP systems in a new home in Wisconsin. Ideally, you will bring experience in building homes with hydronic heating systems, with preference given to builders who have built homes with hydronic cooling (i.e. with geothermal). Your collaboration will involve working closely with manufacturers, Focus on Energy staff, installers, and researchers to identify suitable sites to build with an AWHP hydronic system.

Installers: As an installer, you will be one of the first to gain experience with high efficiency, cutting-edge technology that will see greater market presence in the coming years. By participating, you contribute to advancing the understanding of AWHP technology and its applications in real-world scenarios, especially here in colder climates, with the goal of expanding the AWHP technology in the Wisconsin market.

You will play a crucial role in our field study by potentially becoming one of the identified Trade Allies tasked with installing AWHP systems in residential settings in Wisconsin. Ideally, you bring expertise in both boilers and air source heat pumps, and prior experience in installing combination domestic hot water (DHW) and space heating hydronic systems. Preference will be given to installers with experience of installing AWHP systems. Your collaboration will involve working closely with manufacturers, program staff, and our researchers to identify suitable sites for installations.

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OPPORTUNITY TO PARTICIPATE

Air-to-Water Heat Pump Field Study

Participating sites and customers must meet the following criteria:

- Participant must own the single-family or multifamily building where the heat pump is being installed.
- The building site must receive electricity from a participating Focus on Energy utility.

For either single-family or multifamily retrofit sites, the following are eligibility requirements:

- 75% or more of the heating load is currently delivered by a natural gas or electric boiler.
- A hydronic space heating distribution system capable of delivering sufficient heat from low temperature (<130°F) water, which will be either of:
  - An in-floor radiant heating system.
  - A radiator system in a building that has seen substantial envelope improvement from weatherization.
  - A radiator system in a building where rooms have sufficient space to upsize the radiators

For single-family new construction, the AWHP must be sized to supply the greater than 75% of heating load in a typical heating season.

The study is also seeking to include systems that accomplish some or all of the following:

- At least one home with hydronic cooling.
- At least one home with combined domestic hot water and space heat.
- At least one home with a tank for thermal storage.
- At least one home to test load shifting capabilities.

THE HEAT PUMPS IN THIS FIELD STUDY WILL BE INCENTIVIZED AS FOLLOWS:

	RETROFIT	NEW CONSTRUCTION
Single-Family	Full cost with installation up to $35,000, paid to the homeowner	$10,000, paid to the builder
Multifamily	Full cost of design and installation up to $100,000, paid to the building owner	N/A



INTERESTED IN PARTICIPATING?

Contact the Focus on Energy AWHP study team at:

Cynthia Segura, Researcher
cynthia.segura@focusonenergy.com

Customers will need to take the pre-screening questionnaire to verify if their home qualifies. If you have a customer that might be interested, please share this questionnaire with them:
focusonenergy.com/awhp-field-study

focusonenergy.com • 800.762.7077

REDUCING ENERGY WASTE ACROSS WISCONSIN
Focus on Energy, Wisconsin utilities' statewide program for energy efficiency and renewable energy, helps eligible residents and businesses save energy and money while protecting the environment. Focus on Energy information, resources, and financial incentives help to implement energy efficiency and renewable energy projects that otherwise would not be completed.

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Appendix C: Troubleshooting Timeline for Site 3

- **December 12-18, 2024**: Installation. Last minute change to 3 uses: cooling, heating, and DHW fed by HP through buffer tank (relying on backup from gas boiler)
  - RG (installer) started on December 12th. Slipstream and K&E (distributor) joined on December 16th to check work and do the M&V install.
  - There was continued back and forth on the design throughout this time:
    - Diagram from K&E/LG did not match existing setup and RG did not make changes to align with provided diagram.
    - Using controls to isolate timing of HP-supplied DHW to only winter or supplying DHW a different way (concerns the DHW will need a higher temp and slow recovery).
  - Ultimately set loop and HP temp at 130 degrees with boiler on a delay (inefficient)
  - Boiler was **not** put in a parallel loop at this time (inefficient)
  - AC coil was not installed, wasn't in stock. Ordered the product and installed it at a later date (March).
- **January 23, 2025**: The homeowner communicated that compared to last December his bill was up $287 and gas was only reduced by $47.
  - The project team suspected the bill increase was due to an issue with the controls and the distribution design.
- **February 07, 2025**: Slipstream went on-site to tune the operation of the AWHP (locking out the HP at a higher temp so it doesn't run as much and cause more bill increases). Discovered the HP doesn't have the functionality to enable a switchover and relies on the indoor thermostat to do this. The indoor thermostat is a basic line voltage thermostat, so we were unable to set a lockout ourselves.
  - Slipstream suggested moving to a connected thermostat with more features. RG said that wiring the boiler to the appropriate inputs on the control board in the HP should enable that functionality as well.
- **February 28, 2025**: All monitoring appears to be functioning normally. HP is discovered to be functioning at a low COP (<1). Jon sent a re-piping diagram which RG and K&E reviewed. Figuring out the lock out is a priority.
- **March 10, 2025**: Slipstream met with LG and K&E to talk about a solution. Jon was able to get feedback from Dave Korn (industry expert), who identified that part of the efficiency problem was having the DWH going through two indirect heat exchangers, particularly an undersized exchanger. The water coil needed to be supplied before, not through, the buffer tank.
- **March 5, 2025:** RG communicated concerns about re-piping and budget. Slipstream asked for a quote with additional hours from RG. RG did not provide this.
- **March 10-26, 2025:** Conversations back and forth with RG about what changes they can make aligned with Dave Korn's suggestions.

    - RG stated they can do most things Dave Korn suggested. Biggest concerns/question was about the mixing valves and a new heat exchanger.
- **March 27, 2025:** RG went on-site to implement a combo of Dave Korn's and RG's ideas. They said that they set a lock out for 30 degrees (this was not seen in the data).
    - Boiler is piped into parallel and DHW is moved to a small loop with the boiler (fully off of the HP-supplied loop in theory) .
    - An HBX controller was installed on the buffer tank to enable better system controls. However, the boiler remains controlled primarily by its own aquastat controller and a series of improvised "relay in a box" devices, a cause of confusion and potential cause of continued low efficiency.
- **April 1, 2025:** Slipstream provided the homeowner with a $500 Amazon gift card.
- **April 5, 2025:** Slipstream re-ran the data, still seeing COPs near 1.5 (lower than expected but improved) .
- **April 23, 2025:** Slipstream suspected the HP might not be running from looking at recent utility bills. Re-ran monitoring data, noticed the HP had not been running for 2 weeks .
- **April 28, 2025:** RG and Slipstream went on-site. Figured out that a water pipe outside had been slowly leaking, potentially for months.
- **April 29, 2025:** RG went back on-site and fixed the water pipe. Confirmed the HP should be able to run in cooling mode.
- **May 14, 2025:** Confirmed the HP was not in cooling mode, COP was ok for heating but the HP was also not heating much due to the weather.
- **June 16, 2025:** The homeowner communicated that cooling isn't working and that RG was unresponsive.
- **June 16-19, 2025:** The homeowner had continued back and forth with RG, trying to get them to come out. Was originally scheduled for June 18th but RG had to cancel.
- **June 19, 2025:** RG came out in the afternoon to take a look. Confirmed later that week (6/23) that the issue was not resolved and that RG would have to go back. Homeowner reported that the system was cooling but very slowly. The system was also not dehumidifying and Slipstream suspected that the DHW was fighting with the cooling.
- **July 23, 2025:** RG re-piped and installed a 3-way valve. The HP control board or controller was fried in the process. Slipstream ordered 2 room AC HPs for the homeowner in the meantime.
- **October 7, 2025:** LG, RG, and K&E all went to site and reset the HBX controls.
    - At this time, it was determined that the original heat pump loop did not have enough liquid volume for the heat pump, and an additional buffer tank was added in the heat pump loop.
- **July 2, 2026:** After a functional (though low efficiency) heating season, the homeowner informed the research team that he had just turned on the cooling during a heat wave, and it was not working appropriately, with little dehumidification.

- **July 29, 2026:** After K&E provided guidance, RG made it to site several weeks later and determined that the LWT had reset to Celsius rather than Fahrenheit. Cooling was operational after this visit.
- **August 3, 2026:** The homeowner informs RG and the research team that the heat pump is leaking, and he is mopping daily to protect his baseboards.
- **August 25, 2026:** RG and Slipstream go to site for monitoring equipment removal. It is determined that the condensate pan was broken, causing the leak, and this is fixed.

Appendix D: Installer Interview Guide

Introduction: *Thank you for agreeing to help us understand your experience installing an air-to-water heat pump (AWHP) at this site. I will be asking you questions about the installation tasks, equipment, challenges, and your overall experience at this site. Your responses will help the study team and Focus on Energy understand installation challenges, education gaps, and potential program design.*

Is it okay if I audio record our discussion? This makes it easier for me to take notes and capture your ideas accurately.

Background and preparation

First, let's talk about site preparation and installation.

1. What was your familiarity with AWHPs prior to installation at this site?
    a. Had your team attended any trainings about the technology?
    b. What was your familiarity with installing ground source heat pumps?
        i. PROBE: If ground source experience, ask whether any system knowledge and controls understanding transferred to AWHPs
    c. What was your familiarity with installing boiler systems
        i. Same probe as A for boiler
    d. What was your familiarity with installing ASHPs?
        i. Same probe as A for ASHPs
2. Were load calculations performed for this site?
    a. PROBE: if load calculations, who performed them, and how confident are you in their accuracy?
3. What other prep work was required?
    a. PROBE: Site visit/walkthrough, manufacturer document review, electrical work, etc.
4. Who was the main designer of the AWHP/distribution system?
    a. PROBE: To your knowledge, what site-specific factors most influenced the design (e.g., manufacturer requirements/recommendations, load calc, available space, existing distribution system, ductwork/piping condition, electrical capacity)?
5. Describe the design of the system
    a. If retrofit: How did you handle integration with existing distribution? How well did you understand the distribution system before the day of installation?
    b. If new construction: How well did the building plans match what you actually needed for the AWHP system?

6. To the best of your knowledge, what were the boiler water delivery temperature settings before installation for space heating and (if applicable) water heating? How are the supply water controls set now?
    a. If possible, have installer show where on controls the supply water curve is and take a photo
7. How are backup controls set and integrated?
    a. If possible, have installer show where on controls the backup heating information is and take a photo
    b. FOR GAS SITES: If possible, take a photo of boiler nameplate efficiency rating

Equipment selection & perceptions

1. What has been your experience with this particular equipment brand/model
    a. PROBE: reliability, ease of setup, documentation quality, manufacturer support, etc.
2. How would you rate the installation manual/technical documentation for this equipment?

Installation and Servicing

1. How did this installation compare in scale and complexity to a typical job for you?
2. Which parts of the installation were most straightforward? Which were most difficult or time consuming?
3. Did you need to modify your planned installation approach for this project?
4. Is there anything about this job you'd do differently next time?
5. How prepared did you feel going into this job in terms of training for this specific equipment?
    a. PROBE: Do you think you'd feel more prepared going to another AWHP site?
6. How long did the installation take compared to your original estimate?
    a. PROBE: What caused any deviation?
    b. PROBE: If you installed a similar system in the future, how long do you think it would take?
7. Did you reach out for design or setup support during the installation?
    a. PROBE: if yes, who provided support (e.g. manufacturer)?
    b. PROBE: Please describe the support you required: installation instructions or other aspects of the installs?
8. What steps did you take to verify the system was working correctly?
9. What maintenance is required for this system and how does it compare to systems you've maintained before?
10. How many times did you return to site to service the equipment?
    a. PROBE: How did these visits go? Were these different or more frequent than what you'd expect from a boiler system, and if so, how?

Overall impressions

1. Would you recommend AWHPs to other installers or contractors?

2. What would help dismantle the complexities with installing AWHPs (trainings, case studies, webinars, manufacturer education, etc.)?
3. Is there anything else you think we should know?

Closing: *I appreciate your willingness to share your experiences at this site. Your insights and suggestions will be valuable to help us better understand the AWHP market and barriers to adoption. Thank you for your time and expertise.*