My Buddy the Backup Boiler: Dual-Fuel and All-Electric Air-to-Water Heat Pump Installations in Wisconsin

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ABSTRACT

Domestic hot water, space heating, and space cooling account for most residential energy use, making these systems key targets for efficiency improvements. Air-to-water heat pumps (AWHPs) offer flexible and efficient pathways to install or retrofit radiant heating systems. This FOCUS ON ENERGY® 2025-2026 field study evaluates the performance of five AWHP systems across four residential buildings in Wisconsin.

The study illustrates how contractor experience, system design decisions, and commissioning practices shape system functionality. Installations led by an experienced contractor achieved reliable operation. Early design involvement from a manufacturer helped guide one less experienced installer, while the less experienced installer without early support encountered persistent challenges. System design varied, with a simpler AWHP installation at the new construction project site. The three retrofit projects required careful load assessments, targeted repiping, and the use of variable-speed pumping and controls. Resulting system performance varied widely and was influenced by control strategies. Well-configured systems integrated heat pump and boiler controls to avoid excessive reliance on auxiliary heat and used leaving water outdoor reset controls to increase efficiency. Economic outcomes depended on local rate structures: AWHPs reduced operating costs when replacing electric resistance systems, but not when displacing natural gas. Accordingly, in dual-fuel applications, designing for partial heating displacement could improve cost outcomes. Broader AWHP adoption will depend on greater standardization of design and commissioning practices and programmatic support through contractor training and incentives. As Wisconsin's AWHP market is emerging, programs should emphasize manufacturer and/or designer involvement in system design.

Introduction

An AWHP is an all-electric whole-house HVAC system able to provide space heating, space cooling, and domestic hot water (DHW). AWHPs extract heat from the outside air and transfer it to water via a compressor-driven, refrigerant-based system (i.e. heat exchanger), and can reverse this process for chilled water. For space heating, the heated water is pumped into radiator emitters and in-floor radiant systems, with the AWHP providing the heat that otherwise would be provided by a boiler or geothermal system. AWHPs can operate at over 500% efficiency, transferring more than five times as much heat energy into the water than electric energy consumed, a coefficient of performance (COP) of more than five (LG 2020-2021, Enertech 2025, Arctic 2024). This 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 recent years, AWHP have gained traction in the United States. However, the market remains nascent in many regions, with limited contractor familiarity. Contractors and distributors are often reliant on manufacturers for information. Designers and engineers can be helpful in these cases but are currently not often brought onto smaller residential projects.

The following paragraphs provide key terms, general design concepts, and previous research findings to contextualize the installed AWHP systems.

AWHP systems are often configured as a monobloc system, an all-in-one unit where most heat pump components are in the outdoor unit (ODU), which either contains pumping and DHW controls or houses them in an indoor unit (IDU). AWHPs can also be configured as a split-system like traditional air source heat pumps. 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. Water in the same loop as the heat pump must include glycol for freeze protection. Ideally, for space heating, the leaving/delivered water temperature (LWT) decreases at warmer outdoor temperatures. This is accomplished through LWT outdoor reset controls.

An integrated electric boiler can be installed as part of the AWHP IDU. If keeping an external electric or natural gas boiler, its controls can 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 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.

More detailed AWHP mechanics, and best operational practices have been laid out in several prior reports, including an ACEEE GTI Energy paper on best practices (LaFleur 2022) and a Minnesota Conservation Applied Research and Development report on AWHPs in cold climates (Hill 2023). These two studies reached common conclusions about hydronic system design. First, high-volume emitters (e.g., in-floor radiant heat or radiator piping with a larger surface area) reduce heat pump issues such as short cycling. High-volume emitters also allow for lower LWTs, improving efficiency, and reducing the need for direct buffer tanks. Second, LWT outdoor reset controls improve space heating efficiency at moderate temperatures. Finally, hydronic cooling requires careful design and load assessments to ensure long heat pump cycle times for proper dehumidification and high-efficiency operation. These findings and best practices were incorporated into the design of this field study.

Study Overview

The applicable market for AWHP products in Wisconsin is narrow, yet the opportunity for energy efficiency and reduced utility costs within the market is high. Focus on Energy determined conducting a field study would provide real-world insights into the energy-savings potential in the field and market understanding of the technology. Planning for the field study began in 2023, and installations began in late 2024. This paper reports on the installation and performance findings from the field study through April 2026.

The field study aimed to investigate real-world AWHP operation in both single- and multifamily, as well as retrofit and new construction, sites. The four sites selected were:

- A four-unit multifamily retrofit using two AWHPs paired with natural gas back-up boilers to provide combined space and domestic hot water.
- An all-electric single-family retrofit using an AWHP paired with an integrated electric boiler to provide space heating and domestic hot water.
- A single-family retrofit using an AWHP paired with a natural gas back-up to provide space heating and cooling.
- An all-electric single-family new construction installation using an AWHP paired with an integrated electric boiler to provide space heating and cooling.

Recruitment

This study was open to customers of utilities who participate in Focus on Energy. Participants were required to own their homes and use a hydronic system as the primary heating source. 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.[1]

The single-family new construction site and installer were recruited through a manufacturer. The multifamily retrofit site was recruited through a Wisconsin building owner in contact with the research team. To recruit single-family retrofit sites, the research team sent communications to customers via cooperative and municipal utility customer newsletters.

To recruit installers for the retrofit sites, the research team reached out to Focus on Energy Trade Ally contractors, as well as other contractors in Wisconsin who had worked with the research team previously. 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. Other installers were hesitant to mention this study as an option for their customers due to their lack of familiarity with AWHPs. 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.

Data Monitoring and Processing

Measurement and verification equipment were installed at the time of AWHP installation. Installation at the four recruited sites occurred between November 2024 and August 2025. Data acquisition systems will remain active until August 2026. 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 sensors installed for monitoring inform the following calculations:

[1] Traditional radiator systems typically deliver water at much higher temperatures, requiring alterations to the distribution system and heat emitters to accommodate larger water volume if supply temperatures are lowered. However, 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 also eligible.

- Pre- and post-period efficiency as COP.[2]
- Primary and backup system utilization and runtime by outdoor temperature.
- Domestic hot water demand and impact to system operations (at applicable sites).

No direct monitoring of the pre-period exists for the project. Instead, the team operated each system in "back-up only" mode for three one-week windows spaced across the winter monitoring period. These times are treated as counterfactual (pre-period) data, while the remainder of the monitoring period is considered the post-period.

Results

Results of the study are shared on a per site basis and include information on the existing equipment, the AWHP systems installed, and control approaches. Contractor installation and troubleshooting experiences are outlined. Finally, energy, cost, and efficiency outcomes are discussed.

Site 1: Multifamily Retrofit (four-unit building)

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 an 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 is 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 kicks in after the heat pump compressor has been operating at its top speed for the manufacturer's default time period. DHW heat calls are prioritized.
Contractor Experience Level: Prior experience with hydronic systems (>20 geothermal installations).
Number of Troubleshooting Callbacks: 3

Table 1. Site 1 additional site details

Building Size	Heating Load	Installation Costs[3]
3,360 sq ft	71,500 Btu/hr (calculated from utility data)	$100,871

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).[4]

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[2] Note that 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), and do not include backup heat contributions or distribution losses, which is reported in other metrics.
[3] Installation costs include time and materials for necessary electrical upgrades.
[4] This building required electrical infrastructure upgrades, including an additional electrical meter and sub-panel.

The configuration in both mechanical rooms repiped the system to place the natural gas boilers in parallel to the AWHPs. The variable-speed pumps within the IDUs were leveraged to supply water to zones. The IDU control logic also managed zone valves, backup boilers, and temperature and flow for DHW. The contractor programmed an appropriate outdoor reset curve for space heating. After installation, this larger heat pump had a firmware issue preventing changes to controls. This was fixed upon consultation with the manufacturer.

At the outset of the monitoring period, the DHW target tank temperature was set to 125°F. In the following months, the building owner called the contractor reporting low water temperatures. The contractor adjusted the tank temperature to 135°F (with a mixing valve still decreasing the actual delivered water temperature to 120°F), which proved more satisfactory for the residents.

One major operational issue occurred at this site throughout the duration of the study. The smaller HP began operating in boiler-only mode for several months in winter of 2025-2026. The cause of the issue was a drop in outdoor temperature to -20°F, which locked out the heat pump. Snow accumulation inside the unit then prevented it from turning back on. This issue was resolved in March 2026.

Table 2. Site 1 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	1,288 therms	129 MMBTU	$1,133
Post-retrofit Use	11,998 kWh	277 therms	69 MMBTU	$1,684
Impact	**+11,998 kWh**	**-1,011 therms**	**-60 MMBTU**	**+$551**

Table 2 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, these values are normalized to the site's average daily hot water consumption of 77 gallons per day. 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 more than $550 a year. This is despite 60 MMBTU of energy savings. The larger AWHP displaced 64 percent of annual boiler gas usage, with most boiler contributions happening during DHW calls. This is less than the planned 100 percent heating displacement. A longer time delay before the boiler begins contributing to load could increase heat load displacement (and utility cost impacts) at the risk of impacting resident satisfaction. The smaller AWHP successfully displaced 93 percent of gas usage.

Figure 1 below shows hourly HP COP for the larger AWHP by type of heating and outdoor temperature.[5] Hourly COPs for both space and water heating correlate positively with outdoor temperature, with a more dramatic correlation for space heating. Because of the outdoor reset controls, with delivered hot water temperature decreasing at warmer outdoor air temperatures, space heating efficiency scales "doubly" with outdoor temperature. The hydronic DHW system, by contrast, must be heated to the target tank temperature at all times. The water

[5] Note that COPs may not be reflective of total system performance because of buffer tanks, switching between DHW and space heat, and system thermal inertia.

heating COPs were noticeably lower than the space heating COPs, so average daily COPs for this system were lower in the summer months, when there was no space heating needed. Daily summer COPs averaged around 1.8, and winter COPs averaged around 2.0.

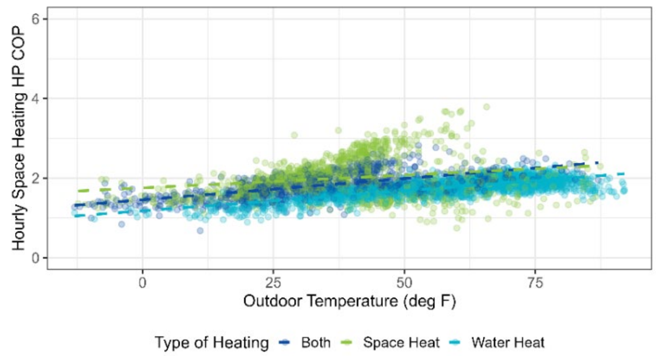

Figure 1. Hourly HP COP per outdoor temperature for larger Site 1 AWHP, for space versus water heating

Figure 2 shows the daily COP of the larger HP (including 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 2.0 at colder temperatures to 4.0 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. At these temperatures, the water heating load also takes up a greater portion of total load at mild temperatures, so heat pump efficiency dips.

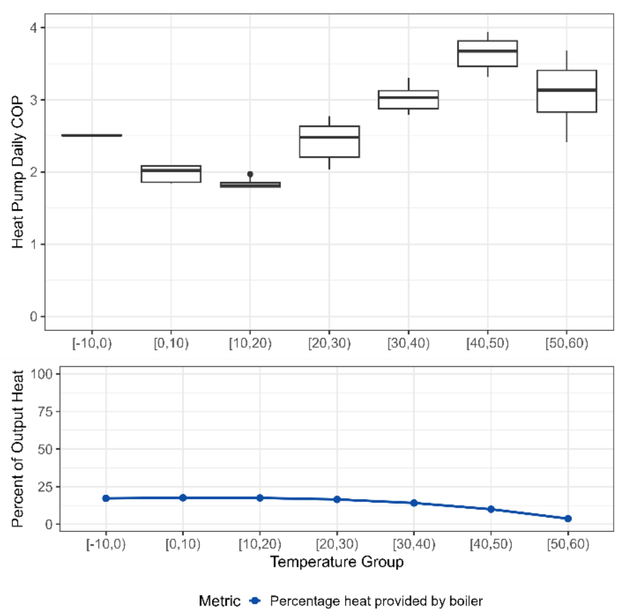

Figure 2. Heat pump performance and boiler contribution per outdoor temperature for larger Site 1 AWHP

The smaller AWHP at Site 1, serving only space heating in another portion of the building, performed reasonably well during the heating season. Daily COPs were the highest of the heat pumps monitored and averaged at around 3.0. These increased with increasing outdoor temperature, as seen in Figure 3 below. Boiler contribution decreased with increasing outdoor temperature, remaining below 15 percent of boiler contribution at all temperatures.

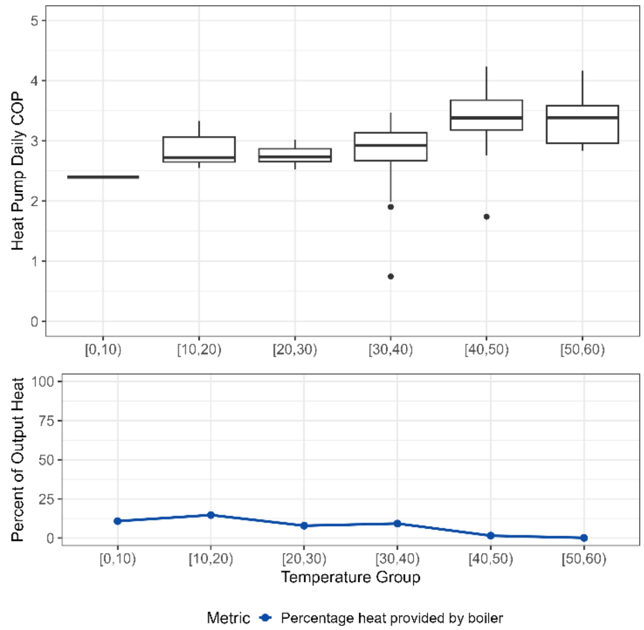

Figure 3: Heat pump performance and boiler contribution per outdoor temperature for smaller Site 1 AWHP

The energy use and economic results above are based on maximizing heat pump operation across all outside air temperatures. With this site's utility rates and assuming a boiler efficiency of 90 percent, the economic breakeven COP is 3.6. Based on the heat pump COPs in the figures above, the homeowner could switch to a 40ºF switchover temperature for the best operational economics after the study concludes.

Site 2: Single-family Retrofit #1

Existing System: An 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 an integrated electric boiler as part of an IDU serving space heat and one 65-gallon indirect water heater. There are 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 kicks in after the heat pump compressor has been operating at its top speed for the manufacturer's default time period. DHW heat calls are prioritized.
Contractor Experience Level: Prior experience with hydronic systems (>20 installations). Same contractor as Site 1.
Number of Troubleshooting Callbacks: 1

Table 3. Site 2 additional site details

Home Size	Heating Load	Installation Costs

1,600 sq ft	30,708 Btu/hr	$43,856

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 appropriate outdoor reset curve was set for space heating. Site 2 was set to a DHW tank temperature of 135°F with a mixing valve lowering delivered water to 120°F, with the contractor citing their experience at Site 1 as rationale.

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

Weather-normalized annual energy and cost impacts of the retrofit at Site 2 are shown in Table 4. 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 14 gallons per day. This site experienced energy savings of 17 MMBTU per year, or 31 percent. This site saved around $440 annually, which would not be enough to pay back over the system's lifetime. Counterintuitively, these dollar savings would have been higher if the site were not on an electric heating rate in both periods.

Table 4. Site 2 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		
Pre-retrofit Use (Baseline)	16,059 kWh	NA	55 MMBTU	$1,445
Post-retrofit Use	11,140 kWh	NA	38 MMBTU	$1,003
Impact	**-4,102 kWh**	**NA**	**-17 MMBTU**	**-$442**

Figure 4 shows HP COP by type of heating and outdoor temperature. Similar to Site 1, both water and space heating COPs correlated positively with outdoor air temperature. However, because space heating COPs were significantly higher than water heating COPs on average, 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.

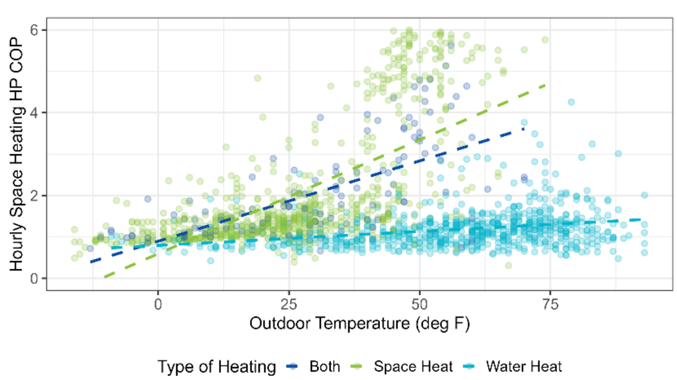

Figure 4: Hourly HP COP per outdoor temperature for larger Site 1 AWHP, for space versus water heating

Figure 5 shows the daily COP 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 1.5 at the coldest temperatures to 5.0 at moderate temperatures. Electric boiler contribution decreased with increasing outdoor temperature, but less dramatically than at other sites, indicating that the boiler played a relatively constant role in DHW heating. On average, the integrated electric boiler provided around 25 percent of site heating load.

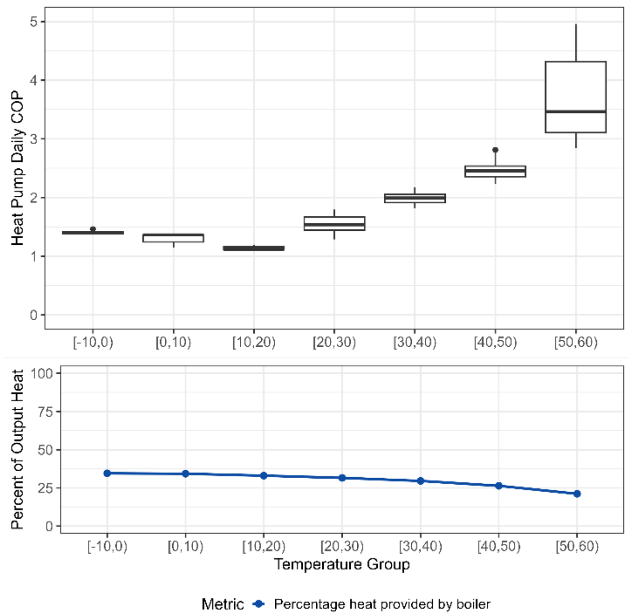

Figure 5: Heat pump performance and boiler contribution per outdoor temperature for Site 2

Site 3: Single-family Retrofit #2

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: Monobloc AWHP without a separate IDU. Existing gas boiler provides backup space heating and all DHW. Space cooling through AWHP into existing ducting. 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. The AWHP system was sized to fully replace gas heating.
Post-Retrofit System Controls: AWHP operation is triggered by the temperature of the buffer tank, and the boiler kicks in after a time delay if the temperature demand has not been met. The boiler heats to DHW setpoint upon DHW calls, and space heat setpoint otherwise.
Contractor Experience Level: No prior experience with hydronic systems.
Number of Troubleshooting Callbacks: 6.

Table 5. Site 3 additional site details

Home Size	Heating Load	Installation Costs
1,900 sq ft	33,537 Btu/hr	$41,900

Site 3 experienced a significant number of installation issues due to an inexperienced contractor who did not receive early design support. There were several system revisions and callbacks. The final system diagram shown in Figure 6 and provides valuable information to contextualize the troubleshooting narrative below.

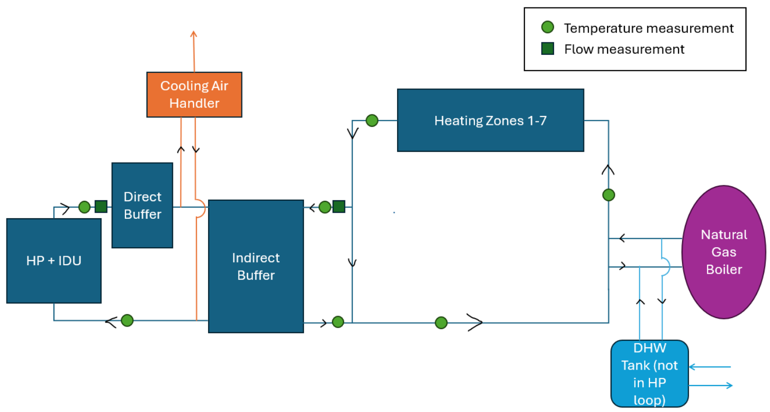

Figure 6: Final system diagram at Site 3

At first, the boiler remained within the primary heating loop 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. 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 remained controlled primarily by its own aquastat controller and a series of improvised "relay in a box" devices, a cause of confusion and a likely cause of continued performance issues.

During the cooling season, the system operated at very low efficiency and with poor dehumidification. It was determined that the heat exchanger in the buffer tank was too small to properly cool. When onsite 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 reset the control board and 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 was implemented.

At the time of writing (June 2026), the outdoor reset control is applied to the buffer tank rather than the heat pump. This means the heat pump supplies 120°F water year-round, contributing to short cycling. The team plans to attempt to shift outdoor reset to the heat pump loop, which may provide some improvement; however, overall performance is still expected to be hindered by the suboptimal backup integration controls.

Annual weather-normalized space heating energy and cost impacts of the ultimate AWHP system are shown in Table 6 (cooling not included due to lack of cooling baseline data). 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 6. Site 3 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 (Actual)	NA	353 therms	35 MMBTU	$378
Post-retrofit Use (Modeled)	2,956 kWh	228 therms	33 MMBTU	$746
Impact	**+2,956 kWh**	**-125 therms**	**-2 MMBTU**	**+$368**

Figure 7 shows the daily COP of the heat pump, the percentage of space heating provided by backup heat, and the percentage of heat lost in the distribution loop (i.e., buffer tanks) per outdoor temperature group. 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 an economic switchover temperature under current system configurations.

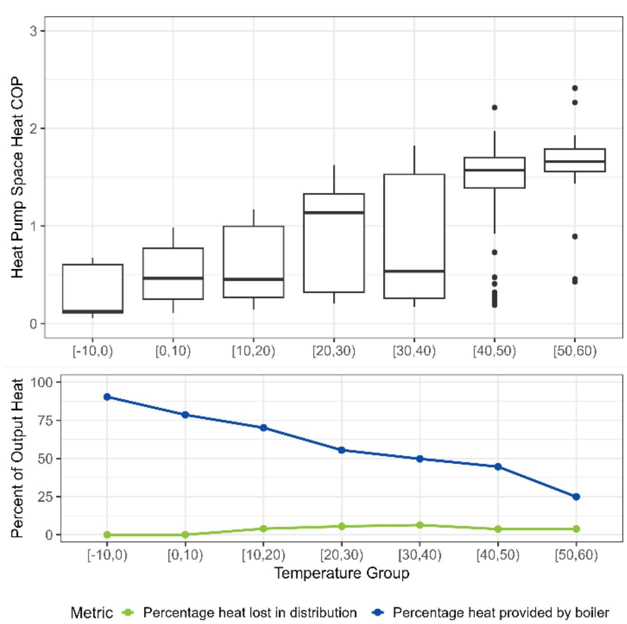

Figure 7: Heat pump performance and boiler contribution per outdoor temperature for Site 3

Site 4: Single-family New Construction

Installed System: 4.25-ton monobloc AWHP with an integrated electric boiler and without a 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 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 systems.
Number of Troubleshooting Callbacks: 0 – the homeowner diagnosed two controls issues with the manufacturer remotely.

Table 7. Site 4 additional site details

Home Size	Heating Load	Installation Costs
2,392 sq ft	36,193 Btu/hr (estimated by heating contractor during construction)	$13,440

Installation went smoothly at this site. The manufacturer provided materials on system design, and since this was new construction, the system could be installed exactly as specified. The site did not have any comfort issues during the cooling season, although the installation occurred late in summer after the hottest days. Cooling season efficiency was, however, far below manufacturer specifications, because of short cycling and the lack of insulation in the mechanical room.

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 hard outdoor temperature requirement and allow flexible boiler operation based on heat pump ability to meet the heating load. 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.

Annual weather-normalized space heating energy and cost differences between the boiler-only baseline periods and the full AWHP system are shown in Table 8 (cooling not included due to lack of baseline cooling data). 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).

Table 8. Site 4 baseline and post-retrofit energy use and cost

	Electricity	Natural Gas	Net Energy	Estimated Annual Costs
Unit costs	$0.15/kWh	NA		
Pre-retrofit Use (Actual)	18,468 kWh	NA	63 MMBTU	$2,770
Post-retrofit Use (Modeled)	8,267 kWh	NA	28 MMBTU	$1,240
Impact	**-10,201 kWh**	**NA**	**-35 MMBTU**	**-$1,530**

Figure 8 shows the daily COP 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. COPs at this site remained between 2.0 and 3.0 most days, increasing slightly with outdoor air temperature. This site was the least reliant on backup heating at moderate temperatures, though backup heat provided 50 percent of heat output below 0ºF. Daily heat losses from the buffer tank ranged from zero to 10 percent.

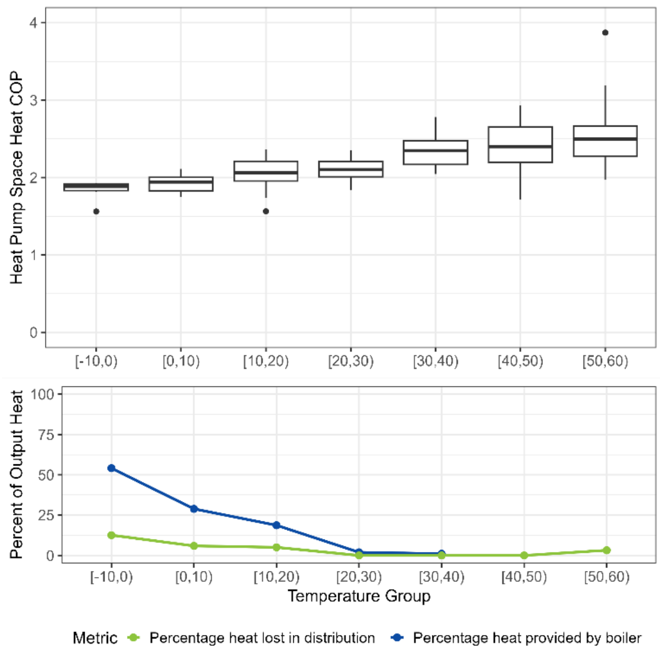

Figure 8: Heat pump performance and boiler contribution per outdoor temperature for Site 4

Conclusions

The performance of the AWHP systems in this field study varied significantly. System performance was impacted by installer design support and previous experience, hydronic system setup and controls, and the backup heat source. Conclusions fall into four major themes: installation best practices, system controls, system economics, and future work.

Installation Best Practices

Installation outcomes varied significantly, even between sites with similar heating loads. Installations were more seamless when installers had access to adequate manufacturer design and troubleshooting support or experience with hydronic systems. Design support before installation can be helpful for incorporating AWHP-specific nuances, especially for inexperienced installers. Site 4 serves as a successful example; the inexperienced installer was able to lean on the manufacturer to optimize system controls prior to installation and during commissioning. In contrast, At Site 3, a less experienced contractor who didn't have initial design support returned six times over 15 months to re-pipe and adjust heating, backup heating, cooling, and DHW controls. Despite repeated revisions and input from the research team, the system was never fully optimized.

When retrofitting an existing hydronic system, installers should carefully assess heating loads and existing hydronic components, re-pipe the mechanical room as necessary, and install variable-speed pumping and controls to balance the system. The experienced contractor at Site 1 and Site 2 followed this recommended retrofit protocol. In contrast, the less experienced contractor at Site 3 was not aware of these best practices and attempted to integrate new equipment with existing components through improvised staging controls, leading to performance issues.

Retrofits are inherently more complex than new construction installations, and increased complexity raises the likelihood of suboptimal AWHP integration into the existing system. The new construction AWHP at Site 4 saved troubleshooting time and cost due to its lack of retrofit complexities.

System Controls

System controls strongly influenced AWHP performance, with a gap between theoretical and realized gas displacement at two of three dual-fuel systems.[6] One AWHP at Site 1 successfully displaced over 90 percent of gas heating. For the other Site 1 system, the AWHP only displaced two-thirds of expected heat. Boiler controls could potentially be optimized for this system during DHW calls, though this may lead to longer heat-up times for residents. At Site 3, excessive reliance on backup heating (65 percent of total heat) reduced system efficiency and increased energy consumption. This was a direct product of confusing and complicated boiler controls.

Backup boiler integration was critical to overall system performance. AWHP system controls should be integrated so the heat pump or standalone controller manages backup operation. This allows the heat pump to raise supply temperatures before activating the boiler, and for both systems to operate together down to the switchover temperature. Boilers in the study controlled by the AWHP's IDU or a standalone controller performed predictably and allowed the heat pump to lead operation. In contrast, the boiler at Site 3 was initially piped in series and continually controlled primarily by its own aquastat, which increased loop temperatures and led to heat pump performance issues.[7]

It also proved 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. In both cases involving inexperienced contractors, systems initially operated without effective reset control.

System Economics

AWHP economic performance depended strongly on electricity and natural gas price differentials. When compared against electric resistance boilers, the AWHPs provided significant cost savings and could recover incremental installation costs under high electricity rates.

[6] There were a total of three dual-fuel systems across two sites (Site 1 and Site 3).
[7] 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.

However, when displacing natural gas systems, operating costs increased due to relatively higher electricity prices in the region when compared to gas.

System design decisions must therefore balance energy performance with operating cost considerations. 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.[8] Given the relatively low water heating COPs seen in the field, air-source heat pump water heaters should be considered for the water heating load to enhance overall household efficiency. 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.[9] Partial heating displacement design results in a smaller and less expensive AWHP, with less drastic changes to the existing hydronic system. It also decreases the risk of issues caused by system oversizing.

Next Steps to Advance Deployment

Validation across a broader sample and/or integration of this study with other smaller deployments will be important going forward. This is a small study working with only four sites and three of Wisconsin's installation contractors. An expanded dataset would enable more robust characterization of performance variability driven by system design and control configuration.

In parallel, contractor-focused training programs should be expanded, with emphasis on hydronic system fundamentals, AWHP-specific control strategies, and proper integration of backup heating systems. Manufacturer or system designer involvement during early design and commissioning phases should be required as a best-practice standard. Programs can further support adoption by shifting incentives toward measured operational performance rather than installation completion alone.

Utility programs should prioritize new construction projects and electric boiler replacements as near-term pathways to scalable deployment. Upfront system cost incentives can help overcome installation cost barriers. Favorable rate structures could also be developed to improve the value proposition of dual-fuel systems. Assumptions for claimed energy savings should continue to be developed and validated for full and partial displacement scenarios.

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[8] Thermal energy storage and dynamic controls can be combined with these designs for better economic outcomes (GridWorks 2023).

[9] There is also flexibility to change backup heat contribution levels after installation through controls alterations (e.g. backup switchover temperature).

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AI-assisted tools used: ChatGPT.
Used for: editing sentences and code.
Extent: light editing.
Human review: the authors reviewed and verified all content, calculations, and citations.