The Midwest 120V Heat Pump Water Heater Field Study

Final Report

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Slipstream

Focus on Energy

ComEd

Consumers Energy

Xcel Energy

Project Manager: Jon Koliner

Acknowledgements: Dani Ball, Robert Klein, Sarah Wells, Dan Cautley, Mischa Egolf, Noah Gabriel, Sonya Pouncy, Kevin Gries, Mila Turner, and Allie Cardiel.

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Executive Summary

Heat Pump Water Heaters (HPWHs) are a promising technology for decarbonizing residential water heating. However, traditional HPWHs require a dedicated 240V circuit, reducing their cost-effectiveness as an electrification solution if major electrical upgrades are necessary. These cost concerns are especially salient for customers earning low incomes.

To address this, manufacturers released 120V HPWH models that plug into a standard wall outlet. These units avoid electrical upgrades, but heat water more slowly. These models are not yet available in the Midwest, as there are concerns about whether they can meet occupant needs in colder climate winters, when groundwater temperatures are colder, and heaters must work harder to meet occupant demand. Focus on Energy, ComEd, Consumers Energy, and Xcel Energy partnered to conduct a year-long field study of 120V HPWHs at 27 sites across the Midwest to investigate their performance in light of these concerns, develop guidelines for site selection and installation practices, and compile best practices for potential incentive programs.

25 of these sites switched from a natural gas unit, one from a propane unit, and one from an electric unit. All sites had an occupancy of four people or less. We installed 19 shared circuit units and eight dedicated circuit units. The dedicated circuit units require more electrical work to install but have higher power draws, and thus shorter runtimes (though they are less efficient).

Manufacturers have said that upon receiving the results of this report, they will reassess cold climate 120V HPWH distribution. This study demonstrates that 120V HPWHs are a cost-saving electrification retrofit technology compared to 240V hybrid units and can meet hot water demand even in colder climates. Installers and participants were generally satisfied with the switch and there were few issues with hot water availability, even at the coldest points in the year.

Installers reported that swapping out natural gas heaters for 120V HPWHs was equivalent in ease and feasibility to a like-for-like replacement. Yet, most installers were not familiar with critical considerations for 120V HPWH installation (e.g. room volume requirements, space constraints and outlet locations) at the start of the study, as these products are new to the market. We recommend that installers work with distributors to have 120V units available for water heater replacements, and that installers follow detailed site and equipment selection criteria to ensure these units are the best choice and are installed optimally. Section IX contains these installation guidelines.

We conducted installer interviews to gather insights into the installation process. One theme of the interviews was that 120V HPWHs are much broader and heavier than their gas and electric counterparts, necessitating two installers be present at most installations. Installers also stressed that before installation day, it is important to confirm that the install space, and the pathway to that space, are large enough to accommodate the heater.

15 of the 25 interviewed install sites required minor electrical work to be done upon installation. The installer was able to do this work for 13 of those sites, while the other two required an outside electrician. There was a tradeoff in the ease of installation between shared and dedicated circuit units. Dedicated circuit units often require more electrical work, but are smaller and easier to transport.

Participants report 92% satisfaction with their 120V HPWHs overall. 67% of participants reported never experiencing a hot water runout and 33% reported occasional hot water runouts. No participants reported frequent runouts.

While these results are promising, there are also lessons learned from the field study to ensure that participants do not experience hot water runouts that impact their daily routines. Most importantly, the field study revealed that runouts often follow a large consumption event. This is true for 240V or gas units as well, but 120V units recover heat more slowly than their counterparts. Manufacturers have included an integrated mixing valve in many units and recommend upsizing the HPWHs to avoid runouts by increasing the available hot water from a full tank. Still, with a 120V unit, when hot water runs out, it runs out for longer and is a greater inconvenience.

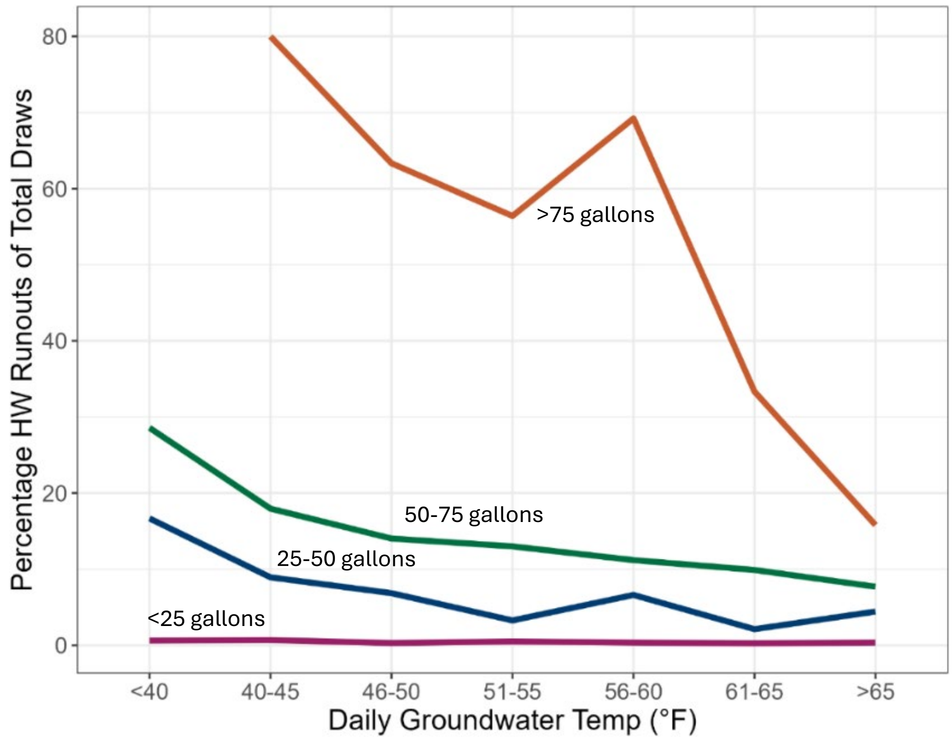
Two proxies can be used to get an idea of a household's water consumption: household size and the frequency of runouts with a household's old water heater (assuming that old heater is not faulty or undersized). We recommend households who do not frequently deplete their current water tank switch to a shared or dedicated circuit 120V HPWH if they have three occupants or less. Households with an occupancy of four should switch to a dedicated circuit 120V HPWH because of these units' shorter recovery times. If installers verify that the household takes short (~5 minute) showers, does not take baths, and has low-flow showerheads in all showers, they can switch to a shared circuit unit.

Groundwater[1] temperature also influences the frequency of hot water runouts. Figure 1 below illustrates the combined effect of previous consumption and groundwater temperature. Larger consumption events[2] during the three hours prior to a draw show a higher percentage of water runouts overall, but all lines over 25 gallons slope downwards, with a higher percentage of runouts at lower groundwater temperatures. The average site experienced a runout on 5% of study days.

[1] Throughout this report, we will use the term "groundwater" to refer to the water piped into a residence, whether from a well, a body of water, or another source.

[2] A large consumption event is characterized as depleting or nearly depleting the HPWH's tank, necessitating full water heat recovery.

Figure 1. Percentage of HW runouts vs. groundwater temperature, grouped by consumption over three hours prior.



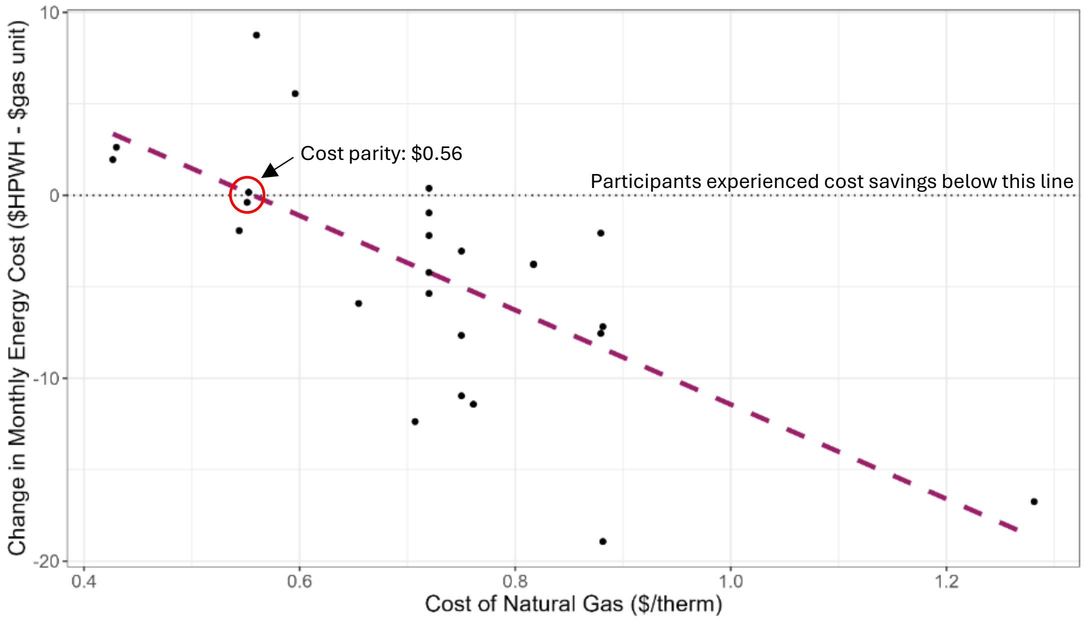
The study measured a decrease in temperature in the room containing the HPWH following compressor operation. Measured room humidity also decreased slightly during the summer season. Dehumidification was seen by participants as a benefit, while temperature oscillated between benefit and drawback depending on the season. Units should not be installed in a place where the resident spends a lot of time, as the noise of the compressor can be annoying.

Units had an average coefficient of performance (COP) of 2.4. The average site used 87% less energy with a 120V HPWH than with their previous unit. We found a negative correlation between COP and groundwater temperature, with lower groundwater temperatures being more efficient, and a positive correlation between COP and the temperature of the indoor air being pulled into the heater, with warmer air resulting in more efficient operation. These two effects worked in opposite directions seasonally, leading to very little variation in COP throughout the year.

The operational cost of 120V HPWHs is similar to that of the replaced gas units, with the HPWH yielding a study-wide average slight cost savings of around $7. The range of monthly water heating energy cost change was from $9 more expensive to $18 saved.[3] After savings, the average total monthly 120V HPWH operating cost was $12. Since the study average 120V HPWH install cost was around $5500, these units cannot pay for their increased installation cost with these savings, but on average, a natural gas price of $0.56 per therm or more resulted in net operational cost savings. Figure 2 below shows the operational cost difference of participants' natural gas versus 120V units.

[3] This range in savings is due to differing gas and electricity rates in different territories, differing efficiencies of old and new units, and differing consumption patterns (people using more energy benefit more from the increased efficiency of the HPWH).

*Figure 2. Change in Water Heater Energy Cost vs. Natural Gas Cost.**



*Costs exclude lump taxes and service fees.

This report presents and discusses the findings outlined above and details the study design, unit performance, participant and installer experience, and aggregate demand patterns.

Section I: Overview

Background

Heat Pump Water Heaters (HPWHs) with backup resistive heating elements offer a promising approach for decarbonizing residential water heating. However, conventional HPWH models require a dedicated 240V circuit, which may involve costly electrical panel upgrades, raising concerns about their overall cost-effectiveness as an electrification solution for customers. This cost increase is especially salient for customers earning low incomes.

In response to this concern, manufacturers introduced 120V HPWH models to plug into standard 120V wall outlets. These models often eliminate the need for major electrical upgrades but heat water more slowly, which can occasionally be inconvenient following large consumption events. Understanding the tradeoffs between cost and performance is crucial, particularly as California will ban the installation of new gas-fired water heaters in 2027, and other regions may follow suit. Incentive programs and manufacturers could benefit from data on whether these 120V units can effectively meet the demands of colder climates, where winter groundwater temperatures are low, and water heaters must distribute more heat to meet occupant demand.

In 2022, Slipstream conducted market research and modeling of the potential for 120V heat pump water heaters in Midwest homes.[4] That study found that 120V HPWHs can avoid the need for costly home electric upgrades that 240V units would likely require, while providing sufficient hot water for residents with typical hot water usage.[5] However, interviews with plumbers, distributors, and retailers indicated that they would be unlikely to sell the product without validation of 120V HPWHs high performance in cold climates. Interviewees also spoke to the needs for fuel switch incentives, since natural gas is quite affordable in the Midwest. In response, Focus on Energy, ComEd, Consumers Energy, and Xcel Energy partnered to conduct a year-long field study of real-world 120V HPWH performance at 27 sites across the Midwest.

Slipstream analyzed hot water availability relative to resident hot water consumption patterns in these climates, coefficients of performance and standby energy use with respect to indoor and groundwater temperatures, aggregate demand curves for water and power, and utility bill impacts in different utility territories. The research team also conducted feedback interviews with installers and collected user satisfaction data from three participant surveys. This final report presents these results and concludes with recommendations for the optimal use and functioning of 120V HPWHs in cold climates.

AWHI Collaboration

This study aligns with the Advanced Water Heating Initiative's (AWHI) research design.[6] AWHI is a national stakeholder group working to increase the adoption of HPWHs nationwide. AWHI is currently implementing field research on 120V HPWHs in Louisiana and completed a similar study in California in

[4] Slipstream Inc., *120V Heat Pump Water Heaters* (2022).
[5] Wisconsin and Illinois TRMs assumed 17.6 gallons of hot water use per day, per resident.
[6] https://www.advancedwaterheatinginitiative.org/.

2023, conducted by the New Buildings Institute (NBI).[7] Although these field studies have different funders, they follow a similar methodology for standardized results. This coordinated approach allows valid comparisons of results across various regions. A similar research approach also enables data-sharing via platforms such as the US Department of Energy's Heat Pump and Heat Pump Water Heater Field Database, to which we intend to upload our results.[8]

To the greatest extent possible, while meeting the objectives of our Midwest collaborating funders, the research team also aligned primary data collection methods with other AWHI monitoring projects. Throughout this study, Slipstream collaborated closely with NBI, building off their screeners, interview and survey guides, and M&V design. The two organizations have shared knowledge and methodologies to best compare 120V HPWH field study results from California's climate to those in the Midwest.

NBI's California study found that 120V HPWHs reduced energy consumption by 80-85% from a gas or propane baseline. In addition, 18 out of 32 sites in the California study demonstrated reduced operating costs, with an average reduction of $12 per month. Nearly all participants were satisfied with 120V HPWH performance. A few participants noted hot water runout events, although these were primarily larger households, sustained high hot water use events, or those with guests during holidays.

Technology

120V HPWHs are an efficient electric option to replace most residential water heaters in the Midwest, which are natural gas or propane water heaters. While 120V HPWHs should not be prioritized over their 240V counterparts when replacing electric water heaters or in new construction (as in these cases, electrical circuit and panel upgrades are unnecessary), they can be an attractive option when replacing natural gas or propane water heaters in older homes.

120V HPWHs have a lower energy input and therefore a slower heat recovery capability than standard 240V HPWHs. This increases the risk of hot water shortages for residents, which can cause dissatisfaction. Manufacturers have attempted to mitigate this lower recovery rate by combining higher-temperature storage with mixing valves and larger tank sizes.

In the US, only one manufacturer sold 120V HPWHs in 2022, and another entered the market in 2023 just before this study began. These two manufacturers (Rheem and A.O. Smith) were included in the study, as well as Nyle, who was planning to go to market with their product but has since postponed those plans. Since this study began, Embertec has also released a 120V HPWH and GE has developed a 120V HPWH for release in 2025.

[7] NBI, *Plug-In Heat Pump Water Heater Field Study Findings & Market Commercialization Recommendations* (2023) https://newbuildings. org/resource/plug-in-heat-pump-water-heater-field-study-findings-market-commercialization-recommendations/.

[8] https://heatpumpdata.energy.gov/index.php/

Recruitment

Customer Recruitment

The research team recruited participants and installed 120V HPWHs in 27 single-family homes across the Midwest over a 12-month study period. 24 sites were in climate zone 5, and 3 in climate zone 6.[9] Manufactured homes were excluded from participation due to concerns about the ability to fit an upsized HPWH into their water heater closets. To assess a variety of installation conditions and homeowner perceptions, recruited participants with a variety of:

- Geographic locations / climate zones within each collaborator territory
- Installation locations within homes (e.g., closet, utility room, basement)
- Occupancy levels within homes, ranging from one to four occupants

The research team also gave preference to sites with older existing water heaters to mitigate any possible dissatisfaction with the new HPWH. Given that we recommended hauling away any water heater older than 3 years after replacement, we did not want dissatisfied customers to feel that we hauled away a water heater which could have lasted them another decade. Although we targeted a mix of geographic locations, we attempted to find clusters of two to three nearby sites to minimize study complexity and reduce travel time.

This study was open to customers of participating utilities in single-family or multifamily residences with a maximum of four full-time occupants. The research team crafted a two-page fact sheet for outreach to customers containing details on the study and technology, customized for each utility collaborator. The Consumers Energy version is shown below in Figure 3.

Figure 3. Two-page fact sheet sent to participants.

[9] As per 2021 IECC climate zones. More information at www.energy.gov/eere/buildings/building-america-climate-specific-guidance.

The research team communicated with customers through different channels for each collaborating utility. The research team also created a central webpage that pointed to each recruitment website. During informal discussions and presentations, the research team and affiliates directed potential participants to this webpage for more information. Emails, social media posts, the webpage, and the fact sheet led interested customers to a pre-screening survey to assess site eligibility. There was significant excitement about this study, and over 300 people completed the survey. Methods of recruitment are detailed in Table 1 below.

Table 1. Outreach channels per collaborator.

Collaborator	Outreach Channels
Focus on Energy*	Social media posts, Reddit posts, utility outreach, utility newsletter
ComEd	Targeted email to prior program participants
Consumers Energy	Contractor emails, outreach through local partners, Reddit posts

* Includes Northwestern Wisconsin customers added through a scope of work with Xcel Energy.

Targeted email: ComEd sent a targeted email to customer homeowners with a prior Home Energy Assessment with a gas or propane water heater older than 5 years, reaching about 2000 customers. This was the primary outreach method for ComEd and generated 92 responses from two email blasts.

Reddit posts: In Wisconsin and Consumers Energy territory, the research team advertised the study on town subreddits such as r/EauClaire and r/GrandRapids. While subreddit moderators took some of these posts down, considering them "advertising," this effort recruited nearly all the potential participants in Wisconsin and Michigan. 142 total responses were generated in Wisconsin, and 68 in Michigan.

Social media posts: Focus on Energy advertised the recruitment site by posting on Facebook through its own account. This post generated very few leads.

Utility outreach/newsletter: The research team created an outreach email and a utility newsletter posting for Focus on Energy. We also primed the Focus on Energy utility liaison to encourage utilities to post their own recruitment messages for the field study. This outreach may have generated some potential participants, but utilities did not report whether or how they passed on the information, and a significantly stronger response was generated by the Reddit posts.

Contractor emails and local partners: The research team created an outreach email to HPWH installers in Consumers Energy territory and additionally conducted informal outreach to all participating installers. In both cases, we asked that they send the study materials or website link to sites they thought would qualify. These efforts did not generate any potential participants.

The research team reviewed all pre-screening surveys to assess site eligibility. Customers who met the eligibility criteria then participated in a virtual walkthrough where a research team staff member asked them questions as they captured photographs and video with their phone using the stream. com service. Research team staff reviewed the videos and responses to ensure:

- No upcoming major home renovations
- No hot water recirculation pump
- Sufficient space (e.g., ceiling hit, closet width) to fit the new water heater
- Available outlet in the space with unused sockets
- A nearby drain or sink for condensate
- Sufficient air volume for the HPWH to exchange heat

Appendix E contains the key for the participant pre-screening survey and the virtual walkthrough guide. Appendix A provides square footage, occupancy, and 120V model information for each site.

Manufacturer Recruitment

Rheem, A.O. Smith, and Nyle provided units for the study, although 120V HPWHs are not currently being distributed to or stocked in states included in the study. These manufacturers have said they are awaiting results from this study to assess whether they can distribute 120V HPWHs in the Midwest, given lower winter groundwater temperatures that may impact unit performance.

Installer Recruitment

The research team recruited six installation contractor companies to cover the study territory. Through this process, we learned several important lessons that to consider for future programs:

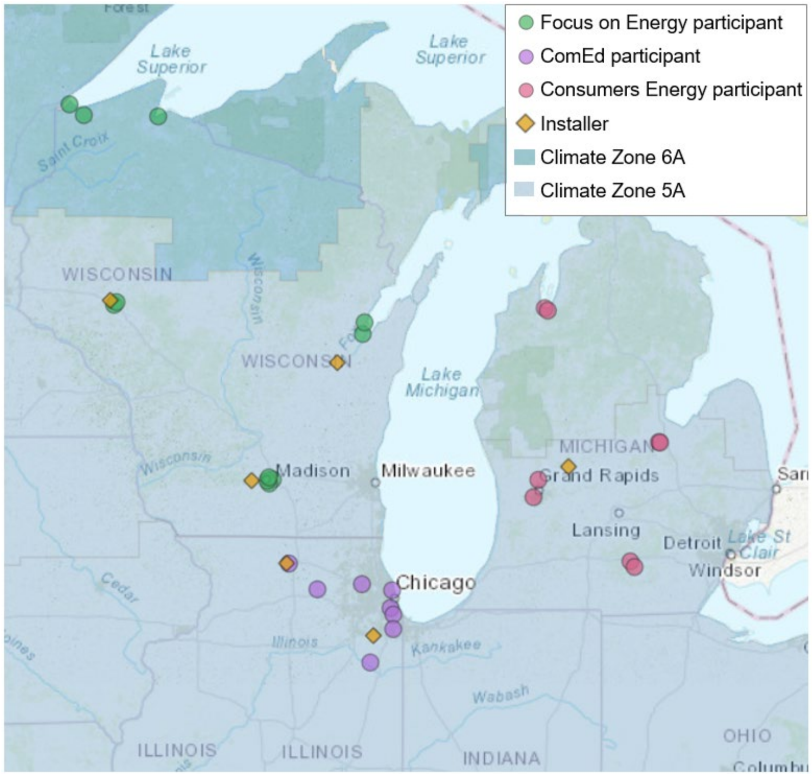
- Some (usually larger) plumbing companies and many HVAC companies have in-house electrical experience and can extend circuits without calling an electrician. This can reduce installation costs for the 120V HPWH.
- Larger contractors have storage areas and can receive custom orders, but smaller contractors rely on picking up the HPWH and other equipment from a distributor. Depending on the territory, early-stage programs may need to work with distributors directly to ensure products are available.
- Many contractors work with one distributor who sources from a limited set of manufacturers. Ensuring the program is agnostic to manufacturers may require working with multiple distributors.

Installation

Installations of the 120V HPWHs took place from October to December 2023, with one site delayed to February 2024. Research team staff attended each installation to coordinate with installers on measurement and verification (M&V) equipment, conduct onsite installer interviews, and assist in participant education. Specific recommendations for 120V HPWH installation practices can be found in Section IX.

The installation locations spanned the breadth of each collaborator's territory. For Focus on Energy, sites were clustered in Madison, Eau Claire, Green Bay, and Superior, Wisconsin. For ComEd, sites were in downtown Chicago, as far west as Rockford, and as far south as Kankakee (Bourbonnais). For Consumers, sites were clustered in Jackson, Saginaw, Grand Rapids, and Traverse City. Figure 4 shows the installation locations and associated climate zones.

Figure 4. Map of field study sites, with IECC climate zones. [10]



Unit Sizing and Selection

Sites were matched to appropriate units (e.g., tank sizes, footprint, occupancy) in consultation with manufacturers, and research team staff assisted installers in ordering these units directly or through distributors. Table 2 shows the characteristics of the delivered HPWHs.

Table 2. HPWH models included in the study.

Manufacturer	Circuit	Split System? [11]	Sizes Available	Integrated Mixing Valve?	Backup Electric Resistance	Quantity in Study
Rheem	Dedicated	Integrated	40, 50	No	No	8
Rheem	Shared	Integrated	40, 50, 65, 80	Yes, external	No	8
A.O. Smith	Shared	Integrated	66, 80	Yes, internal	Yes	10
Nyle	Shared	Split	Separate Tank	Required	No	1

Circuit type: Units were either recommended for a "shared" circuit, which may include branches for other appliances, or a "dedicated" circuit with a single outlet for the HPWH. Shared circuit units had a lower maximum power draw (3-5A) than dedicated circuit units (7-10A). Dedicated circuit units cannot be installed on a shared circuit, as this risks tripping a 15A circuit breaker during simultaneous use with other appliances.

[10] www.energy.gov/eere/buildings/building-america-climate-specific-guidance
[11] A split system unit has its heat pump and water tank separated, requiring a plumber to run piping between them.

If there was plenty of space and an available outlet, the research team installed a shared circuit unit. Where there were space constraints or no outlet present, the team took the opportunity to wire and install a dedicated circuit unit. Power-vented gas water heaters are often installed on a dedicated circuit, so a dedicated outlet may already exist in some fuel switching scenarios. This was the case with two of the sites in this study, and the team installed dedicated circuit units at these sites.

Sizing: Because of longer heating times, manufacturers recommended that the shared circuit 120V HPWH tanks were upsized by two sizes from the participants' previous water heater to prevent long-lasting hot water runouts.[12] Because gas and electric resistance water heaters heat water faster, this upsizing results in a similar first hour rating,[13] a measure of the hot water available in a single hour of use when the tank starts fully heated. Given that consumers were largely satisfied with the performance of their new units, but experienced occasional runouts at around the same rate as with their old heaters, the research team recommends this upsizing for any future 120V installation. Manufacturers recommended to not upsize dedicated circuit units because their larger compressors offer higher heating capacities in conjunction with higher power draws.

Mixing valves: Most shared circuit units also included an integrated mixing valve, and for the ones that did not, we installed an external valve. This allowed the HPWH to heat water to a higher temperature than the desired faucet temperature and mix it with colder water before distribution, further increasing the unit's capacity.

Electric Backup: The A.O. Smith units contained a backup electric resistance element. This element activates as emergency backup when the room air temperature or water temperature fall below certain thresholds, at which points the heat pump is unable to function properly. This backup also allows the heater to operate only on electric resistance mode if the heat pump compressor is experiencing an issue.

Installation Insights

Research team staff were on site during all installations to install M&V equipment and engage with installers. We also returned at the end of the study to remove the M&V equipment.

During these trips, we noted several details, barriers, and constraints:

- Space constraints are highly site-specific and greatly impact the feasibility and ease of installation. Because of the necessary upsizing, shared circuit 120V HPWHs take up more space than their gas or electric resistance counterparts. Closets, low ceilings, raised stands, poured concrete blocks, ducts, furnaces, and pipes can constrain the space available and make the HPWH installation more difficult or, in some cases, impossible. However, most of the installations took place in basements with plenty of available space.
- Installers did not typically bring equipment to site to replace or modify doors, and the 120V HPWH units ordered through this study did not come with ducting kits (this is typical for 240V

[12] Typical tank sizes are 40, 50, 65, and 80 gallons. The team upsized this by two sizes unless the household size indicated that the tank was already oversized, or the maximum tank size of 80 gallons was reached.
[13] https://www.energystar.gov/products/water_heaters/residential_water_heaters_key_product_criteria

units, too). While most installation locations had sufficient air volume to meet manufacturer recommendations, installers at some sites were not prepared at the beginning of the installation to accommodate air volume needs through ducting or adding louvered doors to a secondary space. Confirming whether ducting or door modification is be necessary before arriving on site would save time and trouble at future 120V HPWH installations.

- Due to upsizing and the attached compressor, most of the shared circuit HPWHs installed in this study were heavier and larger than the gas or electric resistance units that plumbers would have chosen. In addition to the ability to install at the final area, this bulkiness led to difficulties navigating narrow stairways and hallways. While some installers were able to bring the HPWH units in alone, others expressed skepticism about their ability to install the units with only one person.
- Units with their hot and cold water piped out of the top required shorter piping runs to connect to existing pipes, saving time and reducing complexity. Units with these ports on the side effectively had a larger horizontal footprint than their diameter dictated because installers had to add a protruding elbow to turn the pipe upwards along the side of the unit.
- Electrical outlet location, panel location, and available breakers impact the complexity of installation. Ideal sites had an electrical outlet within reach of the 8-foot HPWH power cord. If an outlet was slightly too far, an electrician needed to extend the circuit and add an additional outlet. If no circuits could be easily extended, the installer or a contracted electrician needed to add a breaker to an open slot on the panel and run the circuit to the water heater. Each of these scenarios required electrical work, increasing cost and complexity.
- Minor electrical work is often required for 120V HPWH installs. Only two of the eight interviewed dedicated circuit sites had preexisting dedicated 15-amp circuits, and the installation of this circuit was the most complex electrical work done for this study. 10 of the 17 interviewed shared circuit installations required no additional electrical work.
- Some sites had 240V circuits running to the water heater area that had been terminated, likely because they switched from an electric resistance water heater to natural gas in the past. These sites would have made good candidates for 240V hybrid HPWHs.
- Drain or sink location dictated the complexity of installing a condensate line and/or condensate pump. Installers noted that this is not required for gas or electric resistance water heater installations. While many basements had drains or basement sinks below the condensate drain on the water heater, some required condensate pumps, which are separately powered appliances. Closets with water heaters had drains for the laundry machine, which installers ported condensate lines into.

Site-specific details:

- At one site, the two plumbers were not strong enough to maneuver an 80-gallon unit down a long, narrow stairway. They called their boss, who drove out to assist them.
- At another site, the built-in concrete stand for a water heater was too narrow for the installed HPWH. The installer determined that the overhang would not pose a significant problem, and that the tank would not tip when filled and piped.
- There were a few sites that opted out of the study after being selected:
  - One site had sufficient space and an available outlet for the HPWH installation, but the room was a narrow utility closet with the current water heater located just past the furnace. After

visiting the site, the installer determined that none of the available units could fit between the furnace and the opposite wall, and the site was disqualified.

  - One site had a utility closet located just off the kitchen, with louvered doors facing the refrigerator and cooking area. While the closet had sufficient space for the HPWH, the resident became concerned when the research team noted that the doors would vent colder air into the cooking area, and they withdrew their application.
  - Two sites had water heater closets located just off a bathroom. Both bathrooms did not have sufficient air volume according to manufacturer instructions, so the units would have had to be ducted through a wall into a different area. While this is feasible, both participants elected not to move forward.

Section II: Installer Experience

Summary

After each unit install, we interviewed the installation contractor. We interviewed 10 contractors, some multiple times, for a total of 25 interviews. [14] These interviews helped us gain valuable insights into the particularities of 120V HPWH installation.

Eight of 10 installers had previous experience with 120V or 240V HPWH installation. About half of those installers had extensive experience (>10 HPWHs), while the other half had previously installed 5-10 HPWH units.

Three installations were completed with just one installer. One install with an 80-gallon tank that needed to go down a narrow stairway required three installers. The remainder required two installers, to transport the equipment.

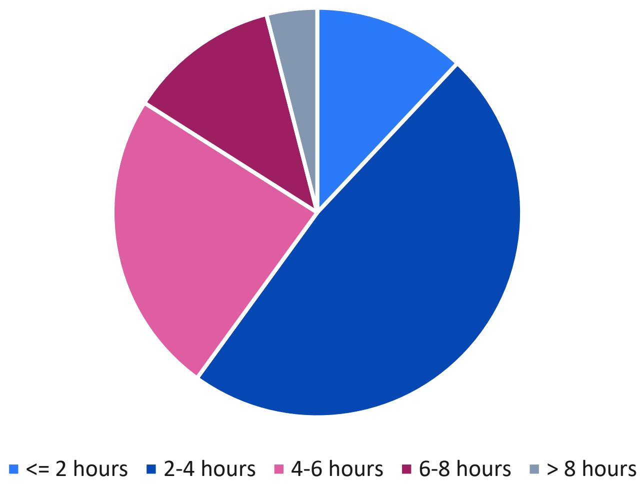
One recurring theme in these interviews was the increased height and width of these units compared to their 240V or gas heater counterparts and the need to confirm that the install space, and the pathway to that space, are large enough to accommodate them. Installers also stressed the unwieldiness and bulkiness of many units, especially the bigger tank sizes and the units with compressors on top (which made them top heavy). Some installers also stated that it would be a good practice to meet virtually with the homeowners before installation to get an idea of the space setup and work required and to verify that a 120V HPWH is the best option.

There was substantial variation in the time required to prepare the sites and install the new heater. Total installation time ranged from two to ten hours, usually taking less than four hours. Figure 5 shows the installation time distribution. Variation in the electrical and piping work needed is the likely cause of this range. Installers with less experience reported that the installs got easier as they did more of them. However, this was not correlated with faster installs. It is likely that site-specific and model-specific constraints were responsible for the variation in time, but that these same constraints felt like less of a "lift" as installers gained more experience.

Most installers said that 120V HPWHs took slightly more time than a gas installation due to extra piping and electrical work, though time was saved by not having to install a gas unit power vent. Installers also specified that installing the water flow meters and thermistors necessary for the M&V of this study added a bit of time (~30 minutes, according to one) to the work.

[14] At two sites, challenges with installer timing precluded immediate interviews, and we could not reach installers soon afterwards. Given that each installer was interviewed at least once for each product type they installed and that late interviews were less likely to be accurate, we did not further pursue these data points.

Figure 5. Time for site preparation and installation, combined.

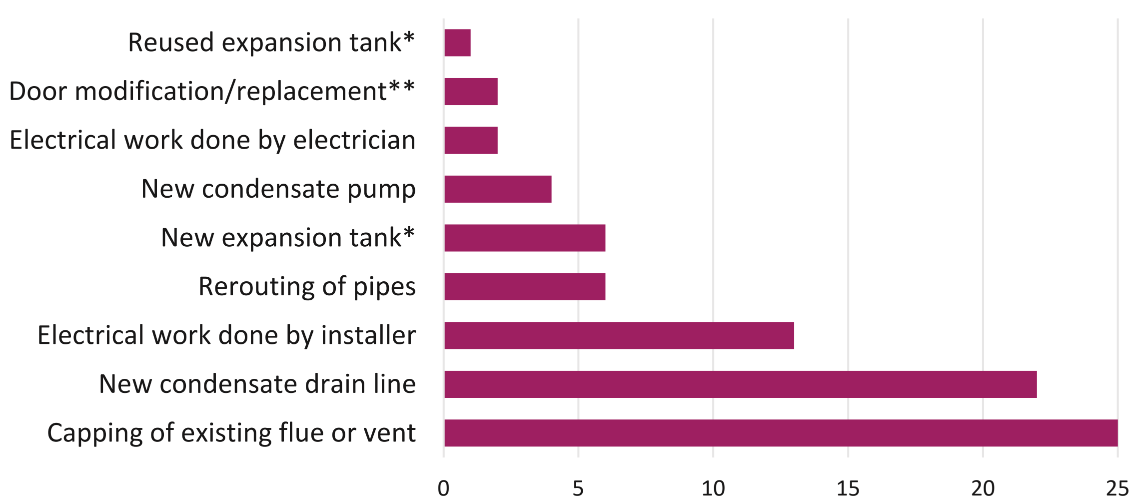


15 of the 25 interviewed installations required electrical work. For 13 of these sites, this work was done by the installer. The other two required an outside electrician.

The electrical work consisted of adding new outlets and ground wires and extending circuits. For the dedicated circuit units, creating and routing that dedicated circuit was often required. In general, installers reported that this was more electrical work than installing a new gas unit would require and less electrical work fuel switching to a 240V HPWH. Dedicated circuit units often required the installer to create and route that dedicated circuit. This necessitated more electrical work than the shared circuit units, but the installers reported a tradeoff, as the dedicated circuit units are smaller and easier to handle.

Figure 6 details different types of work done at various sites, and the frequency of each.

Figure 6. Number of sites (25 total) requiring various work during installs.



* Sites without a reused or new expansion tank did not need one at all.

** One room door was replaced with a louvered door, and one was modified to fit the HPWH through.

Installers relied on manufacturer instructions to varying degrees. In general, installers said these instructions were relatively easy to follow, suggesting minor improvements for added clarity in the graphics and instructions. For two installations, the manufacturer instructions were not enough, and the installer called the manufacturer while on site. They needed more information on piping in one case, and on building a supportive stand in the other.

None of the installers set up communicating controls for the unit. That was left to the consumers, although the research team attempted to assist any customer who wished to enroll.

The installer interview guide can be found in Appendix E, and the full table of responses can be found in Appendix F. Specific recommendations for 120V HPWH installation practices can be found in the Conclusions and Recommendations section of this report.

Selected Quotes

> *"Companies might turn away from the difficulty getting units in and out of places. [Especially] a company who can only send one guy. [An] electric dolly [is] very helpful. [I'm] younger than other guys out there, but a jerk the wrong way or a missed step and you could go flying with the weight of that thing."*
>
> *"You need to be aware of the height available at the site. These are much taller than a standard water heater."*
>
> *"Of the four units installed this week, [my] favorite was the dedicated [circuit] unit [because of the] smaller tank."*
>
> *"Make sure that the customer knows all the features. It would be great to get training on the features and applications of the 120V HPWH to help sell this equipment in the future."*
>
> *"It went pretty good. Typical water heater install with a condensate floor drain."*
>
> *"It was a learning process, but smooth. It was different, but I was expecting [that]."*

Section III: M&V

This study blended site monitoring data, cost data, customer satisfaction data, and installer satisfaction data. Below is a list of the data-gathering activities from the study's M&V plan:

- Collect customer electric, natural gas, and/or propane bills.
- Collect site information through photographs and surveys, both before and after the study.
- Conduct installer interviews.
- Conduct a pre-installation survey on customers' satisfaction with their prior unit.
- Conduct a post-installation survey on customers' satisfaction one month after HPWH installation.
- Conduct a post-winter survey on customers' satisfaction through the coldest groundwater and outdoor temperatures.
- Conduct final surveys on customers' satisfaction after summer.
- Monitor HPWH performance (power demand, water demand, water temperature, and indoor temperatures) from installation through September 2024.

M&V Equipment

The research team installed sensors to measure key variables that inform the study research questions. These sensors are detailed in Table 3. To install immersion sensors, installers were given "baseboard tees" to include in the piping, with a port for the probe. To install the water flow meter, installers had to identify or create a horizontal section of piping suitable for accommodation. In some cases, this made the installation more difficult and was noted in the installers' interviews. However, this difficulty should not have affected water heater operation.

Table 3. Monitoring system components.

Measured Variable	Measurement Sensor or Device	Collection Interval
Water heater electric power	Packet Power Smart Cable	Minutely
Water heater amperage	TruePower CT on short Extension Cable	Secondly
Volumetric hot water flow/consumption	Badger meter with pulse output	Secondly
Hot (outlet)[1] and cold (inlet) water temperatures	Omega 44008 thermistor temperature sensors (immersion sensors in piping)	Secondly
Air temperature - at water heater inlet	E+E model EE08 temperature/humidity sensor	Secondly
Air temperature - in air volume	E+E model EE08 temperature/humidity sensor	Secondly
Air temperature and humidity - edge of required air volume	E+E model EE08 temperature/humidity sensor	Secondly
Condensate pump operation[2]	Current switch	Secondly

[1] Some units have integrated mixing valves. The outlet temperature will be measured after the mixing valve in these cases, but as close to the tank as possible if an external mixing valve is used.

[2] Only 4 units in the study required a condensate pump.

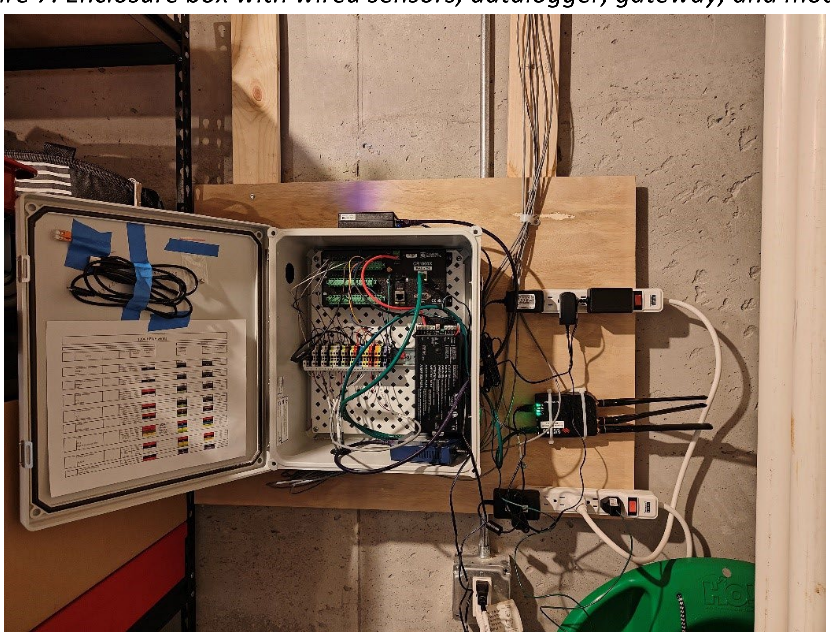
The research team installed three ambient air temperature sensors around the HPWH:

- One sensor was placed at the air inlet of the HPWH.
- The second was placed near the middle of the exchange air volume (referred to as "in air volume" below). Manufacturer installation instructions dictate that this exchange volume be a certain size for each water heater type. Given the disparate ceiling heights, room layouts, and required air volumes, the placement of the air volume temperature sensors was a judgment call at each site. In general, the research team placed this sensor five feet high and within the air volume as dictated by the manufacturer instructions, usually three to five feet away.
- The third "edge of air volume" temperature sensor was placed at the boundary to the living space, unless the water heater was in a space where that would be excessively far away. We considered the living space to be anywhere a person might regularly visit. For example, in a basement with laundry machines, preference was given to place the air volume sensor near the laundry machines to match the perceived comfort impacts to participants. In a room with a door to a living space, preference was given to place the sensor by that door.

Data from all sensors besides the Packet Power strip were recorded by a Campbell Scientific CR1000X Measurement and Control Datalogger. The Packet Power strip data were sent through a proprietary wireless protocol to a gateway device. Note that the Packet Power devices only started recording data in March, but that the amperage measurements from the Campbell device allowed us to calculate power values throughout the duration of the study period. More information about how we infilled these missing wattage values is in Appendix D.

Both the datalogger and the gateway sent data to a cloud database through a cell modem installed on-site with the other equipment. A typical setup is shown in Figure 7. All data was verified and tested for accuracy on site before the study began. More information can be found in Appendix B.

Figure 7. Enclosure box with wired sensors, datalogger, gateway, and modem.



Data Aggregation and Correction

Most metrics were measured every second, allowing for granular analysis of draw behavior, including the timestamping of water draw starts and ends. There were several sites reporting abnormal draw measurements that were investigated and treated at the per-second level. For more information on these abnormalities, see Appendix C.

After these treatments, the data was summed and averaged where appropriate and bundled into minutely increments. We then appended the minutely Power Packet data. The resulting data-frame was used to complete draw-, daily-, site-, and study-level analysis. Note that because power draws were typically greater than 30 minutes long and occurred asynchronously with water draws, this lower granularity did not impact draw-level analysis.

Section IV: Operation

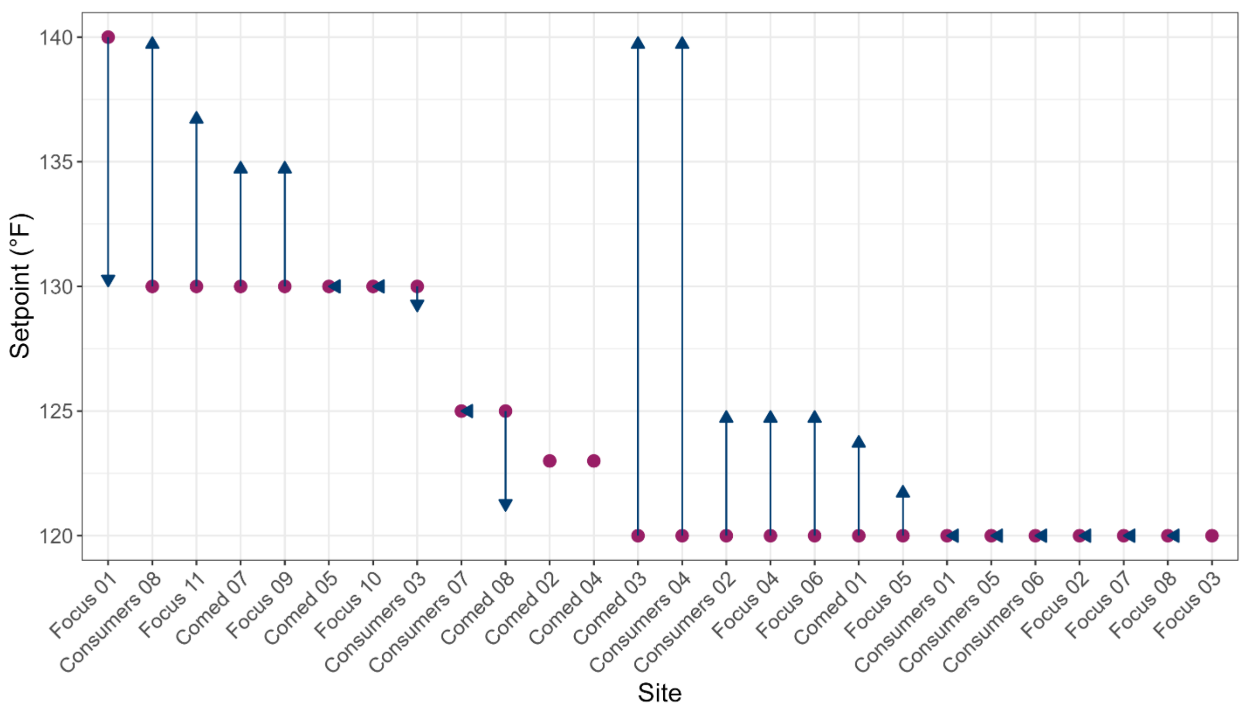
In monitoring sites' power draw, water consumption, and input and output water temperatures, we built a profile of each unit's operation. This section details site setpoint temperatures, followed by basic site consumption figures. We then provide aggregate temperature and humidity measurements and maximum power draws by season. Finally, we break down a typical day-long time series of draw measurements.

Temperature Setpoints

Manufacturers directed installers to set water temperatures between 120- 130°F. The most common setpoint at installation was 120°F, with 14 sites. The second most was 130°F, with seven. Two units were set at 123°F, two at 125°F, and one at 140°F. Thus, the original setpoint average was 124°F. As seen in Figure 8 below, nine participants kept their setpoints constant with the temperature at which they were installed, 10 participants increased them, and three decreased them. Setpoints changed by an average of 3°F increase.

Of the participants who raised their water heater setpoint, three sited hot water runouts as motivation. The rest reported that they raised their setpoints because they wanted warmer water in general, for comfort or safety reasons. The few who lowered their setpoint thought the original setpoint was too hot for their purposes.

Figure 8. Setpoints at beginning and end of study, in order of starting setpoint.



*Sites with arrowheads to the right of the dot did not change their setpoint. For dots without arrowheads, the change in setpoint is unclear, as these sites did not provide final setpoints.

Site-Level Averages

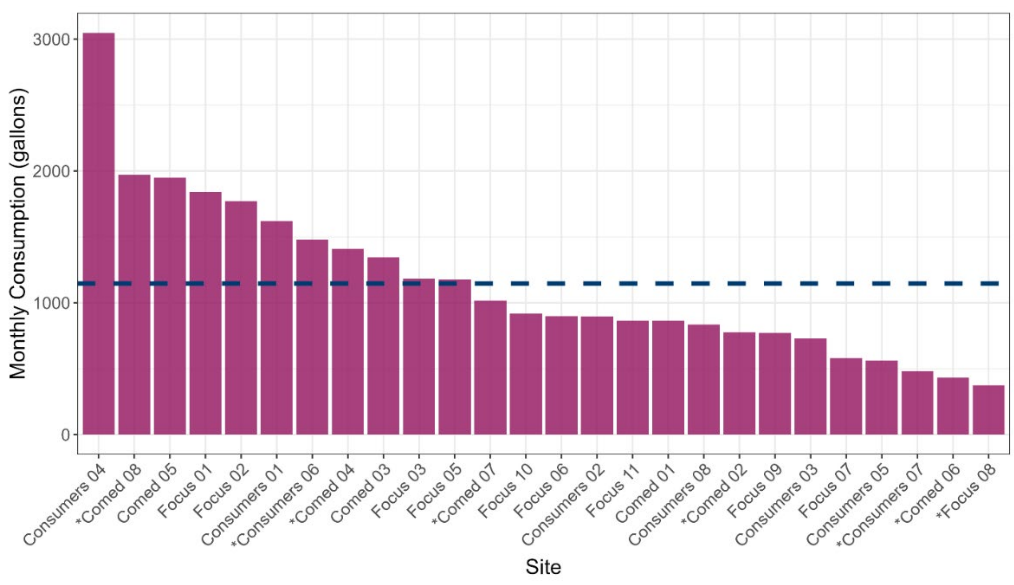
To provide a high-level overview of site consumption characteristics, the figures below display each 120V HPWH's average monthly power consumption, average monthly water consumption, and average daily runtime.

Figure 9 shows the average monthly hot water consumption of each site. Sites consumed an average of around 1100 gallons per month (16 gallons per person per day). This is above Wisconsin[15] and Illinois[16] TRM assumptions, which at 17.6 gallons of hot water use per day, per resident, would predict < 1,200 gallons/month for our average study residence occupancy of 2.26.

The lowest consumer, with a household occupancy of one person, used 400 gallons/month. The highest consumer, with an occupancy of four people, used 3000 gallons of water a month, 50% higher than any other site and above IL and WI TRM assumptions. This participant attributes the household's high-water use to their teenagers' long daily showers.

Consumption generally increases with household size. Out of the top five consumers, four have an occupancy of three or four, and of the bottom five, all have an occupancy of one or two. Notably, the two participants with the greatest consumption had the most issues with hot water runouts.

Figure 9. Monthly water consumption per site, dashed line showing average.



* Sites with a dedicated circuit.

Figure 10 shows each 120V HPWH's average monthly power consumption in kWh. Sites consumed an average of ~70 kWh per month, ranging from ~30 to ~150 kWh. These values follow an order like that of sites' average water consumption. The differences between the relative magnitudes of values on these two graphs are due to the efficiency and operating conditions of each unit, as well as the pattern of each occupant's consumption habits.

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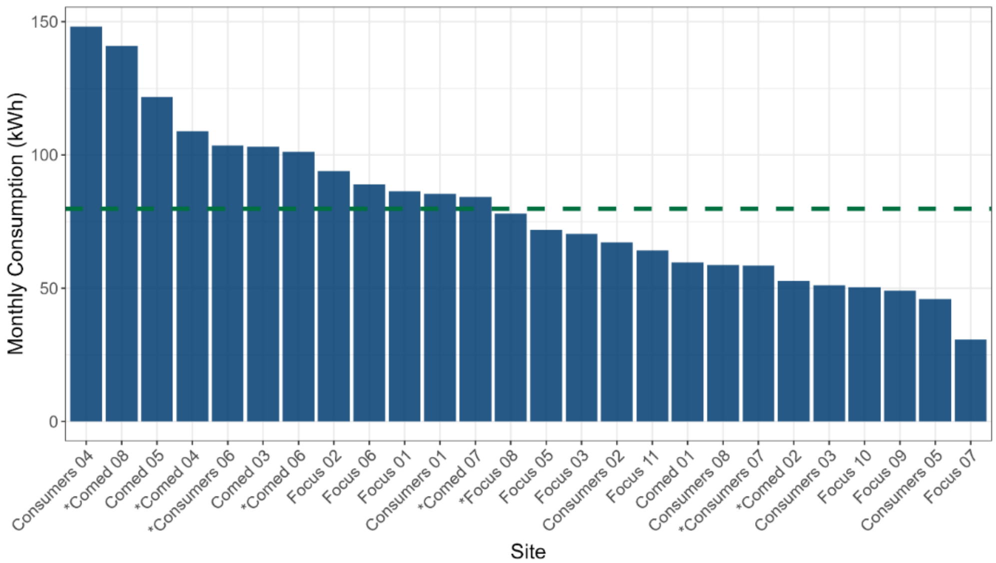
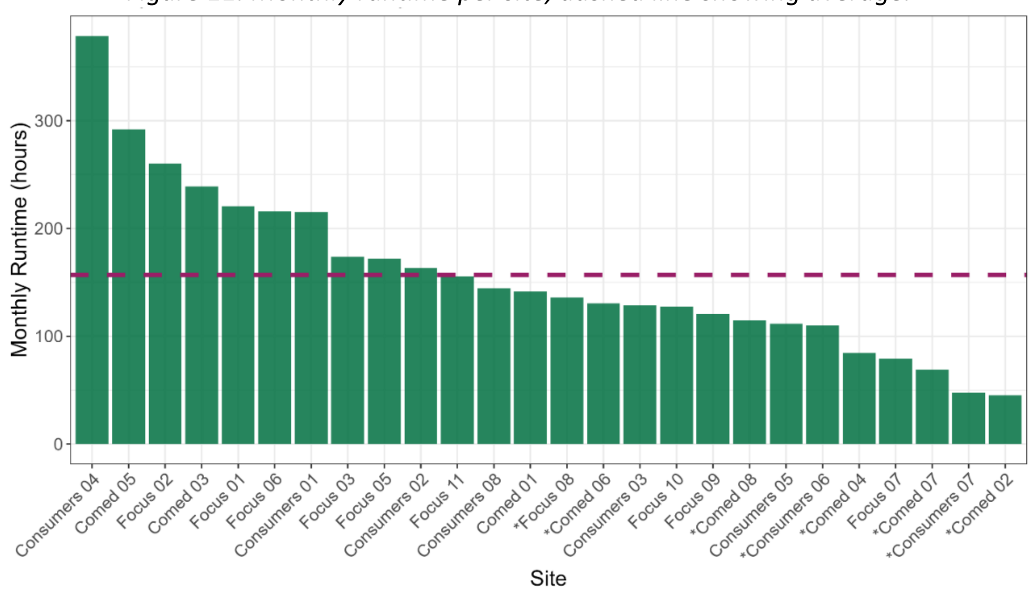
15 2023 Wisconsin Focus on Energy Technical Reference Manual, "Heat Pump Water Heater", W0200, pgs. 795-798.
16 Illinois TRM v12, "Volume 3: Residential Measures", pgs. 250-255.

Figure 10. Monthly power consumption per site, dashed line showing average.



* Sites with a dedicated circuit.

Figure 11. Monthly runtime per site, dashed line showing average.



* Sites with a dedicated circuit.

Figure 11 shows each site's average runtime. Sites ran between 50 and 375 hours a month, with an average of ~150 hours (i.e., three hours per day). The order of the sites is shuffled when compared to the above two figures. This reordering is because dedicated circuit units can procure a given amount of power with much less runtime than a shared circuit unit. These dedicated circuit units are clustered near the lowest monthly runtime values.

Note that because 240V HPWHs have, in general, the same heat pump technology as 120V units, they have runtimes like those of the shared circuit 120V units. However, they have a powerful electric backup mode available that takes over that runtime when their heat pump mode is unable to meet demand.

Electric Resistance Boost

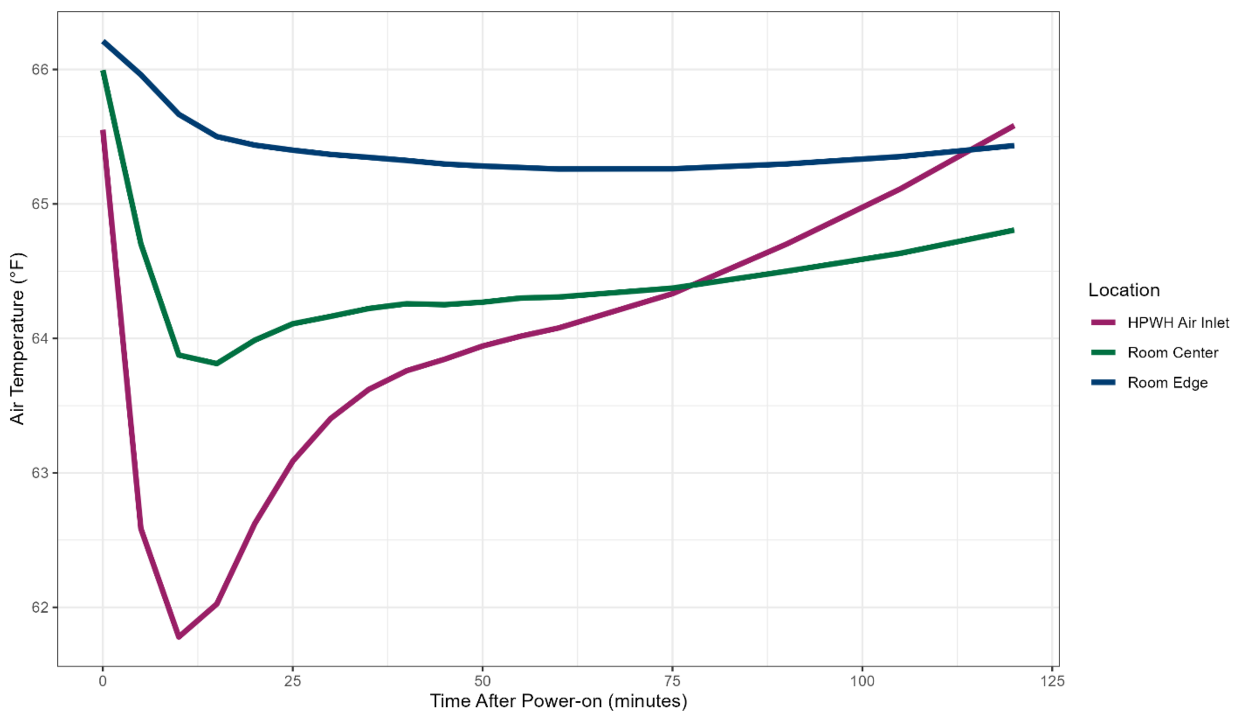
Ten of the units that we installed included an electric resistance element to kick in during emergencies, which the manufacturer defines as times when the air outside the unit is less than 37°F, or the water within the unit is less than 55°F. The resistance elements were activated only sparingly throughout the study period, only seven times across all ten of these units.

One benefit to this mode of operation is that if there is an issue with the heat pump compressor or its controls, these units can switch to electric resistance mode. This decreases efficiency but can provide a consumer with hot water while the heat pump element is being fixed. This occurred at one site during the study period.

Room Temperature and Humidity

In alignment with participant survey responses, we measured a marked decrease (~5°F) in the air temperature at the HPWH inlet after each power draw began. This dip was less severe across the room from the heater (~2°F) but remained low for hours after operation. 60% of participants reported noticing this drop in their final survey responses. Figure 12 plots the temperature, on average, at the minutes following a power draw event.

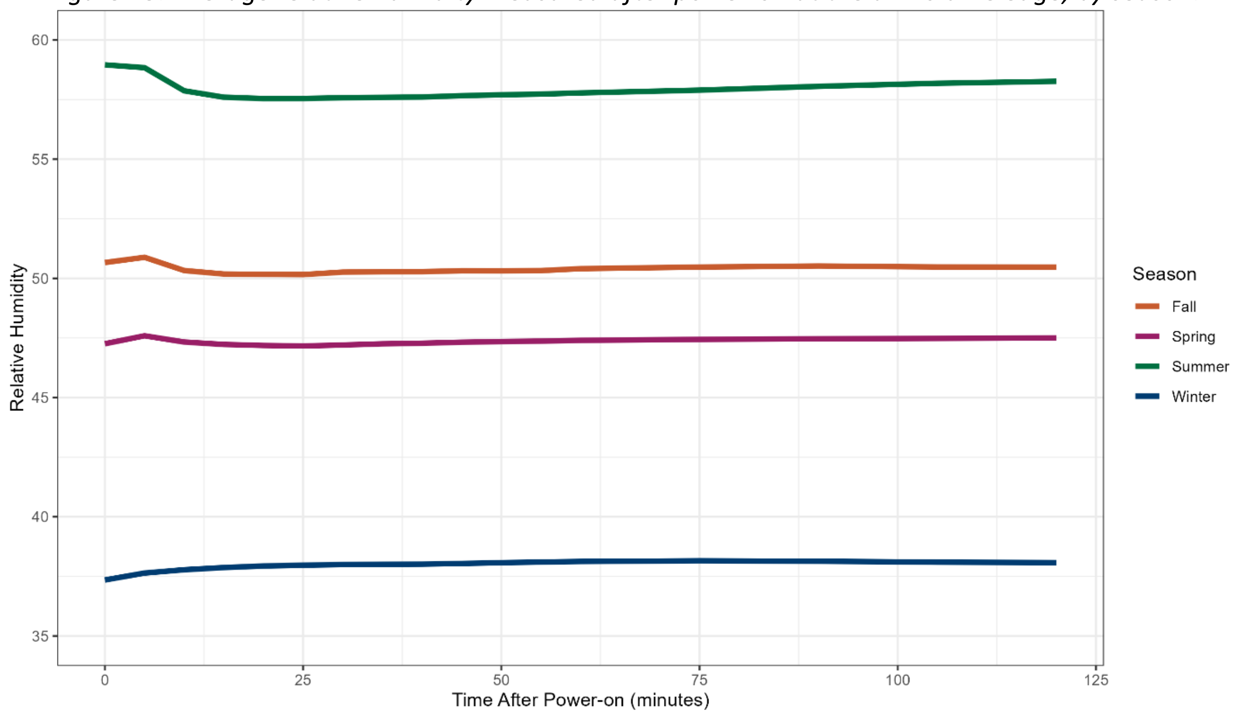
Figure 12. Air temperature after power-on at three locations around heater.



At the time of the final survey, taken in the summer, 30% of participants reported noticing a humidity drop in the room. This number was only 15% in the early winter survey, as well as in the early spring survey. We measured relative humidity only at the room edge, rather than the HPWH inlet, and found only a slight decrease, and only in the summer season. We assume humidity dipped more severely directly next to the heater, like temperature. Absolute humidity, which rises with lower temperatures even as relative humidity is constant, also likely decreased in the room after each power draw.

Figure 13 plots the average relative humidity following power draws within each season. There is a decrease in humidity following power-on in the summer months, when humidity is highest to begin with, and when participants most noticed the change, but not much of a trend during other seasons.

Figure 13. Average relative humidity measured after power-on at the air volume edge, by season.

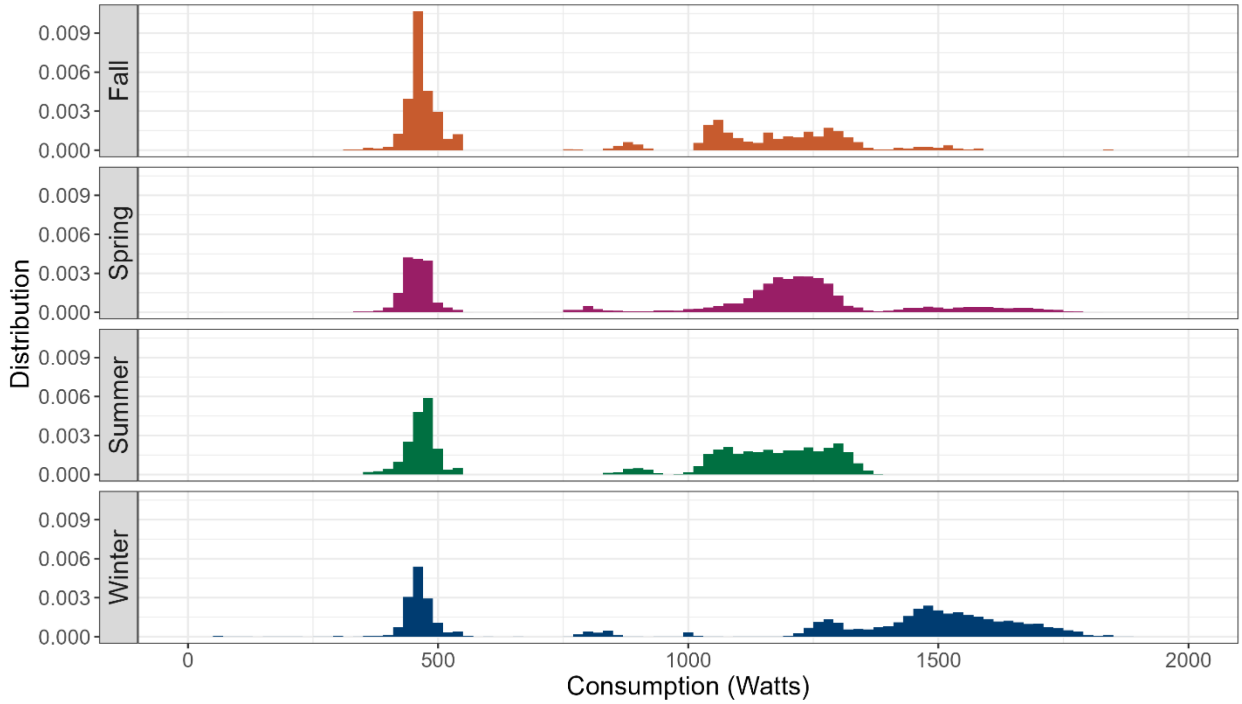


Power Cycle Maximums

Depending on HPWH model and circuit type, sites' power cycles reached different maximum demand values. As noted when discussing the runtimes in Figure 11 above, dedicated circuit units can heat water faster. This is due to these units' ability to reach a higher maximum cycle wattage, and indeed, in Figure 14 below, the clusters at 1000W and above are these units' cycles.

Dedicated circuit units also exhibited the most drastic seasonal variation. The cycle maximums of these units in summer are all around 1000-1300W, but in the winter these reach up to 1800W. Shared circuit models maintained consistent cycle speeds throughout the seasons, peaking almost always around 400W, with one manufacturer's unit peaking at around 800W.

Figure 14. Distribution of cycle demand maximums in each season, across all sites.



Typical Daily Timeseries

Figures 15a and 15b show a typical day-long timeseries plot of water temperature, water consumption, and power consumption, and that same plot zoomed into one hot water draw.

At times when water is not being consumed, the water temperature measurements only detect the temperature of the standing water in the pipe. Accordingly, the spikes in hot water temperature (measured by a thermistor) correspond to water consumption (measured by the flow meter). These hot water spikes in temperature allowed us to complete the data treatments described in Appendix C. Hot water consumption also corresponds to dips in measured groundwater temperature; when water is being consumed, fresh, and colder, groundwater is flowing.

Note that power draw does not happen concurrently with water draw. Because of this, our energy efficiency analysis was done at the daily level.

Figure 15a. A timeseries over the course of one day, with datapoints each minute.

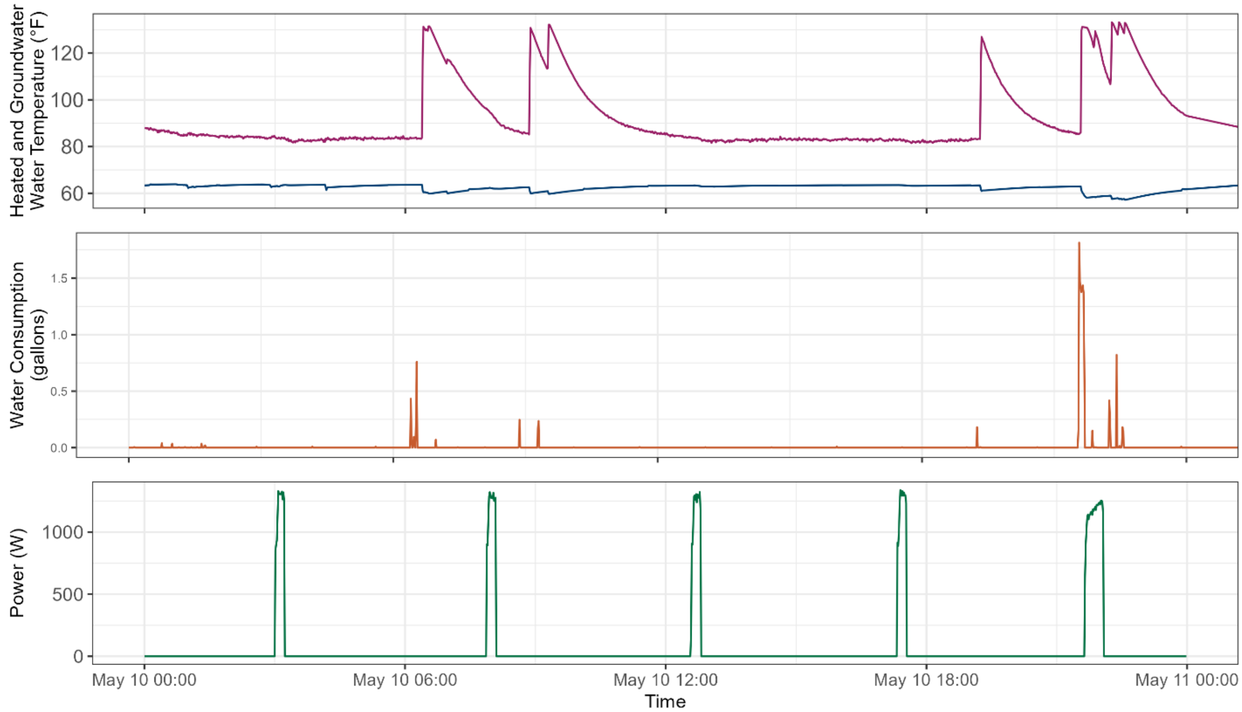
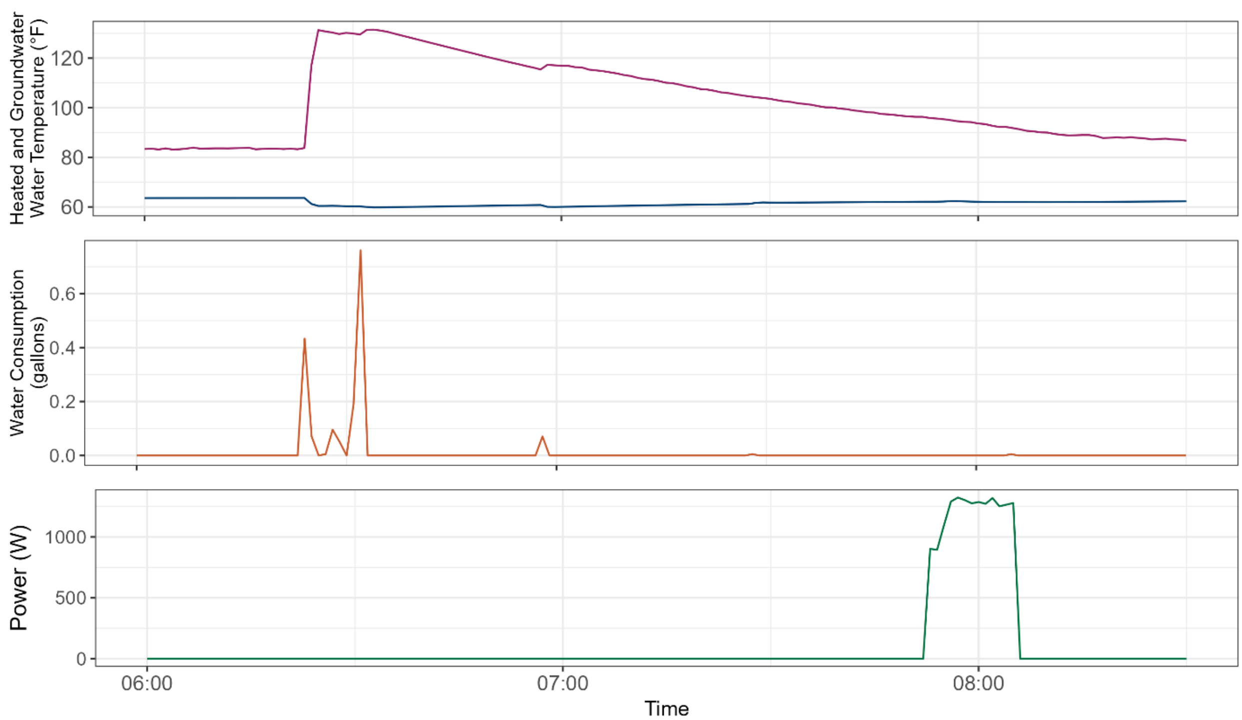


Figure 15b. The same timeseries as above, zoomed into one hot water draw.



Section V: Hot Water Availability

One of the top priorities of this study was to quantify the hot water runouts experienced by participants and characterize any conditions correlating with those runouts. We found that consuming a large amount of water within a few hours significantly increased the chance of running out of hot water in the time following. While this may be true for 240V and gas units as well, 120V units heat water more slowly than their counterparts, even if they have a backup resistance element. With a 120V unit, when hot water runs out, it runs out for longer due to their longer heating time.[17]

Similarly, effects of colder groundwater on heat recovery times are exacerbated by 120V units' lower power draw. The tank of any water heater, when emptied, will take longer to refill with cold groundwater than it will with warmer groundwater. This is especially noticeable with 120V HPWHs because it extends an already lengthy recovery time.

After testing various thresholds, we defined a hot water runout as a draw in which the final output temperature of the water was below 110°F. This definition was further expanded to distinguish between true runouts and draws exhibiting abnormal hot water temperature patterns, detailed in Appendix C, which were filtered out of the runout totals. We also filtered out draws under 30 seconds or 0.5 gallons, as these draws were too short to reach a reliable hot water end temperature datapoint.

There were varying end temperatures of hot water runouts, with some draws dipping just below 110°F and some dipping much lower. Table 4 exhibits a profile of the water draws at all sites throughout the year, tallying draws and runouts by end temperature. We also counted the number of runouts occurring within five hours of a previous runout, to get a sense for how many high-consumption events were causing multiple runouts before the tank was able to reheat.

Table 4. Hot water draw profile.

Final Hot Water Temperature Reading	Total Number of Draws	Number of Runouts Within Five Hours of Previous Runout
<90°F	177	115
90-95°F	84	57
95-100°F	101	60
100-105°F	144	86
105-110°F	174	74
>110°F	45,748	NA

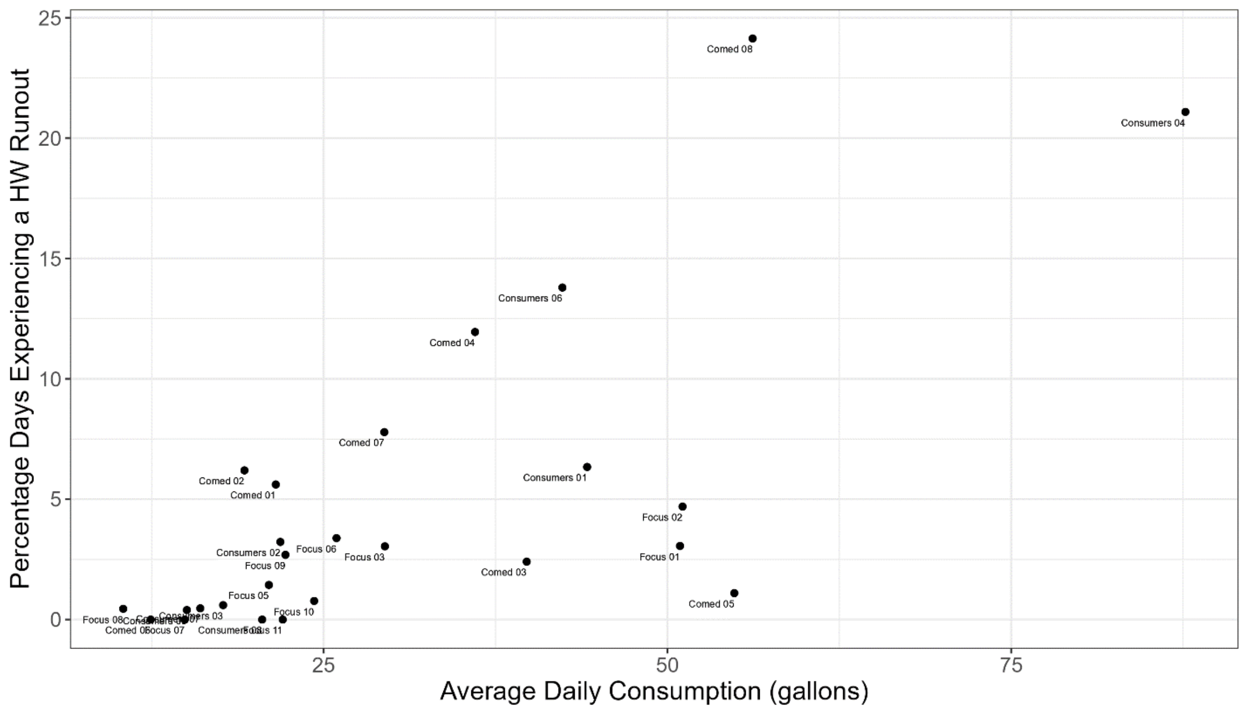
Note that this analysis does not fully capture participant experience. A runout that a resident waited for to get out of the shower, or one that occurred during a dishwasher or laundry machine cycle, may not be noticed, and thus may not impact customer satisfaction. The surveys capturing consumer satisfaction are reported in Section VIII.

[17] As mentioned in Section IV, dedicated circuit units have a shorter runtime than shared circuit units, but a longer runtime than gas or electric resistance units. However, their users recorded the same number of runouts as shared circuit users, and a lower general satisfaction level. This is potentially due to differences in unit sizing practices between the circuit types. Upsizing dedicated circuit units could decrease runouts.

Consumption Versus Hot Water Runouts

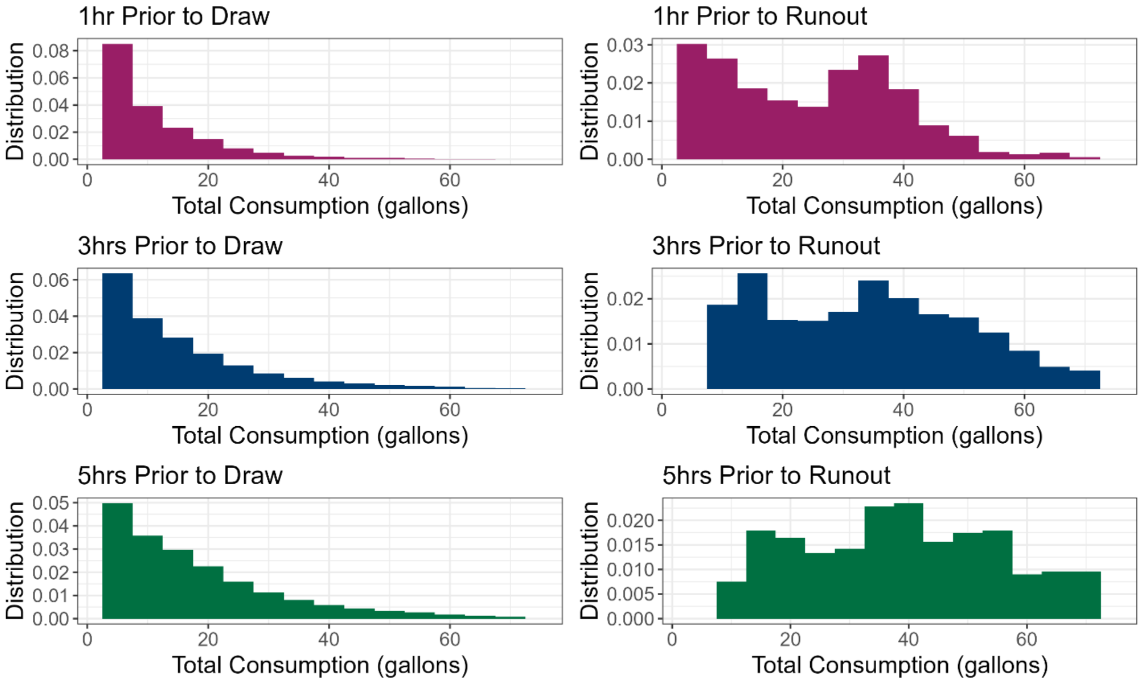
The percentage of days that each site registered at least one hot water runout is shown in Figure 16 below. One-third of sites experienced fewer than 4 days with runouts during the 10- to 11-month duration of the study. The average percentage of days with a runout was 5%. The two study sites that experienced the most runouts (24% and 21% of days) also consumed the most water (52 and 80 gallons per day on average) and had three or more occupants each. One of these sites was the site who opted to replace their unit at the end of the study (more information in Section VIII). In general, sites with a higher daily water consumption experienced more hot water runouts.

Figure 16. Site-level consumption and percent days with at least one measured runout.



More specifically, high consumption during the hours prior to a draw event led to greater hot water runout frequency. Figure 17 below is based on windowed hot water consumption totals leading up to each draw event. We set these windows at different lengths (1 hour, 3 hours, 5 hours) to visualize the impact of 120V HPWHs' slow recovery time. The figure shows distributions of values for cumulative consumption during the hours prior to an average draw with no hot water runout on the left-hand side. The right-hand side shows those distributions for draws with hot water runouts. There are much higher prior consumption distribution values for hot water runouts than for satisfactory draws. Note also that there are some runouts for which not much water was consumed during the 1 or even 3 hours prior. These occur because the unit has not recovered from a large consumption event 3-5 hours before that runout.

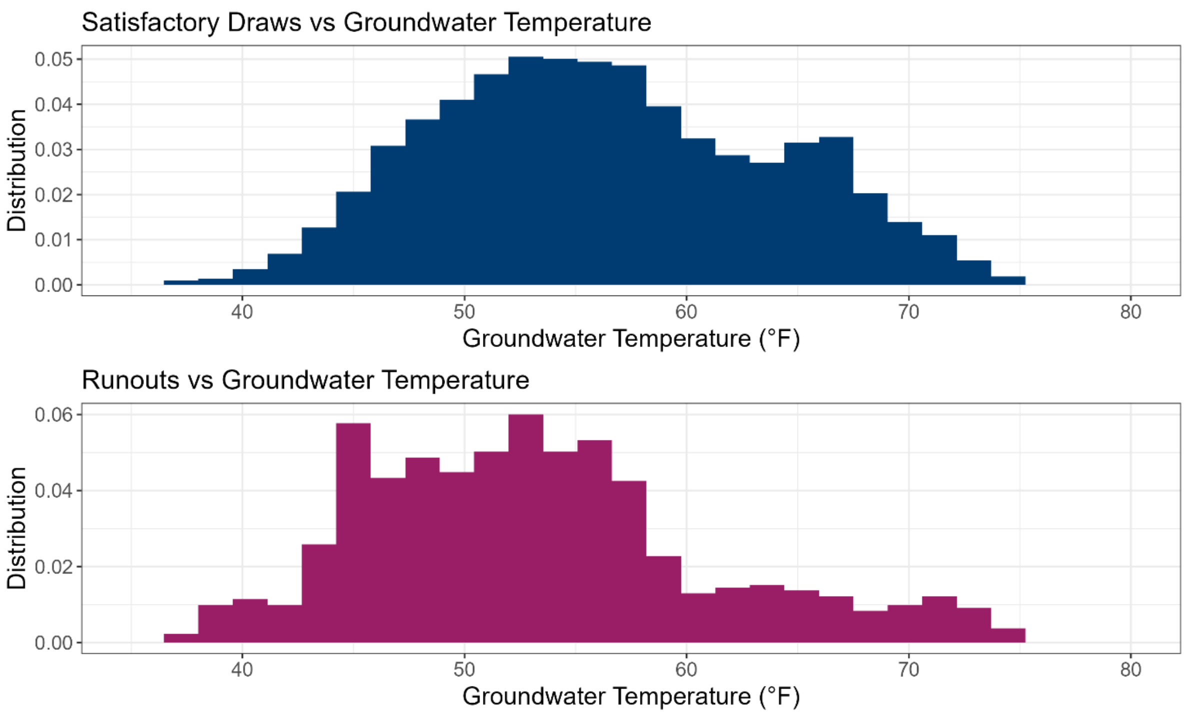
Figure 17. Windowed hot water consumption distributions.



Groundwater Temperature Versus Hot Water Runouts

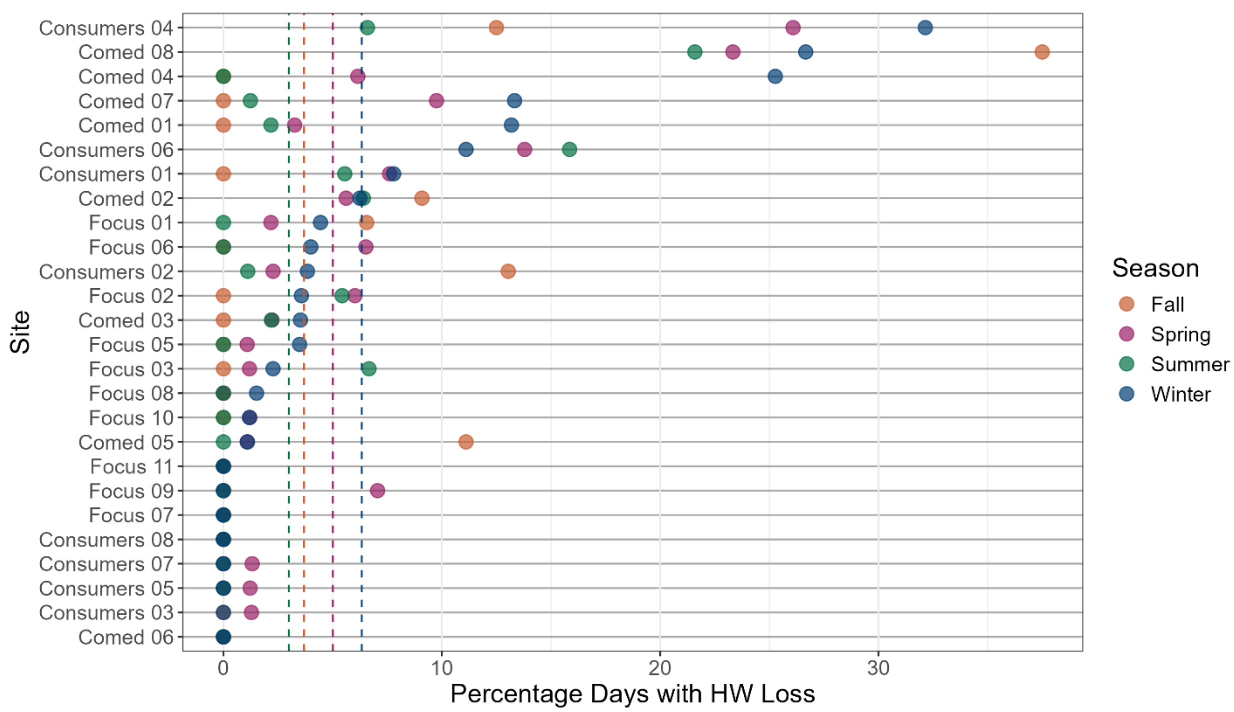
Groundwater temperature also influenced the frequency of hot water runouts. Figure 18 shows the distribution of groundwater temperatures during satisfactory draws versus during runouts. As seen in the figure, the likelihood of runouts increases dramatically below 60°F groundwater temperature.

Figure 18. Distribution of groundwater temperatures during satisfactory draws vs. runouts.



Similarly, Figure 19 shows the percent runouts of total draws of each site during each season. Hot water runout percentages are generally higher in the winter than in the summer months and shoulder seasons. The average percentage of days with a runout was ~7% in the winter months.

Figure 19. Percent runouts of total draws for each site per season.



* Vertical dashed lines represent the average percentage days with HW runout across all units, per season.

Consumption and Groundwater Temperature Versus Hot Water Runouts

We ran a model of the relationship between prior consumption, groundwater temperature, and water runouts. Table 5 below outlines these results. Both variables were found to be highly significant, with runouts increasing alongside prior consumption and decreasing as groundwater temperatures increase.

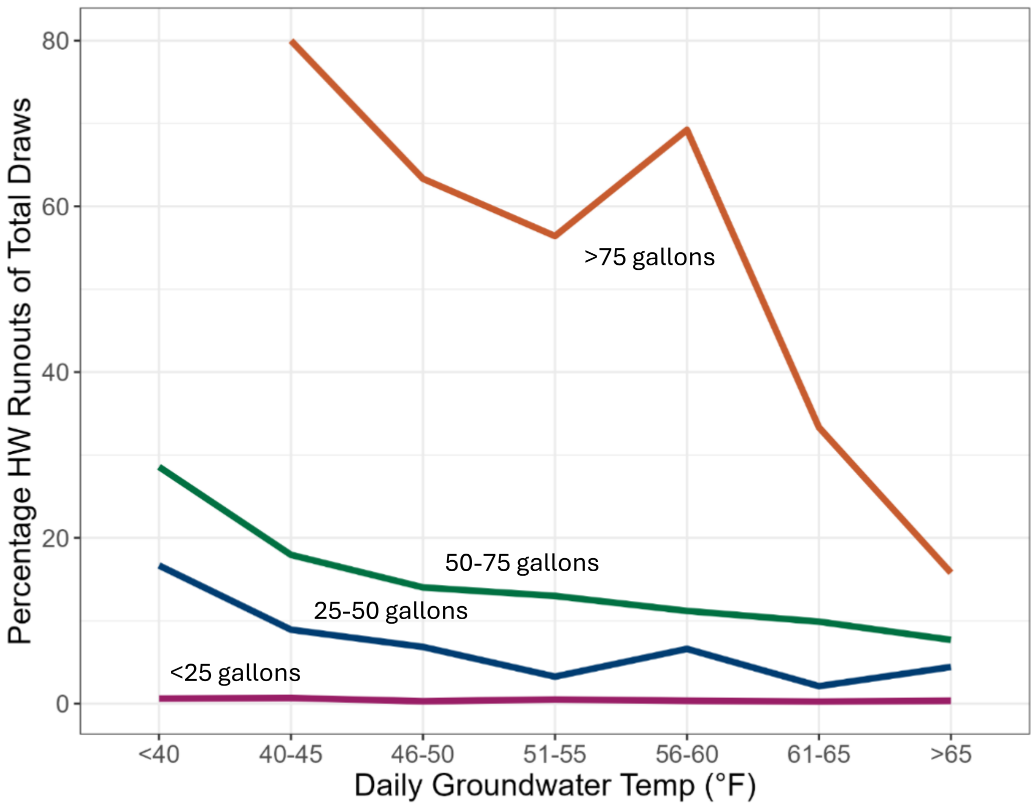
$$logit(is\ runout \sim t_{groundwater} + gallons_{prior\ 3\ hours})$$

Table 5. Prior consumption, groundwater temperature, and hot water runouts.

Variable	Estimate	Std. Error	z Value	Pr(>|z|)
Intercept	-4. 2717	0. 2856	-14. 956	< 2e-16 ***
Groundwater temperature	-0. 0259	0. 0051	-5. 119	3. 07e-07 ***
Gallons consumed in prior three hours	0. 0727	0. 0017	41. 810	<2e-16 ***

Figure 20 illustrates this combined effect of previous consumption and groundwater temperature. More water consumption during the three hours prior to a draw result in a higher percentage of water runouts overall. However, all lines over 25 gallons of prior consumption slope downwards, with percentage of runouts decreasing as water temperature increases. This decrease in runouts with increasing groundwater is especially marked for prior consumption over 75 gallons, with 80% at 40-45°F, but only 18% at more than 65°F.

Figure 20. Percentage HW runouts vs. groundwater temperature, grouped by consumption over three hours prior.



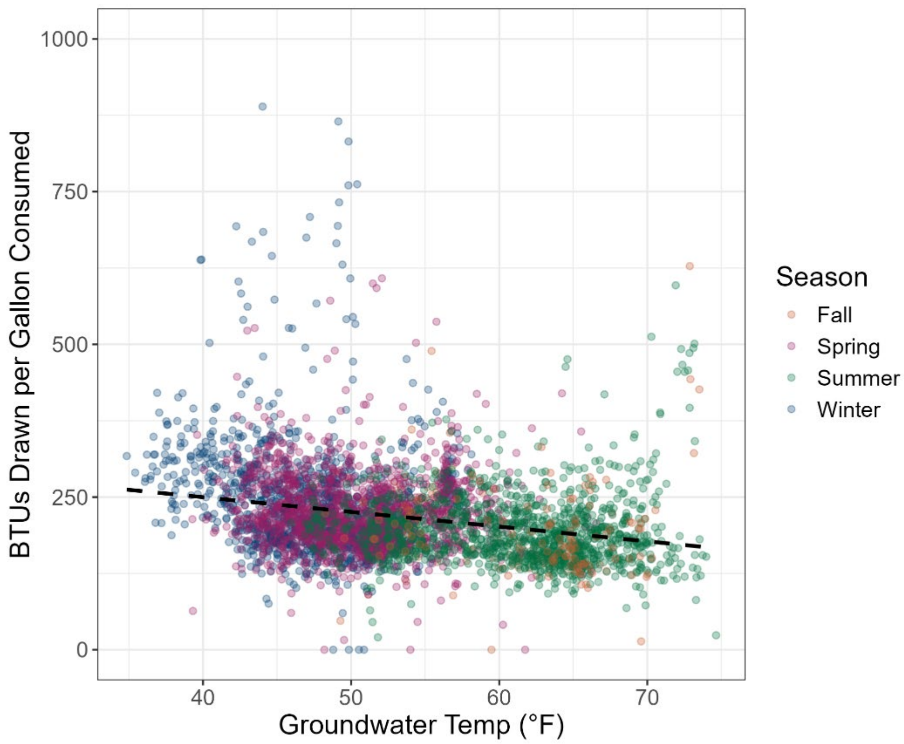
Section VI: Energy Use and Efficiency

Energy Use and Runtime Per Gallon

Increased water runouts occur at colder groundwater temperatures because it takes longer to heat colder groundwater to the setpoint. In accordance with this, we found that substantially more energy was needed per gallon consumed in winter months than in summer and shoulder seasons. This is true in gas and 240V units as well, but 120V HPWHs' lower power draw means that hot water recovery takes longer than in other types of heaters, so even slight differences in energy needed to heat a gallon of water can lead to longer wait times for consumers.

Figure 21 below illustrates this phenomenon, with more power needed to heat each gallon in the winter months, at lower groundwater temperatures. At the coldest groundwater temperatures (around 35°F), it takes ~250 BTU to heat a gallon of water on average. At the warmest groundwater temperatures (around 75°F), it took ~160 BTU to heat one gallon.

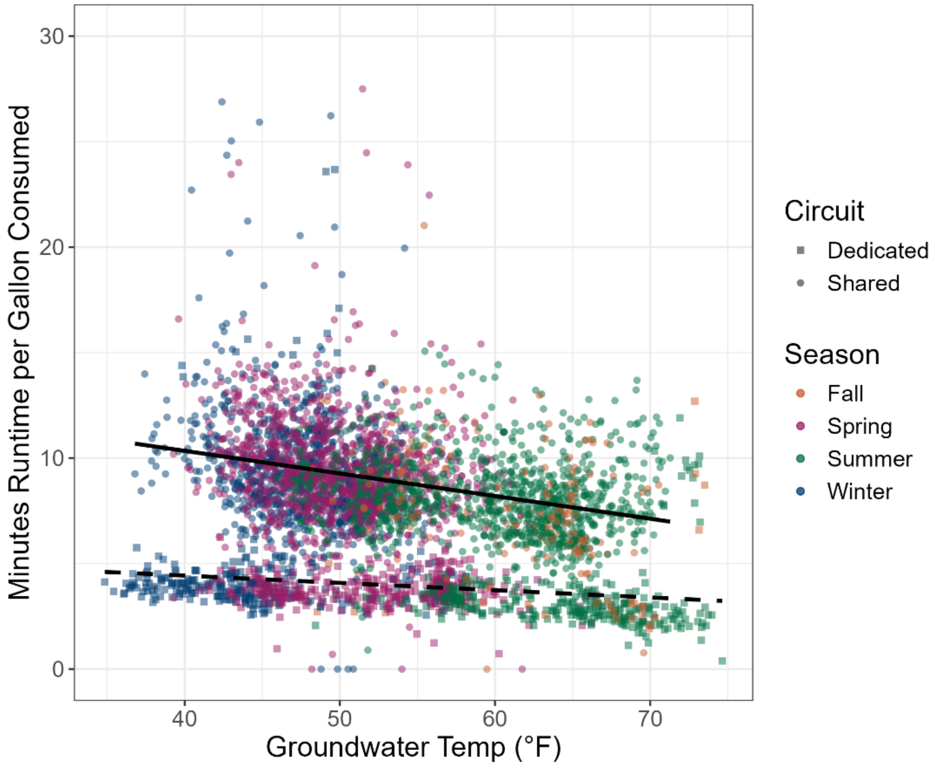
Figure 21. Energy to heat one gallon at different groundwater temperatures.



* Filtered to days with more than 25 gallons of consumption to avoid incorporating standby losses.

Figure 22 shows a similar trend in runtime. This graph includes two clusters and two trend lines, the dashed line for dedicated circuit units and the solid line for shared. The dedicated circuit units use more power and take less time to procure a given amount of heat than shared circuit units, so they have lower runtimes overall. For shared circuit units, it takes ~11 minutes to heat a gallon of water at the coldest groundwater temperatures and only ~7 minutes per gallon at the warmest groundwater temperatures. Dedicated circuit units take on average, ~5 minutes to heat a gallon at the lowest groundwater temperatures, and ~3.5 minutes at the highest temperatures. Gas and 240V units take ~1.5 and ~2.5 minutes per gallon, respectively.

Figure 22. Minutes of runtime per gallon consumed versus groundwater temperature.

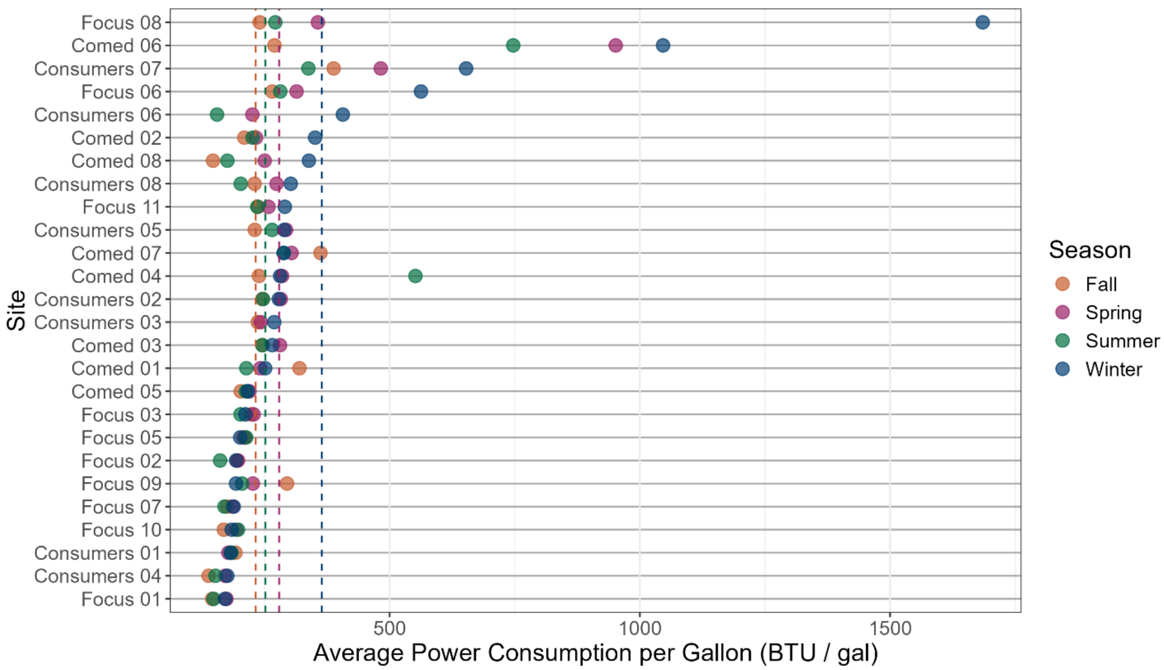


* Filtered to days with more than 25 gallons of consumption to avoid incorporating standby losses

Figure 23 further illustrates these trends, showing the power needed per gallon consumed per site per season. The winter power per gallon average is over 300 BTUs/gallon, while the summer and shoulder seasons are all less than 250 BTUs/gallon.

Two sites have energy use per gallon much higher than the average, with one of these sites especially high in the winter. These sites were the two lowest water consumers in the study. Thus, standby energy loss played an outsized role at these sites, with most of the power of these units going towards keeping unused water warm.

Figure 23. Power needed per gallon consumed per site per season, ordered by winter values.



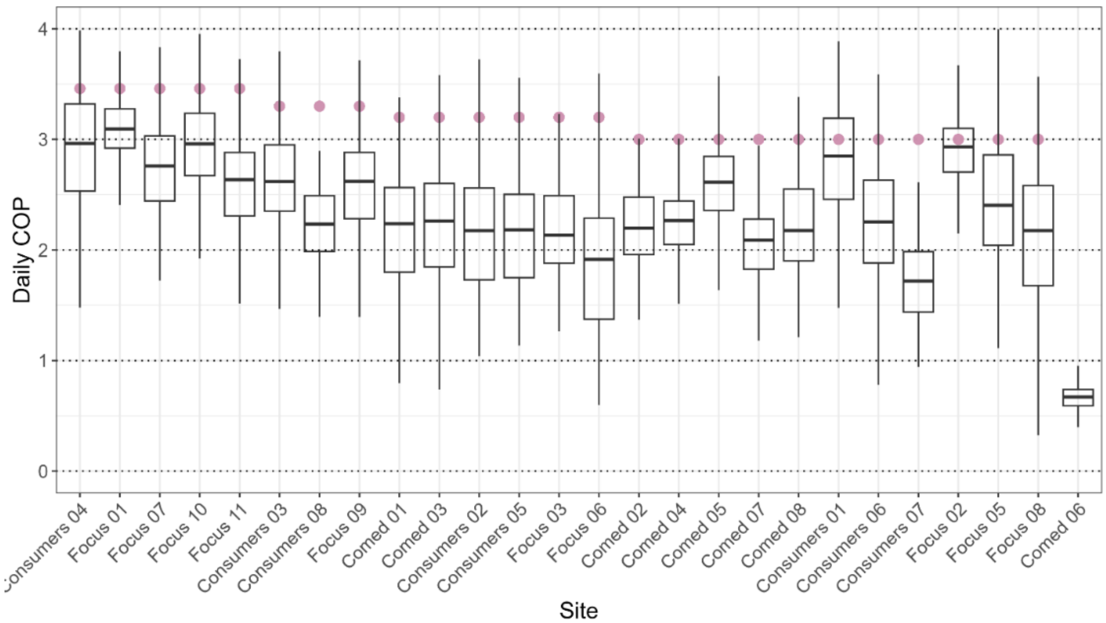
Coefficient of Performance

We calculated a COP for each unit per day. This was found by dividing the total usable energy generated by the heater (i.e. the total amount of heat added to the volume of water consumed) by the energy drawn by the unit, according to the following equation.

$$COP = \frac{flow\ mass * C_p water * (t_{hot} - t_{cold})}{power}$$

For much of the analysis, we filtered for days with more than 15 gallons of consumption to capture COP only on days when the unit was operational. When no water is consumed, 100% of the heat goes to countering standby loss of heat through the tank, which would result in a calculated COP of zero.
A plot of the distribution of COPs for each site is shown in Figure 24. Most sites had an overall average daily COP of 2.4 and a site average range between 0.7 and 3.2.

Figure 24. Daily site COP values, ordered by manufacturer-rated UEF.



*The pink dots denote each unit's manufacturer-rated UEF.
*ComEd 06 and Focus 08 had very little water consumption and thus were frequently operating only to counter standby losses.

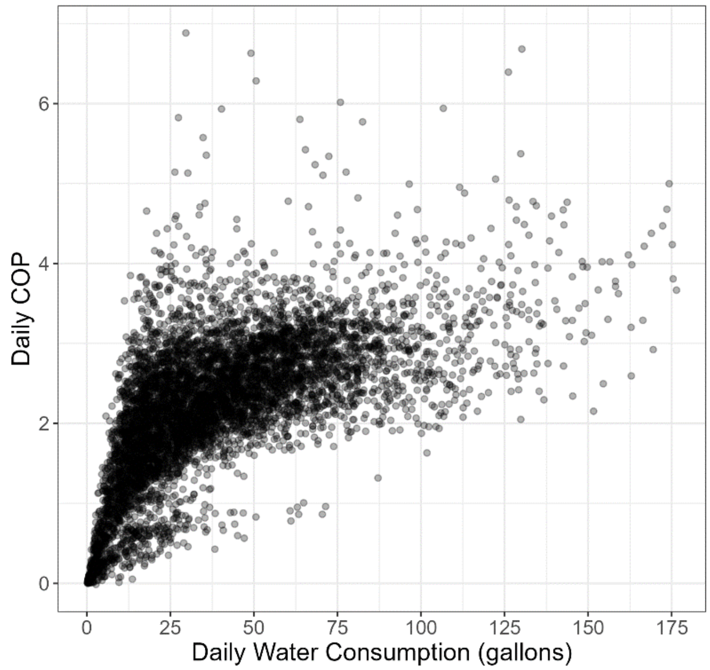
Table 6 below summarizes key characteristics of the sites with the three highest and three lowest median COP values. In general, sites with higher COP had higher manufacturer UEF ratings, higher occupancy and monthly consumption, and a higher water setpoint. Some of these characteristics are interdependent. For example, a household with higher occupancy will likely use more water, which may lead to more runouts, which may prompt raising the water setpoint.

Table 6. Summary of three highest and three lowest median COP values.

Site	Average COP	Manufacturer UEF	Occupancy	Monthly Consumption	Water Setpoint
Focus 01	3.19	3. 42	3	1815 gallons	130°F
Consumers 04	3.15	3. 42	4	3123 gallons	140°F
Focus 10	3.00	3. 42	2	904 gallons	130°F
Focus 06	1.91	3. 2	1	884 gallons	125°F
Consumers 07	1.77	3	1	438 gallons	125°F
ComEd 06	0.68	NA	1	379 gallons	NA

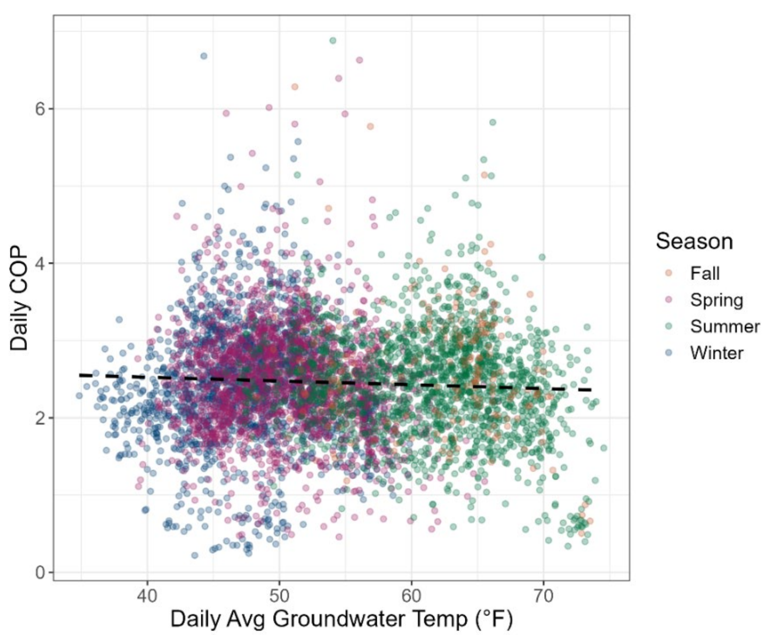
On days with higher water consumption, units performed at a higher COP, as seen in Figure 25. When more water is consumed, a smaller proportion of total energy use goes towards standby heat maintenance. These values level out between two and three as consumption reaches about 25 gallons per day.

Figure 25. Daily COP vs. daily water consumption.



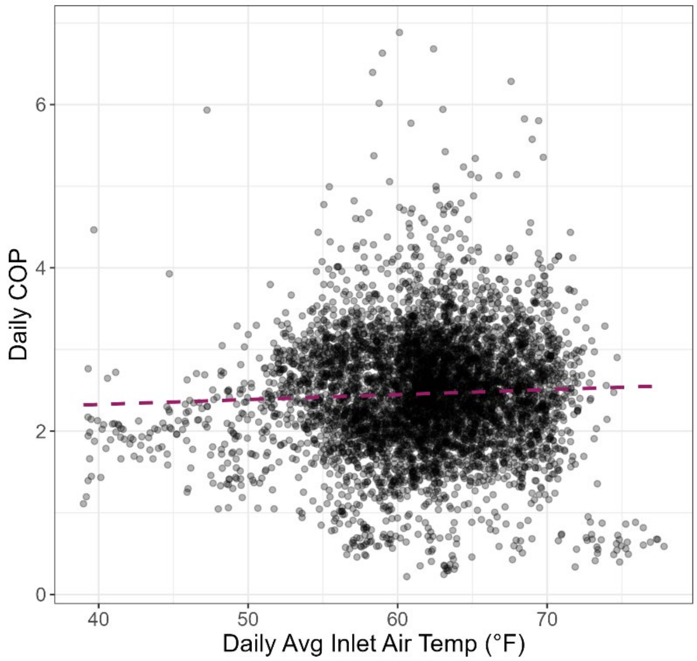
We found a slight negative correlation between groundwater temperature and COP. When groundwater is cooler, heat transfers more efficiently from the heat pump's refrigerant to the water, even though more total heat is required to heat cold water to the setpoint. Daily COP on operational days (>15 gallons of water consumed) versus groundwater temperature is shown in Figure 26. The trend line for COP as a function of groundwater temperature decreases from ~2.3 to ~2.2 over a 40-degree spread.

Figure 26. COP on operational days versus groundwater temperature.



We found a positive correlation between the temperature of the air at the HPWH inlet and COP. When there is less heat in the air surrounding the HPWH, the unit must work harder to pull that heat into the water, using more energy per gallon of heated water. Figure 27 shows daily COP on operational days versus inlet air temperature. The trend line for COP as a function of groundwater temperature rises from ~2.3 to ~2.6 over a 40-degree spread.

Figure 27. Operational COP vs. inlet air temperature.



Seasonally, groundwater and inlet temperatures vary in the same direction, so their impacts counter each other in COP. However, this correlation exacerbates the effect of colder groundwater temperature on runtime and energy use, with colder inlet air temperatures reducing the heat moved from the air to the water per unit of electricity. Relatedly, units located in fully conditioned air benefited from more efficient operation in the winter months than those in partially conditioned air. However, this effect is not noticeable when looking at hot water availability, as unit runtime is more dependent on groundwater temperatures than air temperatures.

A linear model of the effects of daily average inlet air temperature, daily average groundwater temperature, and daily gallons consumed on daily COP is summarized in Table 7 below. All terms in the model are significant with $p<0.01$. As described above, COP is inversely proportional to groundwater temperature, but proportional to inlet air temperature and daily gallons consumed.

$$lm(COP \sim 1 + t_{inlet\ air} + t_{groundwater} + gallons)$$

Table 7. Daily inlet air temperature, groundwater temperature, and gallons consumed.

Variable	Estimate	Std. Error	t Value	Pr(>|t|)
Intercept	1. 4988	0. 1002	14. 858	< 2e-16 ***
Inlet Air Temperature (°F)	0. 0084	0. 0017	4. 929	8. 49e-07 ***
Groundwater Temperature (°F)	-0. 0030	0. 0012	-2. 581	0. 00986 **
Gallons Consumed	0. 0132	0. 0003	42. 667	< 2e-16 ***

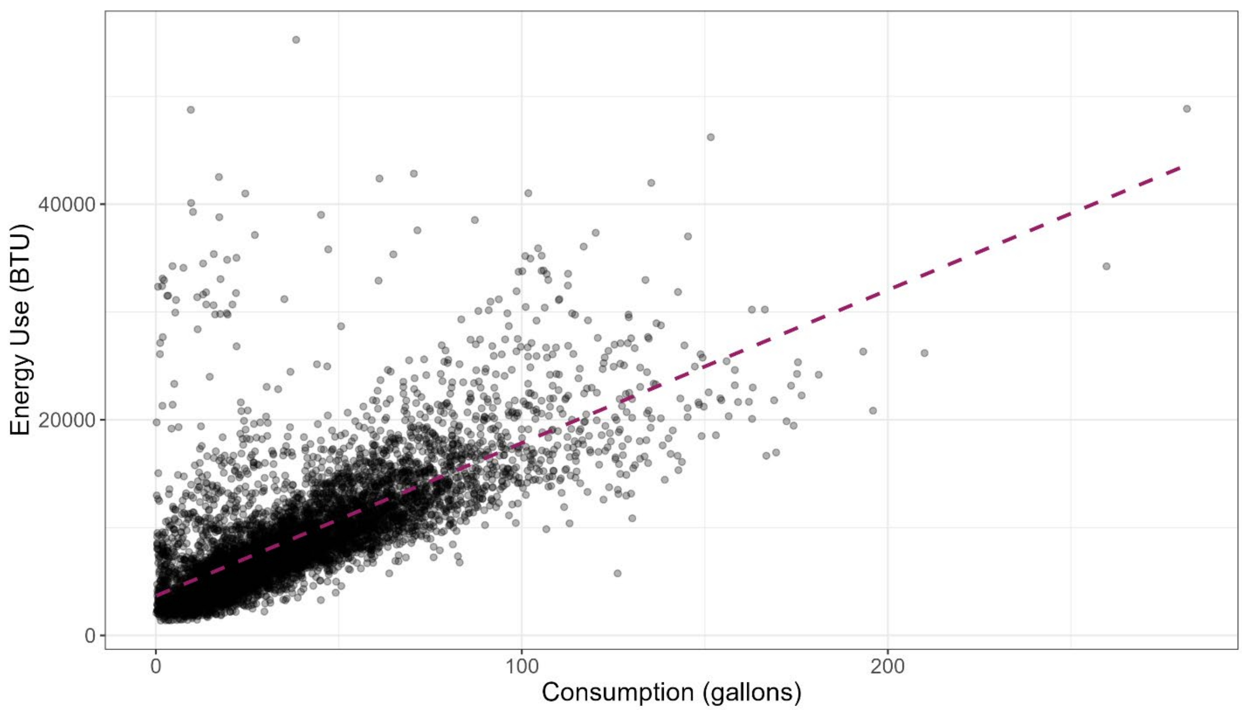
* Filtered to operational days (>15 gallons of water consumed).

Of course, the actual temperatures that affect unit performance are not groundwater temperature and the air temperature at the HPWH's inlet, but the temperature delta between those values and that of hot water in the tank. However, since we did not have detailed setpoint information, this study used the groundwater and inlet air temperatures as a proxy for this delta-T.

Standby Energy Use and Standby Energy Loss

Figure 28 shows the daily energy drawn by a unit versus the daily water consumption. Water heater tanks naturally lose heat to the surrounding environment. Because of this phenomenon, the energy consumption for days with zero hot water use is still around 4000 BTUs.

Figure 28. Daily energy use vs. daily water consumption.

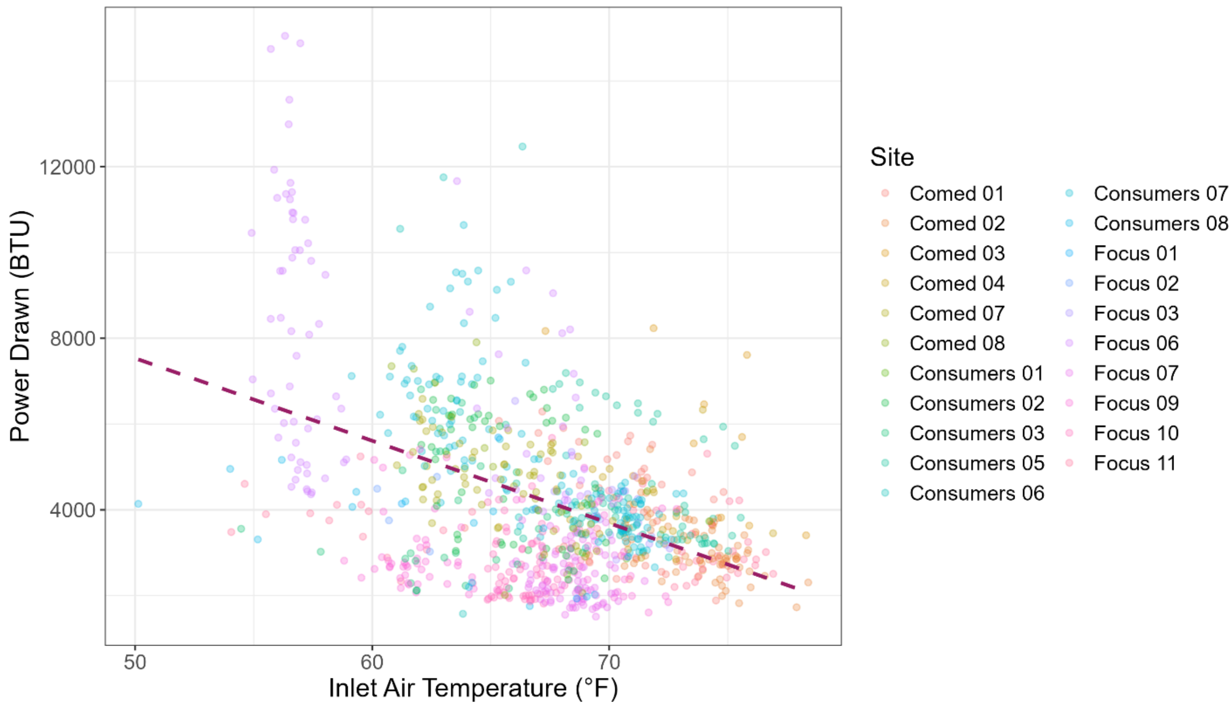


Because of the relationship between COP and inlet air temperature, we fit units' energy use on low consumption days (<15 gallons) to the day's average air temperature at the HPWH inlet. Doing so provided a more targeted standby energy use number than the y-intercept in

Figure 29. This fit of standby energy use versus inlet air temperature can be seen in the figure below. As the inlet air temperature rises from 50 to 80 degrees, the standby energy use decreases from ~7500 BTUs to ~2000 BTUs.

Standby energy use is embedded in daily energy use regardless of consumption. However, note that higher standby energy use at lower air temperatures in winter months contributes to higher energy use than in summer, even at the same setpoint. This factor is one element of the high seasonal variation in energy use (alongside lower air and water temperatures).

Figure 29. Energy consumption on low consumption days vs. inlet air temperature.



*Focus 08 and ComEd 06 are exempted due to the outsized energy per gallon measurements detailed above.

The model represented in the figure is detailed in Table 8 below, with its formula. Both terms are highly significant.

$$lm(standby\ energy\ consumption \sim 1 + t_{inlet\ air})$$

Table 8. Details of energy consumption on low consumption days vs. inlet air temperature.

Variable	Estimate	Std. Error	t Value	Pr(>|t|)
Intercept	26868. 07	1611. 27	16. 68	< 2e-16 ***
Inlet Air Temperature (°F)	-322. 44	23. 97	-13. 45	< 2e-16 ***

The figures thus far document the standby energy use consumed by the sites. Standby energy loss is a slightly different metric that pinpoints the energy lost by the unit to the surrounding air. Since these units are over 100% efficient, more energy will be lost to the environment (standby energy loss) than is consumed from the utility grid (standby energy use).

To find standby energy loss, we found average standby energy use per site on low consumption days (<15 gallons). Then we subtracted this from the total power delivered to the unit and calculated a no-standby COP using this new term in the denominator of the equation for COP. We multiplied this no-standby COP by the standby energy use to find the total amount of heat lost to the environment by the unit. As the units are very efficient, the total standby energy lost is higher than the standby energy consumed.

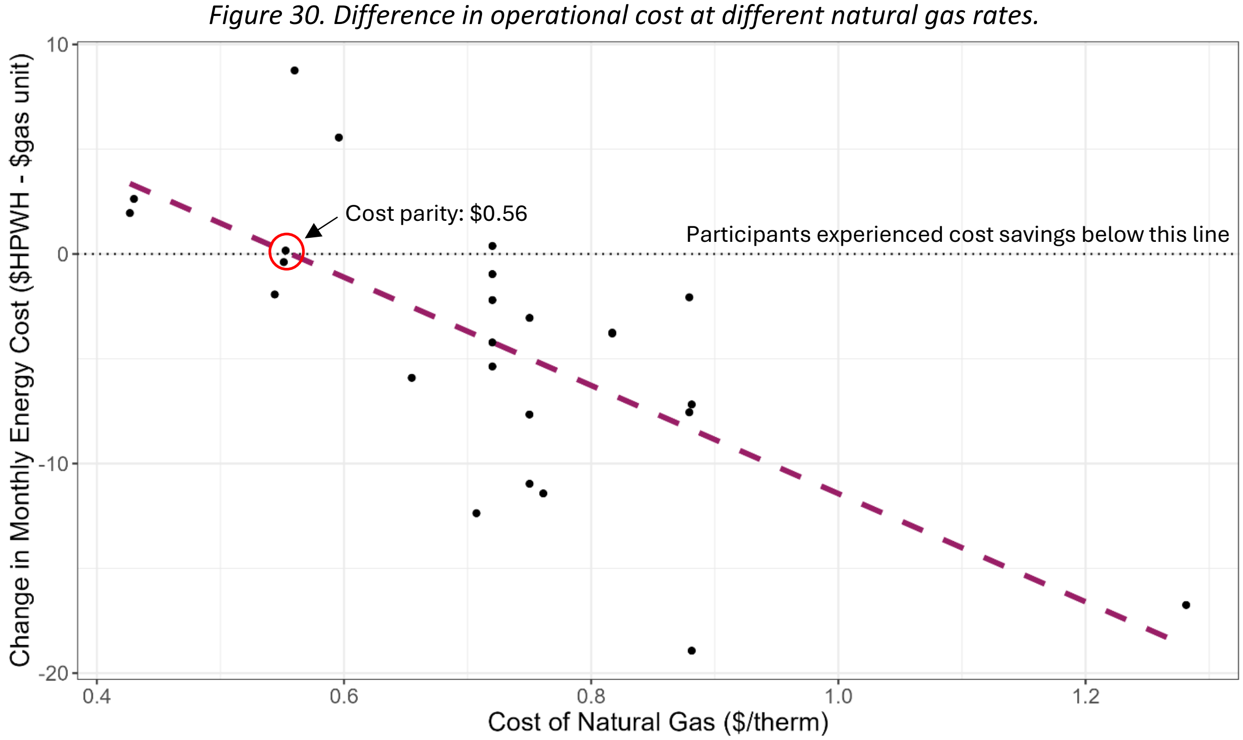
This lost heat plus the original measured heat (the top term in the equation for COP) is the true total heat delivered by each unit. This number was essential in determining operational energy cost and in comparing participants' old units and their 120V HPWH in the same context.

The average standby energy loss per site per day was calculated to be 24,738 BTUs, 53% of the average total delivered heat. A similar amount of energy loss would be expected with all tank water heaters, whether heat pump, electric, or gas, as standby energy loss is primarily dependent upon the temperature of the room and the temperature of the water.

Operational Energy and Retrofit Costs

We analyzed participants' gas and electric bills to determine the operational cost of 120V units versus the replaced gas units and found them to be at around cost parity. Study participants' change in monthly water heating energy cost ranged from $9 more expensive to $18 saved, with the average participant saving $6.67 monthly. After savings, the average monthly 120V HPWH operating cost was $. We found that a gas price of $0.56 per therm resulted in net operational cost savings. Figure 30 below shows the operational cost difference of participants' 120V versus gas units.

Figure 30. Difference in operational cost at different natural gas rates.



*Includes only volumetric costs per unit of energy.

Consumers looking to fully electrify their homes will save more than the above, as switching entirely away from natural gas heating will add service fees and taxes to the total savings. These values are not included in our calculations. We assume that most participants and consumers would still pay these service charges as part of their natural gas space heating, at least in the near term.

At the current cheap price of natural gas in the Midwest, these units cannot usually pay for themselves with savings. However, with an incentive for installation or as a water heater replacement occurring for motivations other than cost savings (e.g. if a consumer's prior water heater is broken), they offer an electric water heating option at around operational cost parity to a natural gas unit. Note, however, that installing a 120V HPWH is a more expensive retrofit than installing a new gas unit.

Our average retrofit cost per site, including the 120V HPWH, removal labor, install labor (including any electrical work), and install materials was $5,546. This average aligns with NBI's findings of an average equipment and installation cost in California of $5,758.[18] There is quite a bit of variation in how these costs are broken out. Hourly labor rates were quoted from $100-$210, and some companies add fees that obscure that rate. In the context of a field study like this one, where a lump incentive is often paid forward, cost breakdowns become even more opaque.

To estimate future install conditions with prepared subcontractors, the research team subtracted the labor and travel costs from each invoice and standardized to an assumption of six person-hours (two hours with two people and two hours alone) per installation at the average hourly labor rate of $146 . The average install cost in this standardized condition, once added back to the average invoiced equipment charges and permit fees, was $4,243.

The one study participant who replaced an electric resistance water heater with a 120V HPWH saved significantly more than the participants who began with gas heaters. The 120V unit saves that participant $40 per month compared to their old electric unit. Though this speaks to the efficiency of HPWHs, we do not recommend this course of action. Consumers with an electric resistance heater could most likely install a 240V HPWH unit without needing electrical service or panel upgrades and end up with a more effective unit (fewer hot water runouts) with similar efficiency and utility cost benefits.

The one study participant who switched from propane, rather than natural gas, also saved much more than the average participant, at $22 per month compared to their old propane unit. This is due to the higher cost of propane and indicates that 120V HPWH retrofits where the prior unit was propane will produce fuel cost savings.

Energy Savings from Baseline

Table 9 below shows sites' energy savings. These calculations took the total heat delivered to the unit over the study period and then multiplied that number by the efficiencies of participants' old versus new units. These calculations were done in both BTUs and kWh. We found that the 120V HPWH saved 87% of the energy consumed by participants' prior water heater, or 561 kWh per month, on average.

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[18] NBI, *Plug-In Heat Pump Water Heater Field Study Findings & Market Commercialization Recommendations* (2023). https://newbuildings.org/resource/plug-in-heat-pump-water-heater-field-study-findings-market-commercialization-recommendations/

Table 9. Site energy savings.

Unit of Energy	Energy/Month Old Unit Avg	Energy/Month HPWH Avg	Energy Saved/Month Range (HPWH – old unit)	Energy Saved/Month Avg (HPWH – old unit)
1,000 BTUs	2,200	280	1,200-5,200	1,920
kWh	643	82	310 to 1,520	561

Section VII: Aggregate Demand

By combining hourly data from all sites, the research team built a profile of typical energy and water demand over a day. This profile is shown in Figure 31 below.

Two spikes in water consumption can be seen, in the morning and evening hours, at the typical start and end of residents' days. Power demand rises briefly after these spikes, showing that units often kick in to heat incoming cold water just after peak times for water demand. Most units in the study consumed less than 500W when operating, and the average maximum daily demand (including units not currently heating) was just below 200W. Long operational times smooth out the power demand curve, resulting in average demand that varies by less than a factor of two.

Figure 31. Aggregate demand curves.

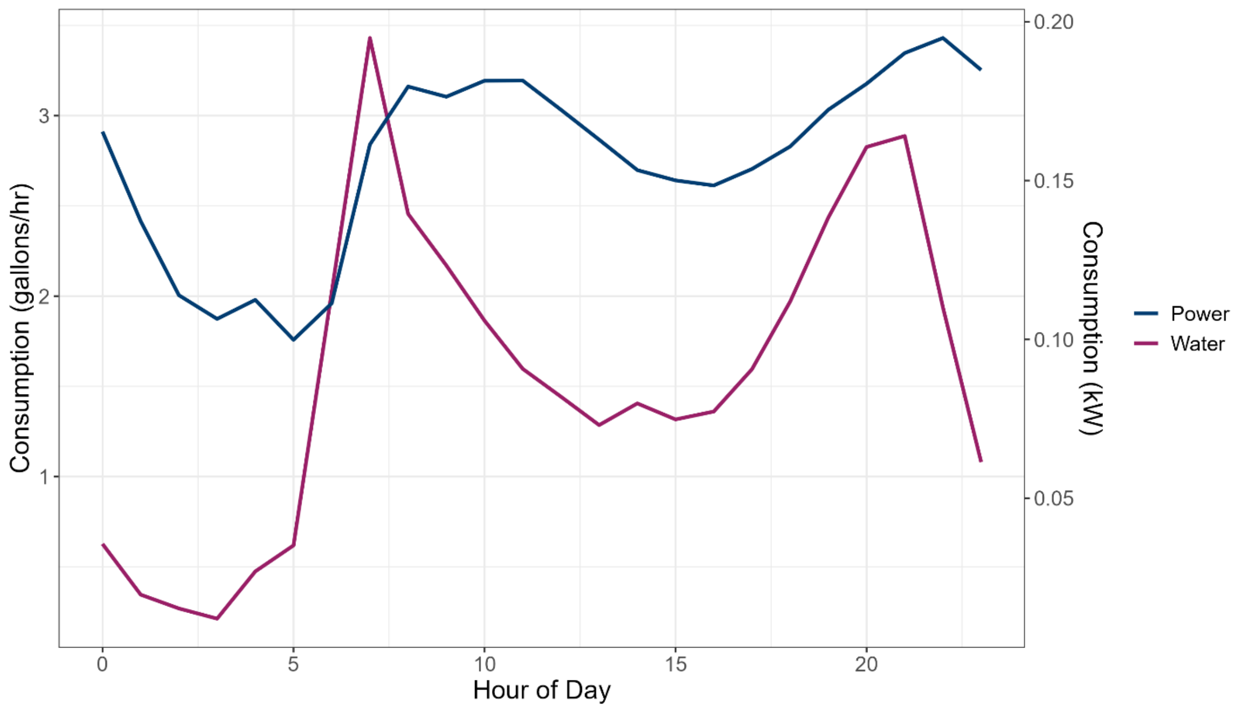
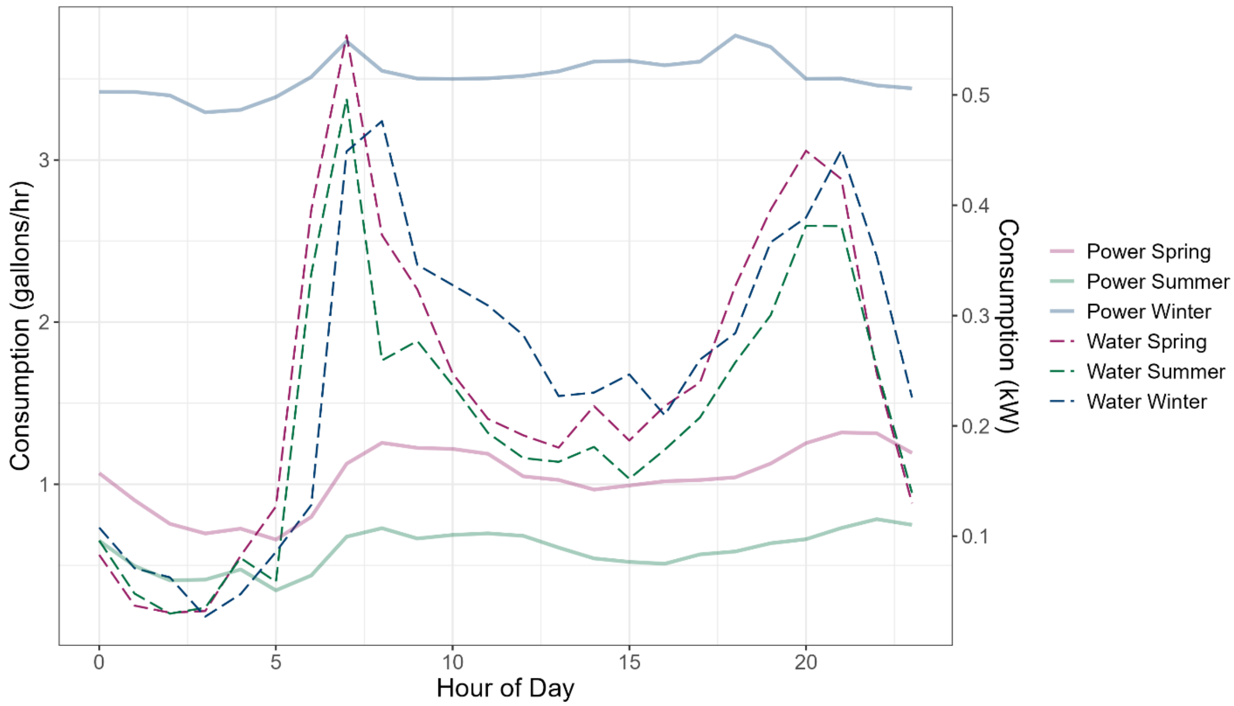


Figure 32 below breaks out this consumption by season. Power consumption peaks are aligned regardless of season because daily hot water use habits are not highly seasonal, as shown in the graph. However, the overall increased power need per gallon can be seen in the drastically (~300%) higher winter power consumption line, compared to the summer and spring.

Figure 32. Aggregate demand curves by season.



Load Shifting

Water heaters' storage tanks offer an opportunity to store thermal energy when energy is abundant on the utility grid. This can be tapped into later, when the grid's power is in high demand. To compensate for slower hot water recovery speeds, 120V HPWHs tend to have larger storage tanks and built-in mixing valves, which add even more thermal storage potential.

120V HPWHs can take advantage of this greater storage capacity by "pre-charging," (i.e., pre-heating) to a higher setpoint. This higher setpoint allows smaller amounts of hotter water to be mixed with larger amounts of colder water via the unit's mixing valve, so the water in the tank is depleted more slowly. Of course, with 120V HPWHs' reduced power draw, dynamic grid and consumption signals must carefully monitor water consumption to guarantee enough hot water in the tank for potential large water consumption events.

By pre-charging when electricity is the cheapest, heat pumps can curtail energy use in the late evening, thereby avoiding higher utility rates. This benefits homeowners through energy bill savings and utilities through peak shavings.

As the Midwest adopts more renewable energy, implementing load shifting programs could prove beneficial in absorbing excess wind and/or solar generation and avoiding the use of peaker plants. All territories in this study offer optional time-of-use rates for residential customers, and each site in the study consumes an average of 0. 94 kWh per day during the most common peak times for these rates (2pm to 7pm).

Determining the total amount of grid shifting potential in the Midwest is outside the scope of this study, but in 2024, NBI and Lawrence Berkeley National Labs (LBNL) conducted a study testing the efficacy of load shifting with 120V HPWHs in California.[19] The study team sent Load Up (pre-charge to setpoint) and Shed (turn off or curtail energy use) signals to 10 HPWHs using SkyCentrics EcoPort modules, a piece of hardware allowing remote communications with the HPWHs. The study found that the 120V HPWHs shifted an average of 39% of peak demand HPWH load away from peak utility demand periods when using the Load Up signal. This load shift resulted in average utility bill savings of 24% of HPWH electricity costs under California time-of-use rates. Notably, the study found no decrease in occupant comfort.

[19] NBI, *Development and Validation of Price and Load-Responsive Controls for 120-volt Heat Pump Water Heaters* (2024).

Section VIII: Consumer Experience

Summary

We conducted three rounds of participant surveys to gain insight into satisfaction and experience with the 120V HPWHs over the course of the study, plus one survey about their satisfaction with their prior unit:

- **Pre-installation:** September 2023 through February 2024, at time of installation
- **Post-installation:** January 2024 through March 2024, one to two months after installation
- **Early spring:** April 2024, at the end of winter
- **End of study:** September through November 2024, alongside M&V equipment removals

Overall, participants were generally satisfied with their 120V HPWH units. In the final study survey, 23 out of 25 respondents rated their satisfaction as 4/5 or 5/5. That same number of people said they were likely or extremely likely to recommend the unit to a friend (though several participants stressed that they would tell their friend to make sure the unit was a good fit, first). The remaining 2 participants rated their satisfaction at a 3/5 overall, though in the post-installation survey, one of these participants rated their satisfaction at a 2/5.

A recurring comment in the final surveys was that participants are now more cognizant of how and when they are using hot water, separating large consumption events. Four participants mentioned scheduling shower, dishwashing, and laundry times more carefully. Two of these participants rated their overall satisfaction at a 3/5. Two participants commented the inverse, that they had increased their water use with their new heater, since they no longer had to worry about their smaller and older gas heaters breaking. Four participants noticed a seasonal variation in their 120V HPWH's operation, with more hot water runouts in winter months.[20]

There was variation in how much adaptation participants were willing to make to their consumption habits. Higher levels of consumption made it more difficult to reschedule consumption to work with a heater's runtime, especially that of a shared circuit unit.

We had three four-person households participate in this study. One of these sites replaced their unit at the end of the study, which is discussed later in this section. As discussed in Section V, they experienced the most persistent hot water availability issues and were unable to adjust their consumption levels (which were higher than all other sites, and above IL and WI TRM estimates) to work with their shared circuit unit. This household took long showers multiple times a day.

Another four-person household had a lower-than-expected consumption level of 1500 gallons/month, closer to that of three people. They rated their satisfaction with their shared circuit unit at 5/5. This household was okay adapting to longer runtimes, which indicates that shared circuit units could work for a household of four, provided that they do not have a habit of taking very long showers or baths.

[20] Only one of the four participants noticing seasonal variation also reported being more cognizant about their water use.

When asked whether they'd recommend the unit, the occupant said "I would suggest it but I know that it isn't the best option for everyone. Recovery time does take longer and that works fine for our household. But that doesn't work for everyone."

The last of the four-person sites had a dedicated circuit unit and a consumption of only 1000 gallons per month, closer to the consumption estimated for two people. They experienced no issues with their unit.

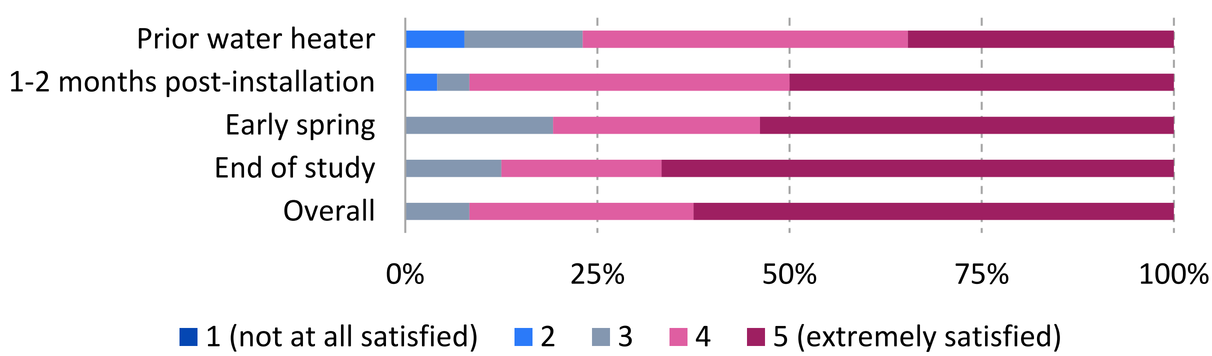
Some participants very much enjoyed the manufacturer apps for managing the controls on the heater and tracking the amount of water left. However, some found the same apps confusing, experienced recurring glitches, or had trouble connecting them to their water heater.

The final survey key can be found in Appendix E.

Satisfaction

The number of people satisfied with their new HPWH versus their old unit increased from 20 out of 26 to 23 out of 25. Throughout the three surveys, only one person reported being dissatisfied with their 120V unit (a 3/5 rating was neutral). Two participants were dissatisfied with their old unit. Figure 33 illustrates participants' satisfaction with their unit at the point of each survey. The final survey prompted participants to give their total satisfaction (Overall), as well as their satisfaction since the last survey (End of study).

Figure 33. Satisfaction over time.



There was an increase in satisfaction with the 120V units as the study went on, from 76% to 87%. This could be due to a learning curve as participants became more familiar with the controls and behaviors of the unit. A second explanation is that the time with the lowest satisfaction was during the winter months, when participants were experiencing the most water runouts due to cold air and groundwater temperatures. Even the participant who needed to replace their 120V unit (more info below) increased their satisfaction compared to their old unit, from a rating of 2/5 to 3/5. No participants were dissatisfied with their units overall.

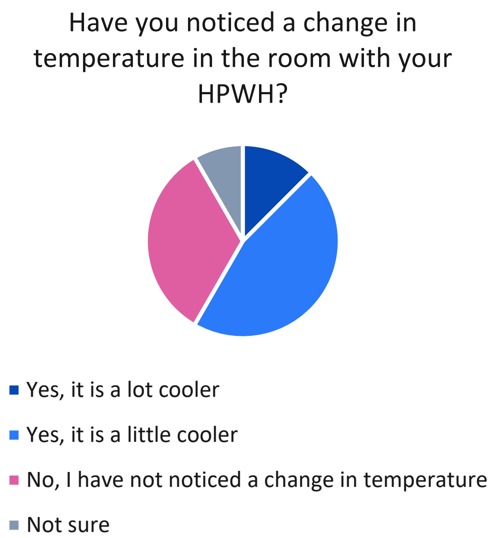
Of the two participants rating their overall satisfaction at a neutral 3/5, one, with a shared circuit unit, was the household with the highest consumption who switched heaters at the end of the study. The other participant had a dedicated circuit unit and two people living in the house. They stated that the reason for their rating was the heater's performance when the occupancy of the house increased. This resident said that, "The 120V HPWH's inability to provide sufficient [hot water] was pronounced when visitors stayed over or during hosting a big holiday cooking event."

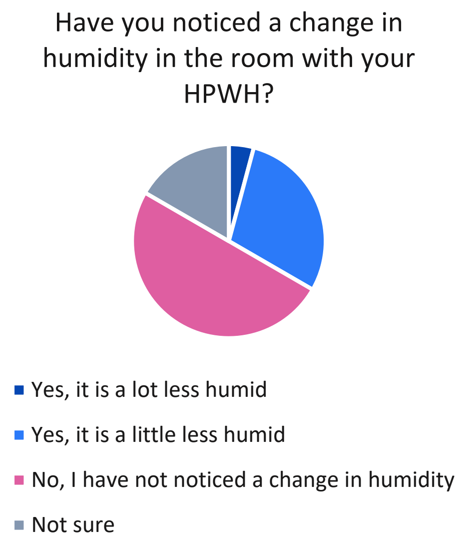
Operation

Figures 34 and 35 show the percentage of participants who experienced a change in temperature and humidity, respectively, due to the unit, according to their final survey responses. Around 60% of respondents noticed a temperature change. That number was only about 30% for humidity. These responses are likely influenced by how often each participant frequents the room, as well as the ventilation of the room in which the heater was installed. If a participant noticed a change in one of these factors, they were likely to notice a change in the other. In the final survey, no respondent noticed the humidity change without also noticing the temperature change.

We measured a humidity change most perceptibly in the summer months. Survey results align with this; only 15% of respondents noticed the change in both the early winter and early spring surveys. On the other hand, the number of people noticing the temperature change remained constant over the course of the three surveys.

Figures 34 and 35. Percentage of participants who experienced change.



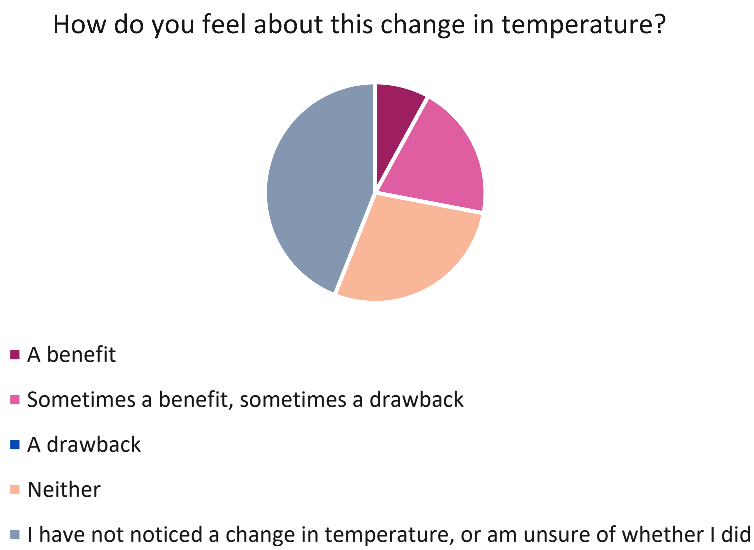


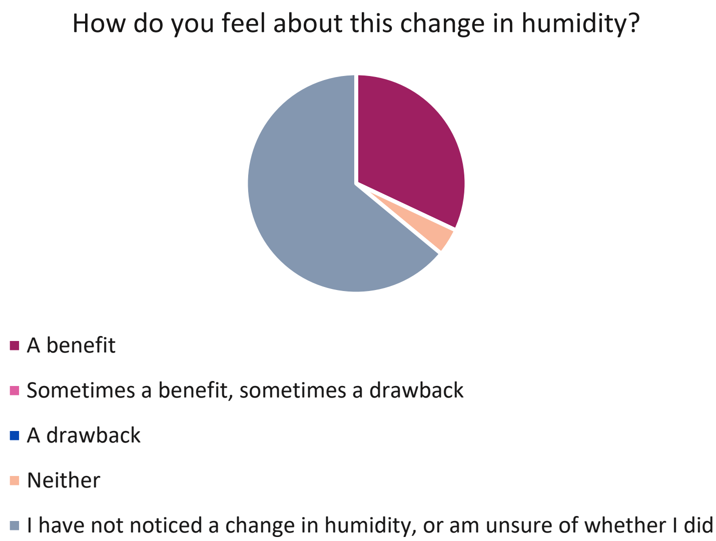
Of the people who noticed a change in temperature, about 15% thought it was a benefit, 35% sometimes a benefit, sometimes a drawback, and 50% were indifferent to the change. Participants noted that the colder temperature was a benefit in the summer months, but not the winter. During the summer months, the cooler temperature around the heater helps with, rather than hinders, the temperature control of the room and residence. These numbers are shown in Figure 36.

For those who noticed a change in humidity, 85% thought it was a benefit, and 15% were indifferent to the change. These numbers are shown in Figure 37.

One noteworthy participant ducted the cold, dry air from the heater into a drink cellar. As detailed in their final survey, this worked very well for them.

Figures 36 and 37. Participant sentiment regarding change.





68% of participants reported noticing noise from their unit. Of these people, almost all classified it as “hardly noticeable” or “noticeable but not annoying.” One participant classified this noise as “annoying.” This heater was in the basement, which in this case was frequently occupied and used as a workshop.

Hot Water Availability

Figure 38 shows participants' experienced hot water availability at each point in the survey. The final survey prompted participants to give their total satisfaction (Overall), as well as their satisfaction since the last survey (End of study).

Overall, 67% of final survey respondents reported never running out of hot water and 33% reported sometimes running out of hot water. Zero participants reported frequently running out of hot water. However, at the time of the surveys conducted in the winter and early spring, up to 12% of study participants reported frequently running out of hot water. This aligns with our findings that there were more runouts when groundwater was colder.

Figure 38. Supply of hot water over time.

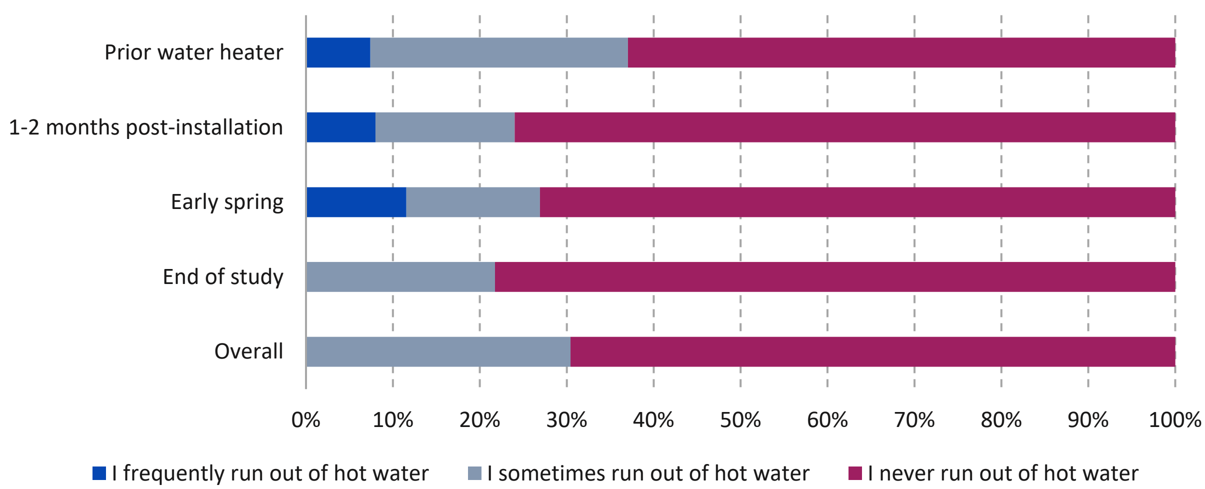
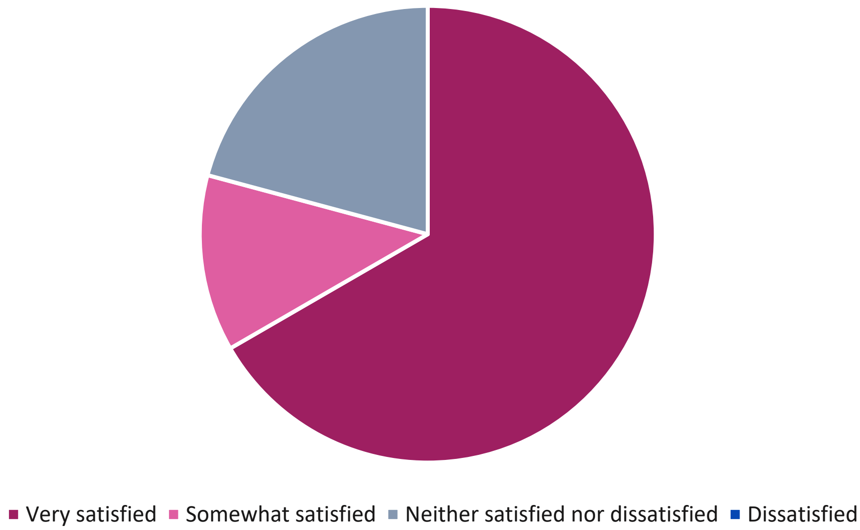


Figure 39 illustrates participants' overall satisfaction with their HPWH's runtime at the time of the final survey. 80% of respondents were satisfied. The remaining respondents were neither satisfied nor dissatisfied. No participants were dissatisfied.

Figure 39. Satisfaction with heating time.



Three participants mentioned that water would briefly turn cold before returning to its regular setpoint temperature. This pattern aligns with the rapid anomalous hot water temperature fluctuation we measured, detailed in Appendix C.

Selected Quotes

"We have noticed little to no difference from our former natural gas storage water heater, so happy with this upgrade because of our personal goals to electrify our home."

"It is so cool having an energy efficient water heater that runs off a normal 120V outlet. I also think [it's] cool that all the heat comes from the air around it. It's like magic."

"I had no problems with the heater. Fast hot water, never ran out."
"Safer than gas and remote functionality."

"Mostly great, but every now and then our water lines will get a seemingly random flow of cold water when they were previously just flowing hot."

"The new 120V heat pump performs adequately for two adults. However, it underperforms (runs out of hot water) when back-to-back showers or baths take place. I'm considering adding an electric tankless on demand hot water heater in series after the 120V HWH as a backup to ensure hot water when the 120V HWH can't keep up."

Other Experience Factors

Space Heating to Boost Winter Performance

During the winter, one site was experiencing frequent hot water runouts. Upon consultation, it was determined that the garage hosting the HPWH was dropping to temperatures too low for the unit to function, and the louvered vent into the conditioned space was too small to effectively transfer heat. As an intermediate solution, the study supplied a space heater next to the HPWH to reheat the air on the coldest days, rather than ducting the HPWH into the house to bring heat from inside. According to the participant, this adaptation successfully stopped the hot water runouts without a noticeable increase in utility cost. However, ducting a cold room like this into an area that is space-heated would be a more permanent solution.

Unit Malfunction

There were several instances in which a homeowner contacted us because their 120V HPWH had malfunctioned. These instances were all resolved within a few days and did not affect M&V for the study. There was no pattern as to the manufacturer of the units malfunctioning. The specific situations are detailed below.

- For one participant, an internal thermistor failed in the unit. The manufacturer’s app alerted the homeowner to this, and the manufacturer mailed a replacement part. Getting into the unit to replace the thermistor proved tricky. This participant’s basement itself had plenty of space, but their unit was situated such that the thermistor access was wedged into the corner of the room. Once replaced, the unit began running normally.
- During monitoring equipment removal, one participant’s condensate pump was mistakenly plugged into the M&V monitoring board, which was switched off. Once full, the inoperable pump overflowed into the spillage tray. This was resolved by switching the plug to the correct outlet, emptying the tray, and restarting the unit.
- One participant had an issue with the heat pump operation of their heater. The water would not reach the setpoint unless it was in electric resistance mode. The manufacturer was called and was able to troubleshoot.

Unit Replacement

One participant of this study was notably dissatisfied with their hot water availability in the winter and spring months. This household was the highest water consumer of the study, consuming 50% more water than any of the other sites, which they attributed to their teenagers’ long daily showers. On top of this, their unit showed signs of water backflow, with measured “groundwater” temperatures spiking as heated water flowed back into the surrounding pipes. This likely put additional stress on the unit when attempting to recover after those large consumption events.

At the end of the study, the team investigated the potential of installing a 240V HPWH at this household as a replacement but ran into budgetary restrictions with regards to electrical service upgrade work, which would have cost more than $4,000. This speaks to the economic benefit of 120V units in houses without sufficient electrical service for a 240V unit. However, with such high water demands, a 120V

HPWH was not working for this consumer. An ENERGY STAR certified gas water heater was installed in place of the 120V HPWH at the end of the study.

Section IX: Conclusions and Recommendations

This section contains recommendations for utility program design, maximizing energy use and efficiency, addressing hot water use and runouts, and sustaining overall user satisfaction. We conclude with comprehensive installation recommendations that can serve as a summarized list of considerations for utilities to accelerate successful HPHW adoption.

Program Design

Findings:

- As a technology specifically designed for electrification retrofits, 120V HPWHs easily replace natural gas units when space is not constrained and a 120V outlet is present. Midwest basements often meet these requirements, presenting utilities with low friction opportunities to install HPWHs in these residences.
- The optimal unit to install depends on whether a shared circuit outlet, dedicated circuit outlet, or existing 240V line is present. In the absence of an outlet and an unconstrained panel, a 240V hybrid unit may be equal in cost to install.
- Installers require additional education and training on required air volumes and electrical work for 120V HPWHs in residences.
- Findings demonstrate that 120V HPWH and gas units are at around cost parity, with slight average monthly savings after HPWH installation. Participants' change in monthly water heating energy cost ranged from $9 more expensive to $18 saved, with an average monthly operational cost savings of $7. A natural gas volumetric price of $0.56 per therm resulted in net savings. However, these units do not pay back their upfront cost in savings across their lifetime.

Recommendations:

- Utilities should incorporate 120V HPWHs into energy efficiency programs that permit fuel switching as a cost-saving measure to switch from natural gas and propane water heaters when an outlet is present, and the electrical panel is constrained. 120V units are not recommended to replace electric resistance water heaters, which have a circuit present that can accommodate a 240V unit. Utilities should leverage midstream programs and distributor relationships to ensure installers have access to these units at the time of unit replacement.
- Utilities should consider locating candidates for 120V HPWH retrofits through weatherization programs, as these programs can gather the necessary information on siting, panel constraints, and outlet location. Utilities should consider adding additional data gathering requirements to these programs to facilitate referrals to a 120V HPWH retrofit program.
- Utilities should prepare educational materials based on the installation recommendations in this section for contractors to distribute and review with their customers.
- Utilities should only recommend 120V HPWHs to customers whose hot water consumption patterns would not be constrained by a 120V HPWH's longer recovery time, even if program cost effectiveness compels the program administrator to choose otherwise.

Unit Availability

Finding:

- Manufacturers have been awaiting the results of this study before evaluating whether to make units available to Midwest distributors.

Recommendation:

- Manufacturers can make these units available to Midwest distributors, provided that clear guidance is provided on appropriate installation scenarios. Distributors should provide the installation recommendations below to installers and educate them on the use case for these units.

Water Consumption and Runouts

Findings:

- Most sites did not have issues with hot water runouts, even during the winter. The average site registered a hot water runout on 5% of total study days, with a range from zero runouts to runouts on 24% of total study days.
- The participant with the lowest satisfaction also reported the most hot water runouts, had the highest water consumption, and had reported frequently running out of water with their prior functional water heater. They frequently took long back-to-back showers.
- 33% of participants reported that they occasionally ran out of hot water during the overall course of the study. The remainder reported never running out. No participants reported frequently running out. 80% of participants were satisfied with the time it took the units to heat water overall. The remainder were neither satisfied nor dissatisfied.
- Consuming a large amount of water across a few hours greatly increases the risk of running out of hot water in the following hours. While this may be true for 240V or gas units as well, 120V units heat water more slowly than their counterparts, even if they have a backup resistance element. With a 120V unit, when hot water runs out, it runs out for longer and is a greater inconvenience.
- A higher percentage of hot water runouts occur when groundwater temperatures are colder. Four participants noticed a seasonal variation in their 120V HPWH's operation, with more hot water runouts in winter months.
- Dedicated circuit units were not upsized, and provided similar hot water reliability with smaller tanks. Upsizing these units could be a way to increase reliability in higher consumption households, but more research is needed.
- A recurring comment in the final survey responses included increased awareness among participants about personal hot water consumption patterns. Many participants stated that they learned to separate large consumption events. However, about the same number of people commented that they had increased their water use with their new heater, because they no longer had to worry about their smaller gas heaters breaking.

Recommendations:

- To avoid hot water runouts, installers should **not** install 120V units at locations where:
    - The occupancy/potential occupancy of the home is more than four people. If there are four occupants, do either or both of:
        - Install a dedicated circuit unit
        - Ensure that the household takes short (~5 min) showers, does not take baths, and has low-flow showerheads in all showers
    - The household's existing water heater often fails to provide hot water (more than once a week).
    - The household frequently uses a lot of water in a small interval (i.e. multiple people taking long showers consecutively).
- Recommend and offer to install low-flow fixtures, particularly showerheads, if they are not present.
- Installers should install a mixing valve if a unit does not have an integrated mixing valve.
- Installers can suggest customers raise the tank temperature if they are experiencing runouts.
- Installers should install backflow prevention valves with the water heater. Due to slower reheat times, 120V HPWH operation is more sensitive to poor installation conditions such as backflow. One participant experienced backflow that was detected by the study's monitoring devices. This likely influenced their hot water recovery times.

Energy Use and Efficiency

Findings:

- There was no measured COP variation by season. COP values are slightly negatively correlated with groundwater temperatures. When groundwater is cooler, heat transfers more efficiently from the heat pump's refrigerant to the water, even though more heat in total is required to heat cold water to reach the setpoint. There is a positive relationship between COP and the temperature of the indoor air being pulled into the heater, with warmer air resulting in less standby energy loss and more efficient HPHW operation. These two effects counteract each other seasonally.
- Units performed efficiently even in the cold groundwater and air temperatures of the Midwest but consumed much more energy in the winter than in other months. Most sites had an average daily COP between two and three, with an average overall COP of 2.4 and a range between 0.7 and 3.2. The average site used 87% less energy with a 120V HPWH than with their previous unit.

Recommendations:

- Installers should confirm that the room hosting the water heater does not regularly dip below the manufacturer's recommended indoor temperature during the winter. If winter temperatures drop below recommended indoor temperatures, ducting into the space heated portion of the house will be required for successful installation of a HPWH.
- Installers should confirm that the room hosting the HPWH is large enough for full functionality, with 700 cubic feet of air surrounding the heater. If not, ensure the installer is trained and ready

to duct the unit appropriately.

Overall Satisfaction

Findings:

- Participants were quite satisfied with their 120V HPWH units. The final study survey responses demonstrated 92% satisfaction overall, with that same percentage of people saying they were likely or extremely likely to recommend the HPWH unit to a friend. A few participants stressed that they would first tell their friends to make sure the unit was a good fit.
- User satisfaction increased as the study progressed. One possible explanation is that participants became more familiar with the HPWH's controls and operations. A second explanation is that user satisfaction was lowest during the winter months (at the beginning of the study), because participants were experiencing increased water runouts due to cold air and groundwater temperatures.
- More than 50% of participants either did not notice cooling, humidity, or noise impacts from their HPWH, or did not classify those impacts as drawbacks. However, one participant who regularly spent time near the unit was dissatisfied with the noise and cooling impacts.

Recommendations:

- The ideal customer for a 120V unit is a household with 4 or less occupants who consume an average amount of water (18 gallons per person per day or less), who currently have a propane or natural gas heater, and who have an electrical setup that accommodates the unit.
- Installers can educate the customer on the HPWH's controls and encourage them to download the manufacturer's controller app, if applicable. Some apps offer control over the water setpoint, have a vacation mode, and provider customers an estimate of available hot water is left in the tank at any given time. Participants in our study found these features helpful.
- Installers should not install a 120V within a room where the occupant spends a large amount of time. Units make some noise and cool the surrounding area.

Installation Recommendations

Before selecting a 120V HPWH, installers should consider the following:

- Always present 240V units and relevant incentives as an alternative to 120V HPWHs. List the pros and cons of each technology to ensure the customer is fully informed of the potential drawbacks of 120V units.
- Upsize the old water heater by two size categories for a shared circuit 120V unit, and ideally one size category for a dedicated circuit 120V unit. Confirm that the installation location can accommodate a larger unit. Closets, low ceilings, raised stands or poured concrete blocks, ducts, furnaces, and pipes can constrain the space.
- Install 120V units only when a customer has a constrained budget that does not allow for 240V electrical upgrades such as running new circuits or upgrading their panel and service. If an electrical upgrade is found to be required to add a new circuit for the 120V HPWH, a 240V unit is a better option.
- Install 120V units only where there is a nearby outlet for unit's 8-foot cord, or where an alternative electrical solution is devised by the installer beforehand.
- Prioritize the installation of 120V units with backup resistive heating elements. This can decrease incidents of hot water runouts and increase customer satisfaction.
- Do **not** install 120V units at locations where:
    - The occupancy/potential occupancy of the home is more than four people. If there are four occupants, do either or both of:
        - Install a dedicated circuit unit
        - Ensure that the household takes short (~5 min) showers, does not take baths, and has low-flow showerheads in all showers
    - The household runs out of hot water often with their existing water heater.
    - The household frequently uses a lot of water in a short amount of time (i. e. multiple people taking long showers consecutively). Our field study has found that consuming a tank-worth of water greatly increases the chance of running out of hot water in the following hours. 120V units heat water more slowly than 240V units, even if they have a backup resistance element, so water goes out for longer.
- Confirm that the room hosting the water heater is large enough for full functionality, and that there are 700 cubic feet of air surrounding the heater. If not, ensure that there is a space that the unit could be ducted into (or connected to via a louvered door) that meets these requirements, and that the necessary equipment for this process is brought to the installation. Inform occupants of the need for this work as soon as possible and present a plan for the job at that time.
- Confirm that the occupant does not spend a large amount of time near the installation location. The units make some noise and cool the surrounding area.
- Consider using the PNNL HPWH installation tool for guidance in sizing and installing the unit.[21] This tool contains many of the above recommendations.

[21] https://basc.pnnl.gov/hpwh_installation_tool

In the case that a 120V HPWH is determined to be a good fit for a customer, we recommend the following on the day of installation:

- If the new water heater needs to be moved up or down stairs, be sure that two people are present for installation, or that the installer has access to an electric dolly. Most of the shared circuit HPWHs installed in this study were heavier and larger than their gas or electric resistance counterparts.
- Bring appropriate manufacturer-supplied ducting materials and be ready to install ducting if necessary.
- Condensate pumps and tubing should be brought to every site.
- Ensure that the screws in the top of the water heater tank shell are not flush against another surface after piping. They may need to be removed so the occupant can access the unit's thermistors if they need to be replaced.
- Install backflow prevention valves with the water heater. 120V HPWH operation is more sensitive to poor installation conditions such as backflow due to slower reheat times.
- Install a mixing valve if a unit does not have an integrated mixing valve.
- Recommend and offer to install low-flow fixtures, particularly showerheads, if they are not present.
- Educate the customer on the recovery time of the unit, tank temperature, mixing valves, and the cooling, dehumidification, and noise during operation.
- Educate the customer on the HPWH's controls and encourage them to download the manufacturer's controller app, if applicable.

Appendix A: Site Details

The below tables detail installation room size, household occupancy, and prior water heater information for all sites.

Table A-1. Focus on Energy installations.

Location	HPWH Room ft^3	Occupants	Baths	Bedrooms	Prior Fuel	Prior Size (gal)	Installed Unit Circuit Type and Size (gal)
Basement	2500	3	3	4	Nat. Gas	74	Shared 80
Basement	>2500	1	1	2	Nat. Gas	50	Shared 80
Basement	2400	2	2	3	Nat. Gas	40	Shared 65
Basement*	1143	2	3	3	Propane	40	Dedicated 50
Basement*	>2500	2	3	3	Nat. Gas	50	Shared 80
Basement*	>2500	1	1	3	Nat. Gas	50	Shared 65
Basement	1745	2	3	4	Nat. Gas	50	Shared 80
Basement	946	2	2	3	Nat. Gas	50	Dedicated 50
Basement	>2500	2	1	2	Nat. Gas	40	Shared 65
Basement	>2500	2	3	3	Nat. Gas	75	Shared 80
Basement	>2500	3	1	3	Nat. Gas	40	Shared 80

* Northwestern Wisconsin installation location.

Table A-2. ComEd installations.

Location	HPWH Room ft3	Occupants	Baths	Bedrooms	Prior Fuel	Prior Size (gal)	Installed Unit Circuit Type and Size (gal)
Basement	>2500	2	1	3	Nat. Gas	40	Shared 65
Closet	1100	3	2	3	Nat. Gas	50	Dedicated 50
Basement	>2500	2	1	3	Nat. Gas	40	Shared 65
Closet	46	3	2	4	Nat. Gas	40	Dedicated 50
Basement	>2500	3	2	3	Nat. Gas	50	Shared 80
Basement	1360	1	1	3	Nat. Gas	40	Shared 80
Basement	1100	4	3	4	Nat. Gas	50	Dedicated 50
Basement	>2500	3	1	3	Nat. Gas	40	Dedicated 50

Table A-3. Consumers Energy installations.

Location	HPWH Room ft3	Occupants	Baths	Bedrooms	Prior Fuel	Prior Size (gal)	Installed Unit Circuit Type and Size (gal)
Basement	2812	4	2	3	Nat. Gas	40	Shared 80
Basement	1138	2	2	3	Nat. Gas	50	Shared 65
Closet*	144	1	1	2	Nat. Gas	40	Shared 65
Basement	750	1	1	3	Nat. Gas	40	Shared 65
Basement	750	4	1	3	Nat. Gas	40	Shared 80
Basement	736	3	1	2	Nat. Gas	40	Dedicated 50
Basement	750	1	1	2	Nat. Gas	56	Dedicated 50
Utility Rm	275	2	1	2	Electric	10	Shared 40

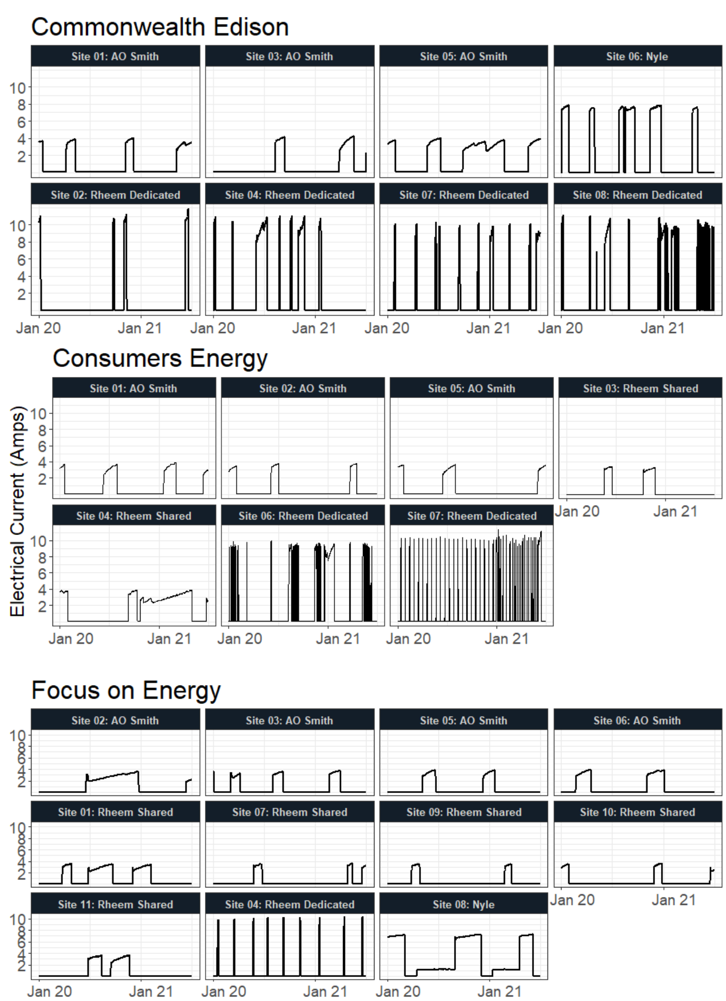
* This participant is now enrolled in the study as a Slipstream-sponsored participant.

Appendix B: Data Verification

To verify the functionality of the M&V equipment, we collected test measurements from all sensors before deploying them in the field. Data from the sensors and Packet Power strip were verified on-site and checked weekly thereafter to ensure good communication. A few needed to be fixed or swapped on-site. After that, all sensors returned values within their expected ranges. Current sensors from the TruePower CTs and the Packet Power strips agreed to within 5%. However, short-duration amperage measurements from the power strips were not available at the time of installation. A representative snapshot of the current draw of all HPWH is shown in Figure A-1.

In Figure A-1 and throughout their data, some units exhibit unexpected behavior in their consumption that seems to indicate rapid and persistent cycling of the compressor for certain periods (see ComEd site 08, Consumers 06 for most obvious examples). This behavior persists across those units and is verified in both the power and current consumption from the power strips and standalone current sensors, which leads the research team to believe the data are accurate.

Figure A-1. Current Draw for All Sites Installed in 2023.



The research team verified hot water consumption on-site by running hot water faucets and timing a set volume of water delivered. We monitored consumption over time and checked both typical draw durations and daily use against national estimates for hot water use. Three sites were reporting abnormally high consumption due to water sloshing back and forth between the expansion tank and the water pulse meter. The treatment of these anomalies is covered in Appendix C.

Groundwater temperatures were verified via comparison with regional averages. For minutely and daily data aggregation, we took the minimum measured groundwater temperature. This was because water warms up when inside the home or nearby pipes. The minimum value shows the temperature when water has been flowing and is freshly pulled from the ground, which is the most accurate measurement.

Appendix C: Treatment of Abnormal Draw Measurements

Most monitoring data yielded daily results like the timeseries described in Section IV. However, upon granular analysis, we discovered several situations in which measurements were deviating from expected patterns. Because this deviation was consistent and identifiable in most cases, we were able to tag these events and adjust our secondly datapoints before beginning data aggregation and analysis.

There were two types of correctable discrepant data. The treatment of each is described below. The last section describes the remaining few situations for which we exempted data due to faulty M&V devices.

Superfluous Water Pulse Readings

Three sites had abnormally high-water consumption values. When we looked at site timeseries, we found these sites were registering very low consumption essentially all the time.

It was determined that these water pulse values were occurring because of water sloshing back and forth between the expansion tank and the water pulse meter. This water was registering as consumption every time it crossed the pulse meter's threshold, even when it was only moving past the threshold temporarily, about to slosh back, and not as an indication of consumption.

We developed a data treatment technique combining hot water draw data and water pulse averages to pinpoint and remove this superfluous water consumption. We ran a script that did the following:

- Calculate the average of the 30 seconds preceding each point in each timeseries. This was consistently at a low positive value for these three sites.
- When hot water temperature spikes, tag this as the beginning of a draw. Freeze the 30 second preceding average as the prior water pulse average for this draw.
- Begin taking the average water pulse value for the 30 seconds following each point.
- When the pulse average for the 30 seconds following a point dip back to the draw's prior water pulse average, tag this as the end of the draw.

We reviewed a multitude of timeseries before and after this treatment was applied to ensure that water pulses were clipped only when there was no consumption visible in the hot water temperature readings. We then checked our resulting consumption and draw data against the other sites' averages. This treatment successfully pinpointed draws and removed superfluous water pulse readings.

Abnormal Hot Water Measurements

When tagging hot water runouts based upon end temperature, we found that certain hot water draws were registering as runouts even though a draw directly after had a satisfactory supply of hot water. Upon investigation, we found that some sites were registering a phenomenon in which hot water temperature would nose-dive more than ten degrees very briefly, only to return to setpoint temperature after a few seconds.

This rapid temperature measurement fluctuation was determined to be caused by mixing valve behavior. In units with integrated mixing valves, the mixing valves were adding cold water into water heated above setpoint to deliver at setpoint, but this cold water was being picked up on by the thermistor before being adequately combined with the hot water. Similarly, in bottom-filling units, long draws would cause incoming cold groundwater to be pulled from the tank for a moment before the unit could mix that cold water with the rest in the tank.

Three participants mentioned experiencing bouts of cold-water during water at setpoint, which leads us to believe that at least some of the times that this phenomenon occurred, the water remained separated up until it left the spout.

In addition, draws occasionally exhibited a mismatch between the end of the water pulse measurement and the water temperature measurement. The water temperature measurement would record a draw-end temperature decrease before the pulse was recorded as ending. Other times, the temperature would droop below setpoint for a draw, most likely due to mixing valve behavior or backflow. For these draws, as well, hot water temperature would return to setpoint at the next moment of demand.

We flagged and quantified these abnormal measurements to the best of our ability. 1,693 draws, or 3.5%, were pinpointed as exhibiting abnormal behavior. These were filtered from the draw results.

Other Data Treatment

There were a few instances in which we filtered data from the analysis because we were unable to correct the input from a faulty monitoring device. These are listed below.

- At one site, the hot water thermistor was constantly jumping up and down around 20 degrees, even at times of no consumption. This made it difficult to determine the actual hot water draw behavior, so we've filtered this site from analysis.
- At one site, the box containing the M&V equipment suffered water damage from condensation caused by the HPWH being directly next to a furnace. This caused hot water thermistor measurements to spike to several hundred degrees. We exempted this site's data following this event, which happened in mid-May.
- There were two sites with scattered instances of extremely high (10x expected) values, for gallon measurements at one site and for hot water temperature measurements at the other. Because these numbers would only spike for one second before returning to values within the expected distribution, we filtered these seconds from the aggregation process.

Appendix D: Power Measurement Methods

The Campbell monitoring devices measured amperage throughout the study. However, for all units, we did not begin measuring minutely wattage data from the PacketPower devices until March. The PacketPower smart strips had a time zone synching issue which resulted in data loss after three weeks of data gathering. The issue could not be resolved without manual adjustments. The research team revisited all sites to resolve the issue.

To backfill power data from the preceding months, we calculated a site-specific amp-to-power ratio from the datapoints for which we had both amperage and wattage measurements. We used this ratio to convert the sole amperage measurements into wattage readings for each minute. We verified that these infilled results were within the expected distribution.

There was one site at which the PacketPower device failed in July. We filled these measurements the same way as we did the measurements prior to PacketPower installation, using the data from the months with both Campbell and PacketPower measurements.

Appendix E: Interview and Survey Materials

Installer Interview Guide

Installer Interview

Date: ________________ **Time:** _______________

Site #: _______________ **Region:** ______________

Installer's First and Last Name: ____

Installer's Company: ____

Installed Make and Model: ____

Introduction: *Thank you for agreeing to help us understand your experience installing a heat pump water heater at this site which is participating in the Midwest 120-volt heat pump water heater field validation study. I will be asking you questions about the permitting process, installation tasks, equipment, challenges, and your overall experience at this site. Your responses will help the study team, manufacturers, and eventually other installers understand installation challenges and training needs. If you have any questions or concerns at any point during our discussion, please do not hesitate to ask for clarification or express your thoughts.*

Is it okay if I audio record our discussion? This makes it easier for me to take notes and capture your ideas accurately. [If "**No**," then note that installer declined.]

Background and Preparation

First, let's talk about how things went today and how you prepared for this installation.

1) How did it go? [PROBE: What went well? What was challenging? How did this compare to a typical water heater installation? 240V HPWH?]
2) Was this your first installation for the Midwest 120-volt heat pump water heater field validation study? Yes/No
3) Do you have experience installing 240-volt or plug-in 120-volt heat pump water heaters outside of this study? Yes/No
   a) If **"Yes,"** please describe
4) How long did it take you to prepare the site for heat pump water heater installation (including existing water heater removal, wiring changes, capping the gas flue, etc.)?
5) Once the site was prepared, how much time did it take to install the 120-volt heat pump water heater?
   a) [PROBE: Is this typical? Yes/No. If no, why not?]
6) Compared to a typical gas water heater installation, how much time did preparation and installation take for the 120-volt heat pump water heater? [probe on why and ask them to clarify if anything was specific to gas water heaters (e.g., timing, running the exhaust vent, attaching gas line]
7) How many people from your company were here for the installation?
   a) [PROBE: Why this number? Is this typical? Would you use a different number for future installations?]

Permitting

Next, let's discuss permitting.

1) Which permits, if any, did you need to obtain for this water heater installation? Were any permits different or unique to a plug-in HPWH installation?
    a) [PROBE: How did permitting staff treat the 120V HPWH as far as codes or understanding/interpreting the technology?]
2) Did you experience any issues with the permitting process? Yes/No
    a) [If "**No**," move to next section]
    b) [If "**Yes**"] Can you briefly summarize the issue(s) for me?

Installation Tasks

Now let's talk about what the installation involved, starting with electrical-related tasks.

1) Were any electrical-related tasks required for today's installation? Yes/No
    a) If **"Yes,"** Who completed the electrical-related task? (Installer/Installer's employee/other Contractor, Other)
2) What electrical related tasks were required (cover the following and probe for explanation and description)?
    a) Did you/they have to run new circuit(s) for this installation? Yes/No
    b) Did you/they have to add or replace breaker(s)? Yes/No
    c) Did you/they install a sub-panel? Yes/No
    d) Did you/they have to split a single outlet into a double outlet? Yes/No
    e) Did you/they have to perform any other electrical-related tasks to complete this installation? Yes/No
        i) If "**Yes**," what were they?
    f) Would additional electric work have been required had this been a conventional electric water heater?
        i) [PROBE – new circuits, added breakers, panel replacement, service upgrade, costs]
3) Compared to a typical gas water heater installation, was the electrical connection here easier, about the same, or more difficult? [PROBE: How much easier or more difficult was it? Why?]
4) Did you modify or install any doors or ducting for the water heater? Yes/No
    a) [If "**No**," go to question #5.]
    b) [If "**Yes,**" then identify the type of modification or installation from the list below and probe for description]
        i) Replaced door with louvered door
        ii) Replaced door with door with air gap
        iii) Added ducting to HPWH air outlet
        iv) Added ducting to HPWH air inlet
        v) Added wall grilles
        vi) Left existing door ajar with doorstep
        vii) Removed existing door
        viii) Other (please specify)
5) Did you dismantle or cap off an existing flue or vent? Yes/No
    a) [If "**Yes,**" find out if they **dismantled** or **capped off**.]
6) Did you install or upgrade a condensate drain? Yes/No
    a) [If "**Yes,**" find out if they **installed new** or **upgraded existing**.]
7) Is the condensate drain a **rigid** or **flexible** pipe?

8) Did you have to install a pump for the condensate drain? Yes/No
9) Does the condensate drain to a sink drain, laundry drain, floor drain, outside the house, or some other location? [If other, identify the specific location.]
10) If there was an expansion tank, did you reuse the existing one or must install a new one? Yes/No
11) Did you have to **replace** or **re-route** pipes around the water heater (not including flex lines)? [Find out if they replaced, re-routed, both, or neither.]
    a) [PROBE: Ask them to describe what they did a bit more]
12) Did you install a thermostatic mixing valve? Yes/No
    a) [If "**Yes,**" find out if they **installed new (previously none)** or **replaced existing**.]
    b) [If "**No,**" find out if they **reused the existing** mixing valve, **a mixing valve was integrated** in the unit, or **none of these**.]
13) Did you haul away the old water heater? Yes/No
    a) [If "**No**," find out what they did with the old water heater.]

Unit Setup

Thanks for sharing those installation details. The next questions are about how you prepared for this installation and set up the unit.

1) Did you set up the communications features of the 120-volt heat pump water heater? Yes/No
    a) [If "**No**," skip to next section.]
    b) [If "**Yes,**" go to next question.]
2) Compared to a typical water heater installation, was setting up the communications features of this unit easier, about the same, or more difficult? [PROBE: How much easier or more difficult was it?]

Overall Impressions

As we wrap up, I'd like to learn about your overall experience with this installation.

1) Were the installation instructions provided by the manufacturer clear and easy to follow? Yes/No
2) What suggestions do you have to improve the installation instructions?
3) Did you require support during the installation? Yes/No
    a) [If "**Yes,**" probe for description of who/where support was sought (e. g., manufacturer).] Please describe the support you required: installation instructions, or other aspects of the install?
4) What are your perspectives on customers trying to install these water heaters without a licensed plumber? [PROBE: Is it more likely that customers will try?]
5) [If not first installation/interview] Can you tell me more about your perceptions of each 120V product and its features? What aspects did you like or dislike about each brand?
6) [If not first installation/interview] How did your perspectives on the market or installation barriers change since the last installation for this project, if at all?
7) Is there anything else you think we should know?

Closing: *I sincerely appreciate your willingness to share your experiences at this site. Your insights and suggestions will be valuable to help us better understand the heat pump water heater market. Once again, thank you for your time and expertise.*

Participant Pre-Screening Survey Key

120V Field Study Participant Prescreening Questionnaire

Intro text: Thank you for your interest in [Focus on Energy/ComEd/Consumers Energy]'s 120-volt heat pump water heater field study! Participants will receive a new, energy-efficient heat pump water heater at no cost in exchange for participating in the 12-month study. The goal of this study is to test the performance of this new technology in homes across [Wisconsin/Illinois/Michigan].

This 5-minute prescreening questionnaire will help us determine if your home is a good fit for the study.

For more information about the study, visit: [link to study website].
Questions? Reach out to us at: [contact email]

1) Who is your electric service provider?
2) Who is your natural gas utility? (if applicable)
3) Please provide your address so we can verify your eligibility:
    a) [Textbox validation: "Must provide a response" if less than 3 characters]
4) Which of the following best describes your home?
    a) Single-family home
    b) Duplex/townhouse
    c) Apartment
    d) Mobile/manufactured home
        i) If this selected, end survey. Show message stating: "Thank you for your interest. Based on the information you provided, your home is not eligible. If you would like to keep up with the progress of this study and others around the nation, sign up for our newsletter at **https://www. advancedwaterheatinginitiative. org/join-us**
    e) Other [Text Box]
5) Including yourself, how many individuals live in the home?
    a) 1
    b) 2
    c) 3
    d) 4
    e) More than 4
6) What is the approximate household income?
    a) Under $42,804
    b) $42,805 to $55,975
    c) $55,976 to $69,145
    d) $69,146 to $82,317
    e) More than $82,318
    f) Prefer not to answer
7) How many bedrooms are in your home?
    a) [Textbox validation: "The value must be a number"]
8) How many full bathrooms are in your home?
    a) [Textbox validation: "The value must be a number"]
9) How many half bathrooms are in your home? If none, enter 0
    a) [Textbox validation: "The value must be a number"]
10) How many combo shower/bathtubs are in your home? If none, enter 0

   a) [Textbox validation: "The value must be a number"]
11) How many walk-in showers are in your home? If none, enter 0
   a) [Textbox validation: "The value must be a number"]
12) How many bathtubs (no showerhead) are in your home? If none, enter 0
   a) [Textbox validation: "The value must be a number"]
13) How many water heaters do you have in your home?
   a) One
   b) More than one
14) Which of the following best describes your water heater (or primary water heater, if there is more than one)?
   a) Natural Gas-fired tank-style water heater
   b) Propane-fired tank-style water heater
   c) Electric tank-style water heater
   d) Tankless Natural Gas water heater
   e) Tankless Propane water heater
   f) Tankless electric water heater
   g) Central system serving more than one housing unit
   h) Other [Textbox]
   i) Don't know
15) About how old is your water heater?
   a) Less than 1 year old
   b) 1-5 years old
   c) 6-10 years old
   d) More than 10 years old
   e) Don't know
16) Which of this best describes where your water heater is located?
   a) Indoor closet
   b) Walk-in utility room
   c) Basement
   d) Crawl space
   e) Central unit serving more than one household
   f) Other (describe)
17) Do you actively heat and/or cool the part of the home where your water heater is located?
   Parts of your home that maintain temperature throughout the year are actively heated or cooled. A basement that gets much colder (more than 10 degrees difference) than other parts of the home in winter is not actively heated or cooled.
   a) Yes
   b) No
18) Do you rent or own your home?
   a) Rent
   b) Own
19) [If rent for #17] Is the property owner aware of and interested in the project?
   a) Yes
   b) No
   c) Not sure

20) Are you a current employee of [Focus on Energy/ComEd/Consumers Energy] or any of its participating utilities?
    a) Yes
    b) No

Encouraging Message: You're almost done! Based on your responses, you may qualify to participate in the study. We just need to confirm that you agree to the study activities described below.

21) Please confirm that the home/building owner agrees to the following required study activities. If you are not the home/building owner, please acknowledge that you understand the building owner will be contacted to confirm their agreement to these requirements:
    - Remove the existing gas water heater and replace it with a high efficiency 120V heat pump water heater.
    - Allow for installation of monitoring and data collection equipment.

    a) I am the home/building owner, and I agree to all the above study activities.
    b) I am not the home/building owner, but I acknowledge that the home/building owner must agree to all the above study activities to participate.
22) Please confirm that the occupant agrees to the following required study activities:
    - Participate in equipment monitoring
    - Complete periodic surveys to indicate satisfaction with the heat pump water heater
    - Allow the research team to take photos of the existing water heater setup and heat pump water heater setup

    a) I am the occupant, and I agree to all the above study activities.
    b) I am not the occupant, but I acknowledge that the occupant must agree to all the above study activities to participate.

Last page message: Thank you again for taking the time to complete this survey! Please provide your contact information so we may follow up with you regarding next steps. Your email address will not be shared and will only be used to contact you with information related to the study.

23) First and last name
    a) [Text box]
24) Email address
    a) [Text box]
25) Phone number (will only be used to contact you if you are eligible)
    a) [text box]

Closing message: The Research Team will be in touch in by July 14th to let you know if you qualify for this project. The installations expected to take place in September 2023. Thank you for taking the time to complete the survey and for your interest in [Focus on Energy/ComEd/Consumers Energy]'s 120-volt heat pump water heater field study.

Participant Virtual Walkthrough Guide

Virtual Walkthrough Questions

1) Is there a recirculation pump? [**If yes, customer is not eligible, no additional questions needed**]
2) Noise concerns: Is water heater located close to bedrooms or living rooms?
3) Is there an existing expansion tank?
4) How close (in feet) is the nearest outlet to the WH?
5) What is availability of the closest plug (open, half, full)? Is it a standard 3-prong 120V?
6) Is the customer comfortable with 6-8 people being onsite for installation?
7) Does the customer have any major home renovations planned in the next 12 months?

Have the customer start by going to the location of the water heater. Capture 2-3 images of the following items:

- Photo of the water heater from floor to ceiling
- Photo of the venting
- Photo of the drainage (where it starts to where it finishes)
- Photo of water lines
- Photo of temperature setting

8) What are the dimensions of the space where the water heater is installed, if in a closet?
9) If in a garage or basement, what are the dimensions from where the water heater would be sitting to the ceiling?

Have the customer zoom in on the name plate. Make sure to capture the following in the photos:

- Manufacturer
- Brand
- Model
- Serial number
- BTU/hr
- Gallons

Have the customer locate the electrical panel that supplies the water heater. Capture 2-3 photos of the following:

One of the primary goals of this is to identify recalled panels – we could not complete the install if the panel was recalled.

- Subpanel (If one is present)
- Photo of breakers
- Photo of nameplate if present
- Photo of the panel opened
- Photos of the entire box, including direction of power lines going into the box

Participant Final Survey Key

Midwest 120V HPWH Study: End of Study Survey Questions

(To be shared with [Focus on Energy/ComEd/Consumers Energy] study participants via Formstack)
*Survey fields (section header, question type) highlighted in yellow.

Logic conditions indicated in purple text.
*All questions are listed as required

Survey Landing Page: Thank you for your participation in the 120-volt heat pump water heater technology validation study! This 5 to 10-minute survey provides an opportunity for you to tell us about the performance of your 120-volt heat pump water heater. This information is extremely valuable to understanding the performance of this new technology.

Note that this survey asks some questions twice. These are **not** duplicates! Rather, the first iteration pertains to your experience in the time since you took the last survey, and the later iteration is asking about your experience over the entire study timeframe.

Questions? Reach out to 120V Heat Pump Water Heater Research Team at: [hpwh-study@focusonenergy. com/HPWH-study@slipstreaminc. org]

Section Header: The questions in this section pertain to the time since the last survey (from early spring through the summer):

1. Rating (Star icon; Count = 5) On a scale of 1 (not at all satisfied) to 5 (extremely satisfied), how would you rate your satisfaction with your new heat pump water heater since the last survey?
2. Long Answer: Please describe your reasons for the water heater satisfaction rating you selected in the previous question.
3. Checkbox: Since the last survey, has the number of people in your home changed for 3 days or longer? This may include visiting guests, vacation away from the home, child home from college, birth of a child, etc. (check all that apply)
   - ☐ Short-term INCREASE in occupancy (e.g. visiting guests)
   - ☐ Long-term INCREASE in occupancy (e.g., child home from college)
   - ☐ Short-term DECREASE in occupancy (e.g., vacation)
   - ☐ Long-term DECREASE in occupancy (e.g., child leaving for college)
   - ☐ No change
4. Radio Button: Which of the following statements best describes your experience with the heat pump water heater's supply of hot water, since the last survey?
   - ○ I never run out of hot water
   - ○ I sometimes run out of hot water
   - ○ I frequently run out of hot water
   - ○ Not sure

Section Header (New Page): The questions in this section pertain to the time since the last survey (from early spring through the summer):

Logic for all questions in this section: Show this field when any of the following rules match: Q4 = I sometimes run out of hot water; Q4 = Not sure

5. Long Answer: For the times that you have run out of hot water since the last survey, please describe how you were trying to use hot water. For example, taking a shower at the same time as someone else in the household, taking a shower right after someone else, running a bath, etc.
6. Radio Button: When you have run out of hot water, how long do you typically have to wait for hot water to be available again?
   - Less than 1 hour
   - More than 1 hour
   - Not sure
7. Radio Button: How disruptive was the lack of hot water?
   - Very disruptive
   - Somewhat disruptive
   - Not at all disruptive
8. Long Answer: What action(s), if any, have you taken in response to running out of hot water?

Section Header (New Page): The questions in this section pertain to the time since the last survey (from early spring through the summer):

9. Radio Button: Since the last survey, how satisfied are you overall with the length of time it takes for your new water heater to heat water?
   - Very satisfied
   - Somewhat satisfied
   - Neither satisfied nor dissatisfied
   - Somewhat dissatisfied
   - Very dissatisfied
10. Radio Button: Has anyone in the household changed any settings on your new water heater since the last survey?
    - Yes
    - No

Section Header (New Page): The questions in this section pertain to the time since the last survey (from early spring through the summer):
Logic for all questions in this section: Show this field when all the following rules match: Q10 = Yes

11. Checkbox: How were the setting(s) changed?
    - ☐ Manually (on the water heater)
    - ☐ Using the manufacturer app
12. Checkbox: What settings were changed? (check all that apply):
    - ☐ Operating mode
    - ☐ Storage tank temperature setting

- ☐ Mixing valve temperature setting (the mixing valve is a device mixing cold water with the hot water to deliver tempered water)
- ☐ ***Add "Other" with a free response box***

13. Long Answer: Why were the settings changed?
14. Radio Button: Did changing the settings resolve the issue(s)?
    - Yes
    - No
    - Not sure

Section Header (New Page): The questions in this section pertain to the time since the last survey (from early spring through the summer):

15. Short Answer: At what temperature is the water heater currently set (typically between 120 degrees F and 150 degrees F)?
16. Radio Button: Have you noticed a change in the room temperature in the space where your heat pump water heater was installed?
    - No, I have not noticed a change in the room's temperature.
    - Yes, it is a lot warmer
    - Yes, it is a little warmer
    - Yes, it is a little cooler
    - Yes, it is a lot cooler
    - Not sure

Logic for Q17: Show this field when all the following rules match:
Q16! = No, I have not noticed a change in the room temperature
Q16! = Not sure

17. Radio Button: How do you feel about the temperature change?
    - It is a benefit
    - It is a drawback
    - It is sometimes a benefit and sometimes a drawback
    - It has no effect on me
18. Radio Button: Have you noticed a change in the room humidity of the space where the 120-volt heat pump water heater is installed?
    - No, I have not noticed a change in the room's humidity.
    - Yes, it is a lot more humid
    - Yes, it is a little more humid
    - Yes, it is a little less humid
    - Yes, it is a lot less humid
    - Not sure

Logic for Q19: Show this field when all the following rules match:
Q18! = No, I have not noticed a change in the room temperature
Q18! = Not sure

19. Radio Button: How do you feel about the change in humidity?
    - It is a benefit
    - It is a drawback
    - It is sometimes a benefit and sometimes a drawback
    - It has no effect on me

20. Long Answer: When is the room's temperature or humidity change a benefit versus a drawback? (If you have no opinion on this, please respond N/A).

Section Header (New Page): The questions in this section pertain to the time since the last survey (from early spring through the summer):

21. Radio Button: Do you ever hear sounds from your new water heater?
    - Yes
    - No

Logic for questions 22, 23, and 24: Show this field when all the following rules match: Q21 = Yes

22. Checkbox: From which living areas of your home can you hear the water heater? (Check all that apply).
    - ☐ Kitchen
    - ☐ Living/Family Room
    - ☐ Bedroom(s)
    - ☐ Bathroom(s)
    - ☐ Laundry Room
    - ☐ ***Add "Other" with a free response box***
23. Radio Button: How would you describe the noise level of your new water heater, as experienced from the living space of your home (living room, bedrooms, kitchen)?
    - Hardly noticeable
    - Noticeable but not annoying
    - Loud to the point of annoying
24. Long Answer: Compared to other household appliances, how would you describe the noise of your new water heater as experienced from the living space of your home? For example, "similar to refrigerator."

Section Header (New Page): The questions in this section pertain to the time since the last survey (from early spring through the summer):

25. Radio Button: Have you noticed any vibration from your new water heater from the living space of your home (living room, bedrooms, kitchen)?
    - I have not noticed any vibrations
    - Noticeable vibration but not annoying
    - Annoying vibration level
    - Not sure
26. Checkbox: Have you experienced any of the following functional issues with your new water heater? (check all that apply):
    - ☐ None
    - ☐ Water or moisture on the surfaces around the water heater
    - ☐ Water heater takes too long to heat water
    - ☐ ***Add "Other" with a free response box***

Section Header (New Page): The following questions pertain to the overall study time frame (~1 year).

27. Long Answer: If possible, please describe any occupancy changes during the entire study period (number of people, approximate dates, etc). Examples may include visiting guests, vacation away from the home, child home from college, birth of a child.
28. Rating (Star icon; Count = 5) On a scale of 1 (not at all satisfied) to 5 (extremely satisfied), how would you rate your overall satisfaction with your new heat pump water heater throughout the duration of the study?
29. Radio Button (Horizontal layout): How likely are you to recommend a friend get a 120V heat pump water heater?
    - 1 – Not likely at all o 2 o 3 o 4 o 5 – Extremely likely
30. Long Answer: Please describe your reasons for the ratings you selected in the previous two questions.

Section Header (New Page): The following questions pertain to the overall study time frame (~1 year).

31. Radio Button: Which of the following statements best describes your overall experience with the heat pump water heater's supply of hot water throughout the duration of the study period?
    - I never run out of hot water
    - I sometimes run out of hot water
    - I frequently run out of hot water
    - Not sure
32. Radio Button: Have you noticed a change in your total monthly utility cost since getting your new water heater?
    - Yes, my total utility costs increased
    - Yes, my total utility costs decreased
    - No noticeable change
33. Long Answer: Have you noticed a change in the way you use hot water compared to before? For example, longer/shorter showers, hot water laundry cycles less frequently, etc.
34. Radio Button: Did you notice any seasonal variations in the performance of your water heater?
    - Performed much better in warmer weather
    - Performed somewhat better in warmer weather
    - Performed somewhat better in cooler weather
    - Performed much better in cooler weather
    - No noticeable change in performance

Section Header (New Page): The following questions pertain to the overall study time frame (~1 year).

35. Long Answer: Please use the space below to describe any other benefits or issues you have experienced, and to provide any additional feedback on your new water heater. This could include general impressions, overall experience, major benefits, or anything else not covered in this survey. If you have no additional comments at this time, you can input "N/A" below.
36. Name (First Name, Last Name): Participant first name and first initial of last name (for example, Jane D.)