Small to Medium Business Heat Pump Water Heater (HPWH) Emergency Deployments

Final Report

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Executive Summary

Plug-in 120-volt (V) heat pump water heaters (HPWHs) are a market-ready technology with potential to support decarbonization in the small- and medium-sized business (SMB) sector, particularly as emergency replacements. In the absence of a simple, fast, and affordable electric replacement option, SMB owners often default to replacing failed units with conventional gas models. This field study was designed to explore whether 120 V plug-in HPWHs can serve as a practical alternative in real-world commercial settings.

The study addresses three questions:

1. What are the typical hot water draw profiles in SMBs?
2. Can 120 V plug-in HPWHs meet SMB hot water needs, particularly in emergency replacement situations?
3. What is the customer and contractor experience with installing and operating this technology?

To answer these questions, the project team installed 120 V HPWHs at five SMB sites—a shopping center, a small office, a small warehouse, a non-profit social service agency, and a religious organization with office and preschool functions—and conducted field metering and surveys. The team monitored hot water draws, HPWH electrical energy use, hot- and cold-water temperatures, and, where available, source air conditions, and used this data to calculate daily hot water usage, equipment coefficient of performance (COP), estimated baseline energy use, and operating costs.

Metered data show that many SMBs have modest and highly intermittent hot water loads, typically dominated by restroom handwashing, breakroom usage, and occasional cleaning. In all five sites, daily hot water use was far lower than predicted by traditional sizing methods, and 120 V HPWHs were more than adequate from a capacity standpoint. However, the low and sporadic usage meant that centralized storage systems spent much of their time in standby, with tank losses and cycling dominating energy use and leading to low equipment COP on very low-use days. At the warehouse, office, and non-profit sites, COP was often below 1 on low-use days, while the religious organization site showed strong weekday COP (>3.0 COP) and substantial energy savings, but weekend performance deteriorated when demand dropped. These results suggest that 120 V HPWHs can technically meet SMB hot water needs in many cases, but that very low-use, dispersed-fixture applications are inherently challenging for centralized water heating and may be better served by point-of-use electric resistance heaters.

The field experience also highlighted the importance of distribution system design and recirculation. The project screened out sites with active recirculation loops because recirculation adds complexity and risk for 120 V HPWHs, which have lower recovery rates than conventional gas or 240 V systems. In practice, this meant that some sites had long runs without recirculation, and customers experienced long wait times and poor hot water delivery at remote fixtures. Installation and cost data indicate that 120 V HPWHs offer a simpler and more cost-effective path to electrification than 240 V HPWHs by avoiding panel upgrades and extensive wiring but remain more expensive than gas-fired tank heaters. Maintenance and warranty issues (including a leak at one site and compressor-related

error codes at two others) and the reduction of warranty coverage from ten years to one year in commercial applications further underscore the need for strong program and manufacturer support.

Customer and contractor feedback revealed significant knowledge gaps and perception issues around water heating. Most customers were generally satisfied with their existing systems and had limited awareness of energy use or efficiency, though some expressed interest in improved consistency, lower utility bills, and app-based controls. Contractors often lacked detailed information about existing system sizing, usage patterns, and electrical capacity, and were uncertain about where 120 V HPWHs were appropriate. At the same time, participants were willing to move forward with 120 V HPWH retrofits when they were offered at no upfront cost, even when modeled operating costs were slightly higher than baseline, suggesting that SMB customers may accept small operating cost increases in exchange for avoided capital costs and clear environmental benefits.

Overall, the field results indicate that 120 V plug-in HPWHs can be a viable decarbonization measure for a targeted subset of SMBs: those with modest but meaningful hot water loads, fixtures reasonably close to the water heater, and limited appetite for panel upgrades, provided that programs carefully screen sites and support contractors. The study also highlights several areas where future work and program design can improve outcomes, including developing SMB-specific sizing and screening tools, targeting sites with appropriate distribution layouts and considering hybrid solutions (central HPWH plus point-of-use electric resistance) for remote fixtures, refining emergency replacement pathways through contractor training and reliable product availability, and engaging manufacturers to provide recovery rate data, performance maps, and clearer warranty terms for commercial applications.

Abbreviations and Acronyms

Acronym	Meaning
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning
Btu	British thermal unit
CALGreen	California Green Building Standards Code
Cal TF	California Technical Forum
CEMS	Comprehensive Energy Management Solutions
CO_2	Carbon dioxide
COP	Coefficient of performance
eTRM	California electronic Technical Reference Manual
GHG	Greenhouse gas
GPM	Gallons per minute
HPWH	Heat pump water heater
IOU	Investor-owned utility
kWh	Kilowatt-hour
M&V	Measurement and verification
PG&E	Pacific Gas and Electric
psi	Pounds per square inch
RH	Relative humidity
SDG&E	San Diego Gas & Electric
SMB	Small- and medium-sized business
TOU	Time-of-use

Acronym	Meaning
UEF	Uniform energy factor
V	Volt

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Introduction

Plug-in 120-volt (V) heat pump water heaters (HPWHs) are a market-ready technology with significant potential to support decarbonization, particularly as emergency replacements in the small- and medium-sized business (SMB) market. A 2019 Consumer Reports study estimated that 90 percent of water heating replacements occur on an emergency basis (Farrell, 2019). In the absence of a simple, fast, and affordable electric replacement option, SMB owners often default to replacing failed units with conventional gas or propane models.

Fuel-switching from gas water heating to a 240 V heat pump water heater can create a barrier to fuel-switching, especially during emergency replacement scenarios when time is critical. Plug-in 120 V HPWHs offer a compelling solution because they only require 120 V and less than 15 amps, allowing them to connect directly to existing wall outlets and avoid the added coordination and delay of calling both a plumber and an electrician to the site. The project team notes that some 120 V HPWHs on the market expressly recommend against permanent installation on a shared circuit, in which case the plumber can potentially install the 120 V HPWH on a shared circuit during an emergency replacement until the site can get an electrician out to add a dedicated branch circuit to serve the 120 V HPWH. In some edge cases, 120 V HPWH may avoid a costly panel or service upgrade; however, the project team's collective experience is that this is not a common issue in nonresidential applications.

This field study is designed to assess the viability of 120 V plug-in HPWHs as emergency replacements in SMB settings. To quantify the energy and hot water performance of these units, the project includes the installation of five 120 V HPWHs at five sites and documentation of characteristics at any emergency replacement locations. Targeted site types include retail, religious, office, warehouse, grocery, and school buildings, as well as other customer types with similar low- to medium-usage water heating profiles.

Background

A recent California-wide residential field study found that 120 V HPWHs reduced average monthly energy consumption by approximately 85 percent compared to existing gas or propane water heaters (New Buildings Institute, 2023). Widespread adoption of this low-power technology in SMBs could meaningfully contribute to California's goal of installing six million heat pumps by 2030.

The most significant feature that distinguishes a 120 V HPWH from a standard 240 V unit is its ability to plug into an existing 15-amp outlet and, in some cases, share a circuit with other appliances. This compatibility is possible because 120 V models either lack an electric resistance backup element or include one that is significantly smaller than those found in 240 V units. As a tradeoff, hot water recovery times may be slower when the tank is fully depleted. Today, manufacturers are increasingly bringing 120 V HPWHs to market.

The New Buildings Institute's focus on 120 V HPWHs in California's residential market, including 32 single-family and multifamily sites, provides valuable insight into the technology's performance across multiple climate zones (New Buildings Institute, 2023). The study focused on homes with gas- and propane-fired tank water heaters, currently the most common types in California. It included monitoring and analysis of energy performance, frequency of hot water runout events, and electricity usage across different operating conditions and rate structures. The study also explored the potential for load shifting away from peak time-of-use pricing and high greenhouse gas (GHG) emission periods. In addition, researchers gathered information relevant to utility program eligibility and explored installation and code-related barriers. This study was conducted to investigate whether 120 V HPWHs have potential for SMB applications.

This study will provide insights into the benefits and tradeoffs of using 120 V HPWHs for emergency replacements in SMB settings. Specific areas of focus include hot water usage profiles, installation costs, and customer and contractor satisfaction. In addition, the team will quantify average energy savings from a limited number of field installations. The project team will also develop recommendations for future research, including market characterization, expanded field testing, laboratory studies, and potential utility program integration.

Objectives

This study aims to answer three key questions:

1. What are the typical hot water draw profiles in small and medium businesses?
2. Can 120 V plug-in HPWHs meet the hot water needs of these businesses, particularly in emergency replacement situations?
3. What is the customer and contractor experience with installing and operating this technology?

To address these questions, the project team conducted a small-scale field demonstration of 120 V plug-in HPWHs in five SMB sites. The project team assessed technical feasibility, installation and operating costs, user satisfaction, and hot water usage patterns. Since the draft report has been approved, the project team has provided the recommendations from the project to the California Technical Forum (Cal TF), investor-owned utilities (IOUs), and other California electronic Technical Reference Manual (eTRM)-governing entities, with the intention of informing future updates to existing measure packages and supporting the addition of 120 V HPWHs to the eTRM. Once adopted, utilities may use the measure to serve hard-to-reach and disadvantaged community customers through direct install programs or same-day installation offerings.

Methodology and Approach

Site Selection and Contracting

The project team conducted a literature review to better understand hot water demand by SMB building type and usage by fixture type. This review informed the development of a calculator to support site selection and to estimate changes in energy use and greenhouse gas emissions. Through conversations with each site, California Green Building Standards Code (CALGreen) use assumptions (Commission, 2022), and plumbing code guidelines, the team calculated a maximum daily hot water use case based on the number of fixtures, fixture flow rates, occupant count, and occupant behavior. The findings provided baseline estimates of hot water demand across various business types and helped identify small and medium businesses eligible for participation in the field study.

Site recruitment efforts included collaboration with San Diego Gas & Electric (SDG&E)'s Comprehensive Energy Management Solutions (CEMS) program, outreach through community-based organizations, a public webinar, direct outreach (cold calling), and leveraging both personal industry connections and outreach to other program administrators.

During initial contact, the project team educated each site on the potential benefits and limitations of installing a 120 V plug-in heat pump water heater. The project team then screened out sites that were not suitable for demonstration due to technical limitations or operational constraints, including:

- Excessive or highly variable hot water use based on the project team's judgement
- Presence of a hot water recirculation system
- Sites with instantaneous electric water heaters

The project team developed a pre-screening survey to collect data on each site's equipment and hot water use patterns. For interested businesses, the team followed up by phone to clarify survey responses and confirm eligibility. Sites that passed the initial screening received an in-person walkthrough by our engineering team to document existing equipment, plumbing fixtures, usage frequency, and available space.

For each prospective site, the team estimated GHG emissions and bill impacts using assumptions from the CALGreen Use Assumptions dataset in the 2022 California Green Building Standards Code (Commission, 2022). These included estimates of hot water demand, pre- and post-retrofit operating costs, and GHG emissions. Site-specific data from facility managers or on-site observations were used when available to refine assumptions. When existing hot water systems used electric resistance, we calculated positive cost savings. In some cases, switching from natural gas or propane to HPWH resulted in increased operating costs rather than savings. These increases were modest and could be justified by the expected annual GHG emission reductions. Participants were still willing to move forward with the retrofit when it was offered at no cost, underscoring a key program design opportunity: SMB customers may accept small operating cost increases in exchange for avoided upfront capital costs and clear environmental benefits.

After sites reviewed the cost and GHG impact analysis, TRC worked with a contractor to provide an installation quote and sent the customer a site agreement confirming participation in the study. Table 1 below shows the outreach results.

Table 1: Outreach progress to date.

Action	Result
Total sites contacted	178*
Pre-screened	20
Site visits	12
Quotes in progress	8
Installed	5

*Note: The SDG&E CEMS team also conducted outreach to additional customers beyond the 178 contacted by TRC.

Survey Methodology

In parallel with field metering, the project team conducted a series of surveys to gather insights from customer and contractor experiences with the 120 V HPWH installations. These surveys are intended to:

- Evaluate customer satisfaction before and after HPWH installation.
- Understand the operational impact of the HPWH on daily business activities.
- Document contractor perspectives on installation feasibility and costs.
- Identify long-term performance trends and customer willingness to recommend the technology.

A total of four surveys were conducted:

- **The pre-installation customer survey** captures user satisfaction with their existing gas-fired water heater, including performance, reliability, energy consumption, and cost. Customers are also asked about their expectations for the new 120 V HPWH.
- **The contractor survey** gathers information on the installation process, including installation duration, any electrical or plumbing modifications required, total costs, and any challenges encountered. This survey helps assess the market readiness of the technology from an installer perspective.
- **The three-month post-installation customer survey** assesses short-term performance and user satisfaction with the HPWH, including hot water availability, changes in energy bills, equipment reliability, and any business operation impacts. Customers are asked to share feedback on the transition to heat pump technology.
- **The eight-month post-installation customer survey** evaluates longer-term performance, satisfaction with equipment durability and consistency, and overall system impact on operations. This survey also explores whether the customer would recommend the 120 V HPWH to similar businesses.

The project team analyzed all four surveys and, in conjunction with metering data, derived insights to evaluate whether the 120 V plug-in HPWH is a viable emergency replacement solution for SMB.

The project team fielded the survey through Qualtrics, a survey platform used for collecting, organizing, and analyzing data. The project team mostly asked multiple-choice questions for ease of use; however, the project team also asked respondents some open-ended questions, specifically around issues and challenges with their old and new water heating system.

Field Metering

The project team developed a measurement and verification (M&V) plan to assess the average energy savings and system performance of the 120 V plug-in HPWH based on a limited number of field installations. The M&V plan is designed to address two core objectives:

- **Characterizing flow profiles in commercial buildings and verifying sufficient hot water delivery:** This includes documenting hot water use patterns and tracking the hot water temperature leaving the HPWH to ensure it meets set point, both of which are supported by customer surveys.
- **Analyzing energy performance:** This involves measuring the electricity consumption of the 120 V HPWH and **estimating** the expected baseline performance based on post-retrofit monitoring of hot water use.

The field metering period began after the installation of 120 V HPWHs at all five sites. The metering period for each site was approximately four months, although some metering periods were longer. The project team aimed for at least four months to cover seasonal variation, which will help increase the diversity of source water temperatures.

The project team monitored power and the independent variables that impact energy output, including hot water draw, hot water supply temperature, cold water inlet temperature, and ambient air temperature and relative humidity in the room where the HPWH is located. The data acquisition system was configured to sample hot water demand and hot water supply temperature at a high frequency, which enables more accurate characterization of the efficiency and basic data validation checks. Other variables, such as power, ambient air temperature, and relative humidity, are collected at one-minute intervals, which provides sufficient granularity for characterizing ambient conditions and energy consumption. Figure 1 illustrates the locations of the metering equipment.

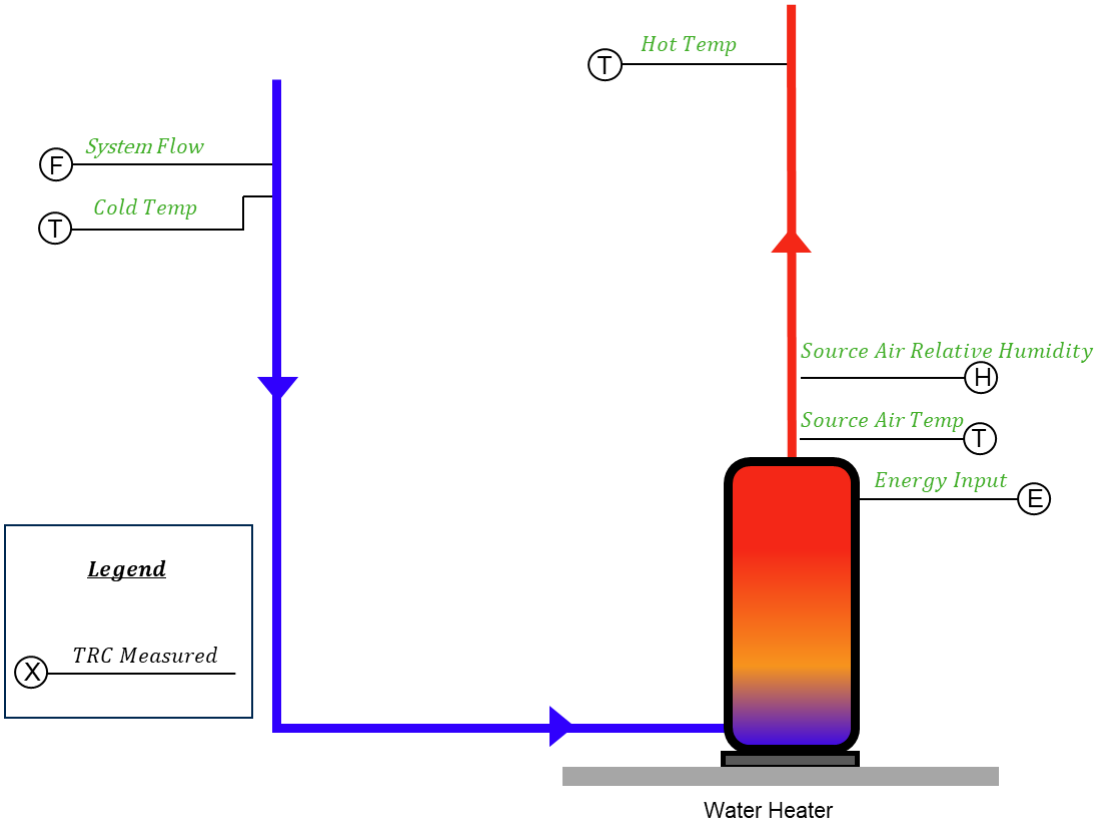


Figure 1: Field metering schematic.

See Table 2 for the proposed data collection points, instrumentation, and monitoring frequency.

Table 2: Data collection points and instrumentation.

Parameter	Type	Variable Symbol	Manufacturer/Model	Unit	Sampling Interval
Hot water supply	Temperature	T_{hot}	Dwyer 10k Ohm Thermistor	°F	5-second
Cold water	Temperature	T_{cold}	Dwyer 10k Ohm Thermistor	°F	5-second
Cold water	Flow rate	$\dot{V}$	Badger Nutating Meter	GPM[1]	5-second
Source air	Temperature	$T_{ambient}$	Attune Node	°F	1-minute

[1] Gallon per minute (GPM).

Parameter	Type	Variable Symbol	Manufacturer/Model	Unit	Sampling Interval
Source air	Relative humidity	$RH\%_{ambient}$	Attune Node	%RH[2]	1-minute
Electrical	Power	P	eGauge EG4015 true power meter	kW	1-minute

Data Analysis Methodology

The research team analyzed the data to calculate energy use, equipment efficiency, and key performance metrics that affect efficiency, such as hot water use. As system performance is a function of mass flow rate and temperature rise of water through the water heater, the team implemented a mass weighting function that weights the measurement of the cold water and hot water temperatures by the mass flow rate of hot water use. All average cold water and hot water temperature data in this report are reported as the mass-weighted average unless noted otherwise.

Table 3: Variable nomenclature.

Variable Symbol	Variable Type	Variable Units
T_{cold}	Temperature	°F
T_{hot}	Temperature	°F
$\dot{V}$	Flow rate	GPM
$COP_{equipment}$	Performance	COP
P	Power	kW

The project team calculated the heating energy delivered to the hot water distribution system (delivered hot water energy) at each step according to Equation 1. The project team calculated the density of water based on a table lookup of water properties (USGS, 2018), (ToolBox, 2003). The project team used the cold water inlet temperature as the lookup temperature value to determine the water density. The team determined the delivered volume of cold water to the water heater (V) at each time step by integrating the measured volume flow rate for each timestep. The team totaled delivered hot water energy daily for further analysis of the daily data based on Equation 1.

[2] Relative humidity (RH).

Equation 1: Delivered hot water energy (delivered to the hot water distribution system).

$$q_{kBTU} = \frac{(\rho * V) * c_p * (T_{hot} - T_{cold})}{1000}$$

The team calculated the timestep electrical energy input (E_{in}) for each timestep by integrating the measured power for the timestep. The team then added the energy use over any specified interval, such as daily, to determine energy use over the specified interval. The team calculated equipment coefficient of performance (COP) for any given period based on Equation 2. The team did not calculate system COP, which accounts for the equipment and distribution system losses to the point of use, but in some cases, the team did make inferences about the system COP based on the survey data.

Equation 2: Equipment COP.

$$COP_{equipment} = \frac{q_{kBTU}}{E_{in} * 3.412}$$

The team estimated the electrical energy impact of HPWH tank losses at sites with no hot water use over the weekend.

- **Baseline energy use:** Using post-retrofit flow/usage data, the project team estimated the energy consumption of the pre-retrofit system based on equipment nameplate specifications and typical performance characteristics informed by engineering judgment. This modeled baseline was used to estimate energy savings in both Btu and kilowatt-hour (kWh). The project team also applied utility tariff data to estimate changes in monthly utility bills. Where seasonality is evident—such as changes in incoming water temperature—the project team adjusted our savings estimates to account for these effects over the monitoring period and across different geographic sites.
- **Baseline system estimated energy use:** The team used current federal uniform energy factor (UEF) requirement curves for both gas and electric resistance systems and adjusted the curve up or down to match the rated UEF of the baseline equipment. From this curve and the average daily water use of the site, the team calculated the appropriate UEF to apply to the daily energy transfer of the intervention system. Because the EUF curve becomes inaccurate below 10 gallons per day, the team took the conservative approach of applying the adjusted UEF at 10 gallons per day for sites where average water use was under 10 gallons per day.
    - Daily water use >= 10 gallons per day
        - 1/UEF at average daily water use * intervention period energy transfer per day = estimated baseline energy use.
    - Daily water use < 10 gallons per day
        - 1/UEF at 10 gallons per day * intervention period energy transfer per day = estimated baseline energy use.
- **Energy savings calculation**: Average daily baseline energy input - average daily HPWH energy input.

- **Baseline energy cost calculation:**
    - **Baseline gas systems:** The team applied IOU-specific gas rate schedules from Pacific Gas & Electric (PG&E) and Southern California Gas (SoCalGas) to each corresponding site. Gas rates were applied at the daily level to account for seasonal variability in costs and were averaged for reporting.
    - **Baseline electric resistance systems**: The team applied IOU-specific electric rate schedules (PG&E and Southern California Edison) to each corresponding site. While estimated energy use was calculated at the daily level, electric rates have sub-daily rate fluctuations, or time-of use (TOU) tariffs. For this reason, the team developed site-specific probability distributions of when energy was likely to be used based on intervention period water use. These probability distributions were binned by TOU tariffs and applied to calculate a more accurate baseline energy cost.
- **Energy cost savings calculation:** Average daily baseline energy cost - average daily HPWH energy cost.

Test Sites

To evaluate the feasibility and energy performance of 120 V plug-in HPWHs for small and medium businesses, the project team selected a diverse group of test sites across different business types and use profiles. Each site was selected based on alignment with the project's hot water usage criteria, existing baseline water heating equipment, and willingness to participate in the full scope of installation, monitoring, and surveying. Sites represent a range of commercial settings and vary in size, operating hours, fixture types, and use patterns, which allows for the analysis of key independent variables such as water draw frequency, site square footage, and climate zone.

The sections below summarize each participating test site, including the type of business, key characteristics, rationale for selection, hot water usage assumptions, and estimated energy and emissions impacts of replacing their existing water heating systems with a 120 V HPWH. Please note that all installed units are classified as residential 120 V HPWHs, and that the HPWHs were installed on shared circuits. Where possible, the project team includes site photographs and layout details to provide additional context for understanding site-specific factors that may influence water heating loads.

Site 1: Shopping Center (San Diego, California)

This test site is a shopping center located in San Diego, California; within Climate Zone 7. The venue includes numerous small independent commercial businesses and communal areas for staff use. Water heating needs are primarily driven by handwashing and dishwashing. Previously, there was a 30-gallon electric resistance water heater serving the fixtures below. The site had a mix of public and employee users, as well as existing systems on site serving multiple water draw locations in distributed areas. The mechanical room where the HPWH is installed is roughly 620 cubic feet. The project team ducted the HPWH to an adjacent indoor space to meet manufacturer ventilation requirements.

Water fixtures:

- Four bathroom public lavatories

- One three-compartment sink used as break room sinks for vendor staff and are never filled
- One service sink used by janitorial staff

Water use:

Flow rate is based on a one-time measurement. Use assumptions are based on conversations with the site and standard industry assumptions. Fixture use per hour is stated per fixture.

- **Bathroom lavatories**: Five uses per hour, 0.25 minutes each, 0.5 gallons per minute (GPM) at 60 pounds (lb) per square inch (psi).
- **Three-compartment sink**: 2.25 uses per hour, four minutes each, 1.8 GPM at 60 psi.
- **Service sink**: Two mop bucket fills per day, ~10 gallons per day.

Operating hours: Nine hours per day, seven days per week.
Estimated hot water use: ~135 gallons per day.

The project team estimated the hot water demand for each of the sites based on industry sizing methods, and alternative methods as needed, and the type of fixture, usage, frequency of use, and operating hours. The project team worked with the respective representative from each site to ensure that our estimates and assumptions were as accurate as possible.

Initial estimated impact of HPWH installation:

- **Annual energy savings:** 17.87 kWh/day.
- **Estimated cost savings**: $6.97/day or $1,812.21/year.
- **GHG emissions reduction**: 2,311 lb carbon dioxide (CO_2)/year (estimated annual emissions. reduced from ~3,379 lb CO_2 to 1,068 lb CO_2).

Overview of existing baseline equipment:

- **Fuel type:** Electric.
- **Capacity:** 30 gallons.

Overview of installed 120 V HPWH equipment:

- **Brand:** Manufacturer A.
- **Capacity:** 80 gallons.

Site 2: Small Office (La Mesa, California)

This site is a small professional office building located in La Mesa, California; within Climate Zone 7. It houses several employees who use the space primarily during business hours for deskwork and meetings. Water heating needs are low and mostly limited to handwashing and light kitchen use. The HPWH is in a room that is fully open to the entire office space, so ventilation is not a concern.

Water fixtures:

- One bathroom lavatory.
- One break room sink.

Water use:

Flow rate is based on a one-time measurement. Use assumptions are based on conversations with the site and standard industry assumptions. Fixture use per hour is stated per fixture.

- **Bathroom lavatory**: Three uses per hour, 0.3 minutes each, 0.5 GPM at 60 psi.
- **Breakroom sink**: One use per hour, two minutes each, 1.8 GPM at 60 psi.

Operating hours: 10 hours per day, five days per week
Estimated hot water use: ~30 gallons per day

Initial estimated impact of HPWH installation:

- Annual energy savings: 7.75 kWh/day
- Estimated cost savings: $0.14/day or $37.68/year
- GHG emissions reduction: 757 lb. CO_2/year (estimated annual emissions reduced from ~998 lb. CO_2 to 241 lb. CO_2)

Overview of existing baseline equipment:

- **Fuel type:** Natural gas.
- **Capacity:** 30 gallons.

Overview of installed 120 V HPWH equipment:

- **Brand:** Manufacturer B.
- **Capacity:** 40 gallons.

Site 3: Small Warehouse (Antioch, California)

This site is a small warehouse building located in Antioch, California within Climate Zone 12. The facility serves as a warehouse for an electrical supply store, primarily functioning as a shipping hub for parts. On busy days, it accommodates up to ten employees. Hot water demand fluctuates depending on the number of staff working on any given day.

The mechanical room is 3 feet x 5 feet x 9 feet, or 135 cubic feet. The project team installed a fully louvered door to meet the manufacturer's ventilation requirements.

Water fixtures:

- Four bathroom lavatories (sinks).
- Two breakroom sinks.
- One service sink used by janitorial staff.

Water use:

Flow rate is based on a one-time measurement. Use assumptions are based on conversations with the site and standard industry assumptions. Fixture use per hour is stated per fixture.

- **Bathroom lavatories:** Five uses per hour, 0.3 minutes each, 0.5 GPM at 60 psi.
- **Breakroom sinks**: One use each per hour, four minutes each, 1.8 GPM at 60 psi.
- **Service sink:** One mop bucket fills per day (~5 gallons per day).

Operating hours: Eight hours per day, five days per week.
Estimated hot water use: ~105 gallons per day.

Initial estimated impact of HPWH installation:

- **Annual energy savings**: 27.16 kWh/day.
- **Estimated cost savings**: $0.51/day or $132.00/year.
- **GHG emissions reduction**: 2,651 lb. CO_2/year (estimated annual emissions reduced from ~3,494 lb of CO_2 to 843 lb CO_2).

Overview of existing baseline equipment:

- **Fuel type**: Electric.
- **Capacity:** 30 gallons.

Overview of installed 120 V HPWH equipment:

- **Brand:** Manufacturer B.
- **Capacity:** 80 gallons.

Site 4: Nonprofit Social Services Agency (Redwood City, California)

This site is a community-based, nonprofit, social service provider located in Redwood City, California; within Climate Zone 3. The non-profit has several employees who use the space primarily during business hours for deskwork and meetings. Water heating needs mostly include handwashing and break room use.

The water heater is in an outdoor mechanical closet. The project team installed a security door with adequate net free area to meet the manufacturer's ventilation requirements.

Water fixtures:

- Three bathroom lavatories.
- One breakroom sink.

Water use:

Flow rate is based on one time measurement. Use assumptions are based on conversations with the site and standard industry assumptions. Fixture use per hour is stated per fixture.

- Bathroom lavatories: three uses per hour, 0.3 minutes each, 0.5 GPM at 60 psi.
- Break room sink: two uses per hour, four minutes each, 1.8 GPM at 60 psi.

Operating hours: Ten hours per day, five days per week.
Estimated hot water use: ~115 gallons per day.

Initial estimated impact of HPWH installation:

- **Annual energy savings:** 29.72 kWh/day.

- **Estimated cost savings:** $0.56/day or $144.45/year.
- **GHG emissions reduction:** 2,902 lb of CO_2/year (estimated annual emissions reduced from ~3,824 lb of CO_2 to 922 lb of CO_2).

Overview of existing baseline equipment:

- **Fuel type:** Natural gas.
- **Capacity:** 30 gallons.

Overview of installed 120 V HPWH equipment:

- **Brand:** Manufacturer A
- **Capacity:** 80 gallons

Site 5: Religious Organization (Los Gatos, California)

This site is an inclusive religious building located in Los Gatos, California, within Climate Zone 4. The religious building has three water heaters on site, however, only the unit serving the office is being replaced. The office area is occupied by several employees during regular business hours for administrative work. Hot water demand is minimal and generally limited to handwashing and cleaning purposes.

The mechanical room is greater than 700 cubic feet, meeting the manufacturer's requirements. Additionally, there are IT servers in the room which also heat the room.

Water fixtures:

- Four bathroom lavatories.
- One service sink (used by janitorial staff).

Water use:

Flow rate is based on a one-time measurement. Use assumptions are based on conversations with the site and standard industry assumptions. Fixture use per hour is stated per fixture.

- **Bathroom lavatories:** 2.5 uses per hour, 0.3 minutes each, 1.6 GPM at 60 psi.
- **Service sink:** One mop bucket fills per day (~5 gallons per day).

Operating hours: Eight hours per day, five days per week.
Estimated hot water use: ~30 gallons per day.

Initial estimated impact of HPWH installation:

- **Annual energy savings:** 7.40 kWh/day
- **Estimated cost savings**: $0.14/day or $35.98/year
- **GHG emissions reduction:** 723 lb of CO_2/year (estimated annual emissions reduced from ~952 lb of CO_2 to 230 lb of CO_2)

Overview of existing baseline equipment:

- **Fuel type:** Natural gas.

- **Capacity:** 30 gallons.

Overview of installed 120 V HPWH equipment:

- **Brand:** Manufacturer B.
- **Capacity:** 40 gallons.

Field Metering Findings

Site 1 (Shopping Center)

Site 1 is a shopping center with multiple small tenant spaces and shared restrooms. Service hot water is primarily used for restroom handwashing, employee breakroom, and janitorial activities, resulting in modest but regular daily demand. The team installed a 120 V HPWH where an electric resistance 30-gallon tank water heater had previously served this load. The new unit is located in an interior mechanical room adjacent to the restrooms and operates under semi-conditioned indoor conditions.

The research team installed an 80-gallon 120 V HPWH in mid-February 2025 and performed monitoring until mid-December. The monitoring period was longer than planned due to changes in the plumbing to increase the number of fixtures hot water was delivered to, as well as due to a warranty replacement of the HPWH midway through the metering period due to an internal leak. The analysis excluded the days that the team commissioned both HPWHs as well as days plumbing was extended to service new fixtures as shown in Table 4.

Table 4: Site 1 key dates.

Dates	Description
2/13/2025–12/18/25	Monitoring period
2/13/2025–3/9/2025	Temperature setpoint 130°F
3/10/2025	Hot water line extended to employee breakroom

Dates	Description
8/11/2025	Water heater leak forcing warranty replacement on this date; all data dropped due to water use, temperature, and energy metrics impacts
8/11/2025–12/18/2025	Temperature setpoint 120°F [3]
8/11/2025–12/19/2025	Source air temperature/relative humidity node not replaced by contractor during warranty replacement; data missing

Figure 2 characterizes HPWH energy use versus daily water use. As expected, days with higher hot water use cluster at higher energy use values, indicating a clear relationship between draw volume and HPWH energy consumption. The dashed lines indicate the average observed water use. The R2 value is low and the trend in the data is visually scattered. This is likely due to a change in the set point when the warranty work was performed. Days with very low hot water use still show non-zero energy use, reflecting standby and cycling losses on low-demand days. The unit at this site was set to Heat Pump mode only throughout the monitoring period and electric resistance never switched on during the metering period.

[3] During installation, the installers talked with the site and they agreed on 130°F setpoint. During warranty replacement, the default 120°F was not changed by the contractor or the site.

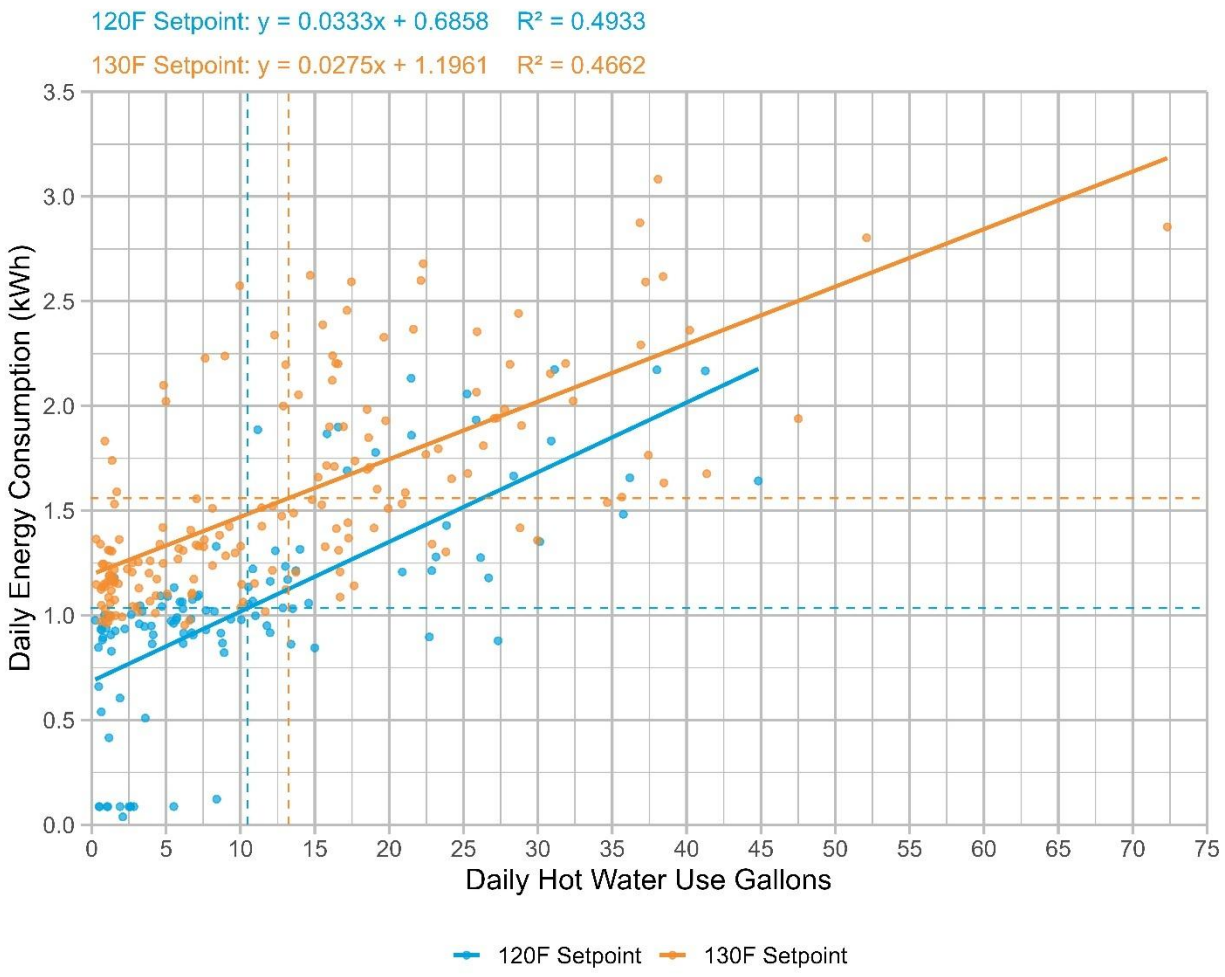


Figure 2: Site 1 water use versus energy use by day (full period).

Figure 3 below illustrates equipment COP versus daily hot water use. For all days where the usage is below about 10 gallons, the equipment COP is almost always less than 1. The dashed lines indicate the average observed water use. There is some variability in the result due to when the water cycles. For example, when the water heater cycles overnight, the timing can impact the daily equipment COP calculation depending on if the cycle happens just after or just before midnight. For 10 gallons to 20 gallons per day, the equipment COP ranges from about 1 to 2. For above 20 gallons per day, equipment COP ranges from 1.0 to 3.1. Data points in the figure below with COP greater than 5.0 are due to cycling effects on daily COP calculations. The figure highlights a key operational insight:

HPWHs at low-use commercial sites like Site 1 perform best and deliver savings on days with higher draw volumes, while very low-use days can erode savings due to fixed standby and cycling losses.

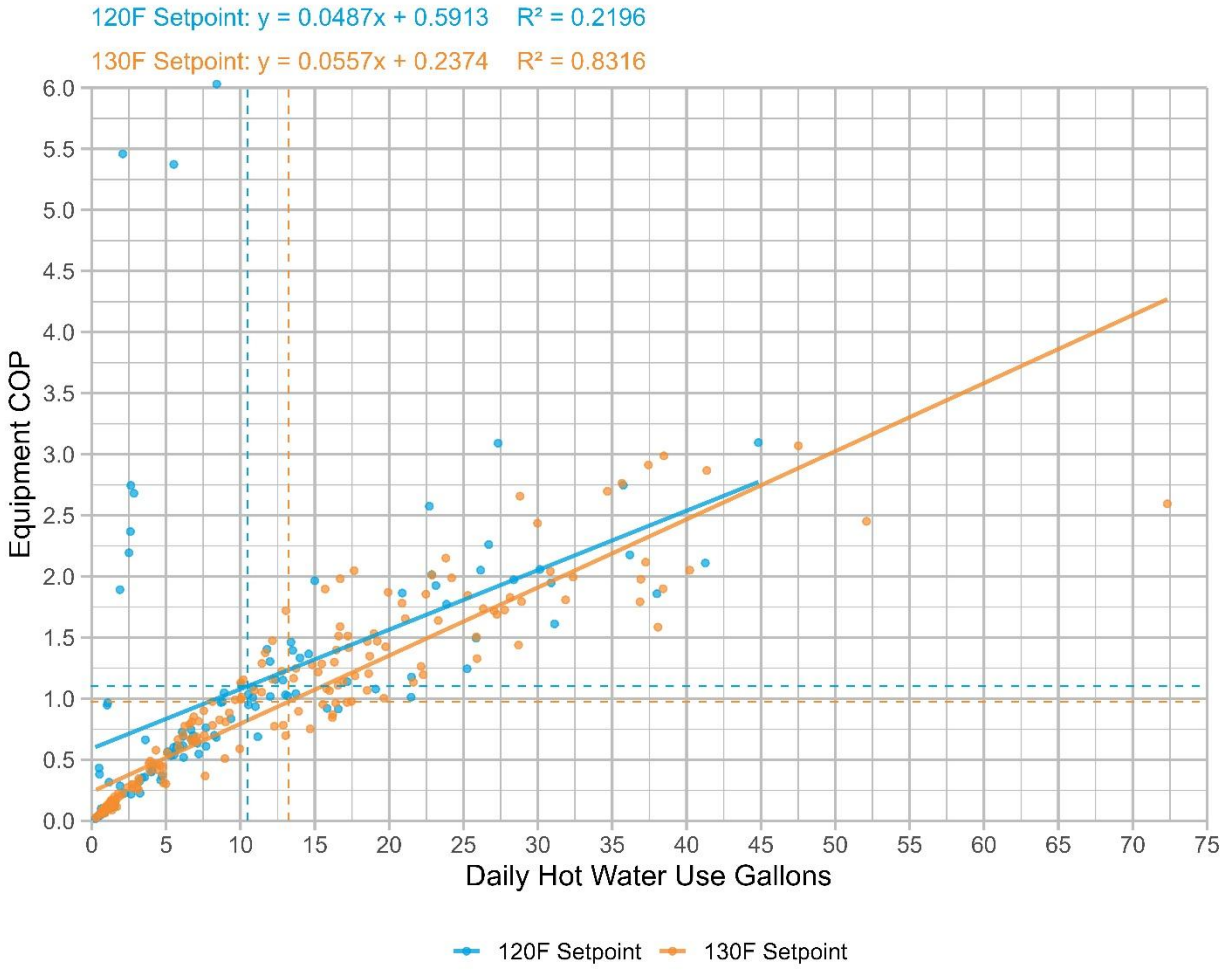


Figure 3: Site 1 COP versus daily hot water use.

Table 5 below shows the average daily hot water use and average daily energy use. Due to low water use, the mass-weighted hot and cold water temperatures were inaccurate. The team used daily maximum hot water temperature in place of mass-weighted hot water temperature and daily minimum cold water temperature in place of mass-weighted cold water temperature in all analyses. This may slightly overstate equipment COP, but the error is expected to be low. Additionally, this method only works because the team did not observe hot water runouts under normal operating conditions. At site CA01 and CA03, someone unintentionally left a faucet on overnight as an isolated event. The team excluded all data from these days to ensure accuracy of this method.

Table 5: Site 1 average daily hot water and energy use.

Site ID and Period	Average Daily Water Use (Gallons)	Average Daily Energy Use (kWh)	Hot Water Average Max Temperature (°F)	Cold Water Average Max Temperature (°F)
CA01 Weekdays	11.4	1.3	121.3	72.8
CA01 Weekends	14.1	1.4	122.0	72.8
CA01 All Days	12.2	1.4	121.5	72.8

From Table 5, average daily hot water use at Site 1 is low overall, and higher on weekends than weekdays. On weekdays, the shopping center uses about 11.4 gallons per day, reflecting typical restroom and breakroom use under normal tenant and customer traffic. On weekends, average daily water use increases to 14.1 gallons per day, consistent with busier shopping days and more frequent restroom and breakroom usage. Based on our knowledge of the site, the team believes this is due to higher staffing and higher use by customers.

Table 6 summarizes average daily energy output, equipment COP, estimated baseline energy use, and estimated energy savings for Site 1, categorized by weekdays, weekends, and overall.

Table 6: Site 1 average daily equipment COP and energy savings.

Site ID and Period	Average Daily Energy Output (Btu)	Average Daily Equipment COP	HPWH Energy Input (Btu-Electric)	Estimated Baseline Energy Use (Btu-Electric)	Estimated Energy Savings (Btu-Electric)
CA01 Weekdays	4643	1.02	4553	5381	827
CA01 Weekends	5742	1.20	4788	6593	1805
CA01 All Days	4948	1.07	4619	5719	1100

Overall, the results in Table 6 show that water usage is low, and subsequently the thermal energy required to meet the thermal demand associated with the water usage is also low. The equipment COP is very low, most likely due to parasitic heat losses from the tank. Given the lack of recirculation

and the low use, the actual efficiency of the water heater to deliver hot water to the point of use is very likely lower than 1. The data shows that use of a HPWH at this site is far from ideal; it is a high possibility that distributed point-of-use electric resistance water heaters would result in a higher overall efficiency.

Table 7 reports estimated operating costs for the base case and retrofit systems, and energy cost savings of switching from the base case centralized electric resistance water heater to the retrofit case centralized HPWH. The results show marginal on-bill savings associated with the retrofit; the magnitude of the savings is low at about $40 per year.

Table 7: Site 1 operating cost and estimated energy cost savings per year.

Site ID and Period	HPWH Energy Cost	Baseline Fuel Type	Estimated Baseline Energy Cost	Estimated Energy Cost Savings
CA01 All Days	$140	Electric resistance	$180	$40

Figure 4 and Figure 5 are modified box plots that illustrate hourly water use in gallons. The figures illustrate the average water use (black line), 75th percentile of water use (blue bar), and 99th percentile of water use (top whisker). The hourly data is overlaid over the box plot. Error! Reference source not found. illustrates data for weekdays, and Figure 5 illustrates data for weekends. Overall, the figures show low average usage in any given hour. Use during the weekday is more concentrated around lunch hours, while weekends are more dispersed from about noon until 5:00 p.m. These observations highlight how customer and employee traffic impact hot water use at the site. Both weekdays and weekends have long periods of almost zero use where the HPWH is able to recover. While the research team didn't characterize the sequence of hourly uses, the plots below demonstrate that the HPWH can meet the 99th percentile demand for the peak hours.

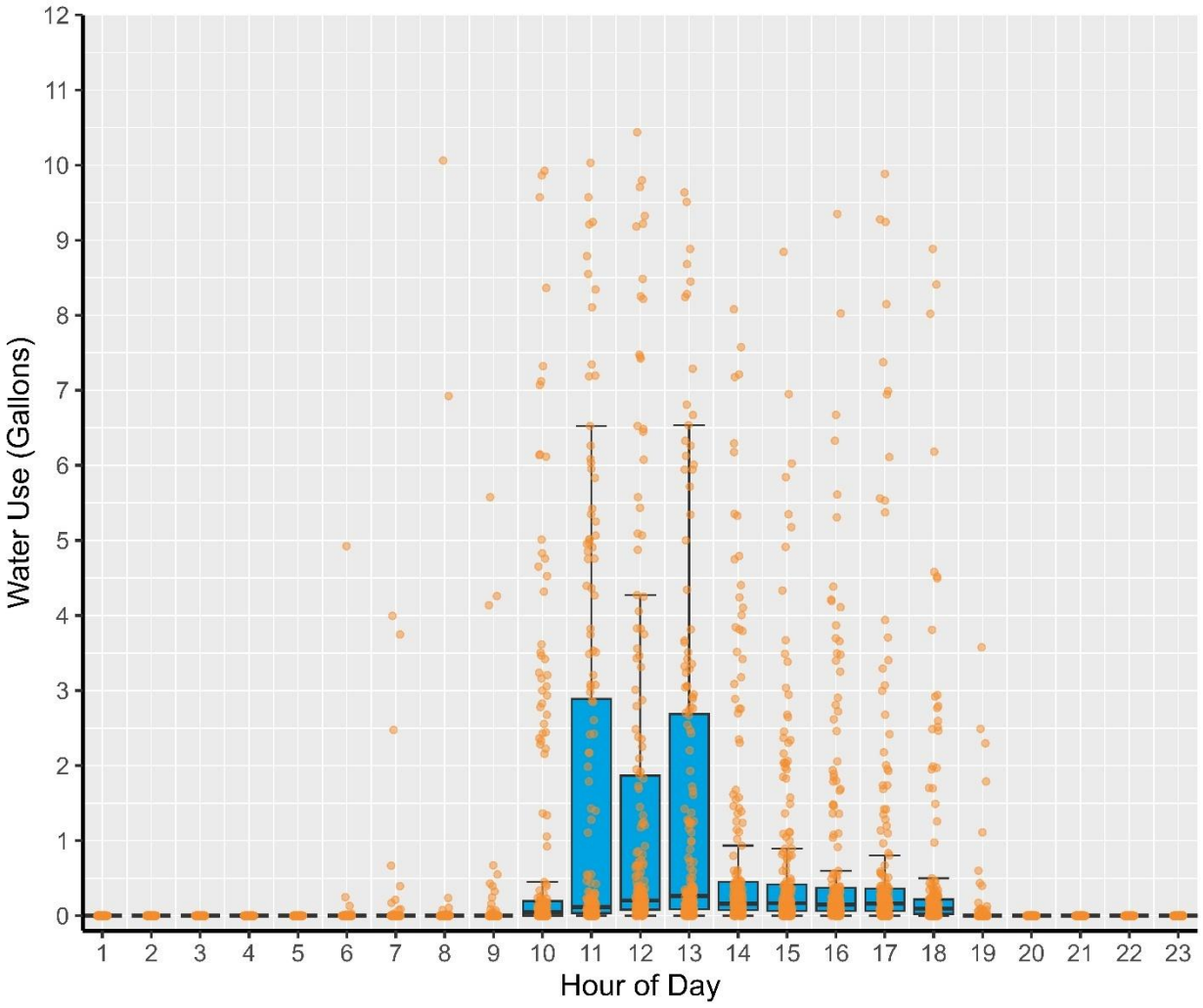


Figure 4: Site 1 weekday water use by hour of the day.

*Dot plots exclude the 99th–100th percentile of data . Box plots are based on all data.

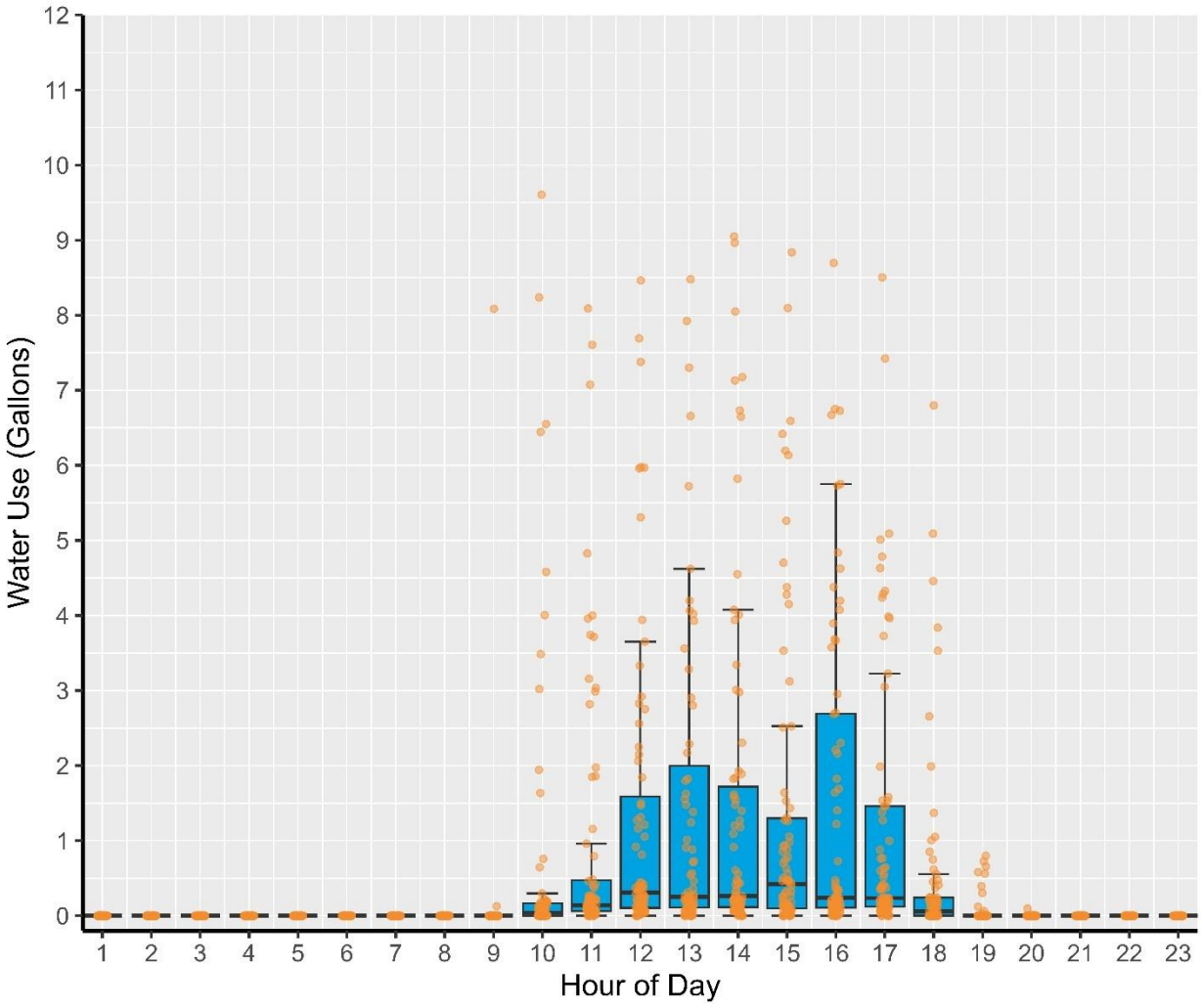


Figure 5: Site 1 weekend water use by hour of the day.

*Dot plots exclude the 99th–100th percentile of data. Box plots are based on all data.

Site 2 (Small Office)

Site 2 is a small office space with three employees. Service hot water is primarily used for restroom handwashing and an employee breakroom, resulting in small but regular weekday demand. The team installed a 120 V HPWH where a gas-fueled 30-gallon tank water heater had previously served this load. The previous water heater had been removed prior to this research. The unit is in a conditioned indoor space adjacent to the employee breakroom. The rooms are connected via a hallway with no door, and the HPWH has access to a very large air volume.

The research team installed a 40-gallon 120 V HPWH in mid-March 2025 and performed monitoring until early-September 2025. The analysis excluded both the days that the team commissioned the HPWH, as well as days sampling frequency was reduced, shown in Table 8.

Table 8: Site 2 key dates.

Dates	Description
3/13/25–9/3/25	Monitoring period
3/13/25–9/3/25	Temperature setpoint 120°F

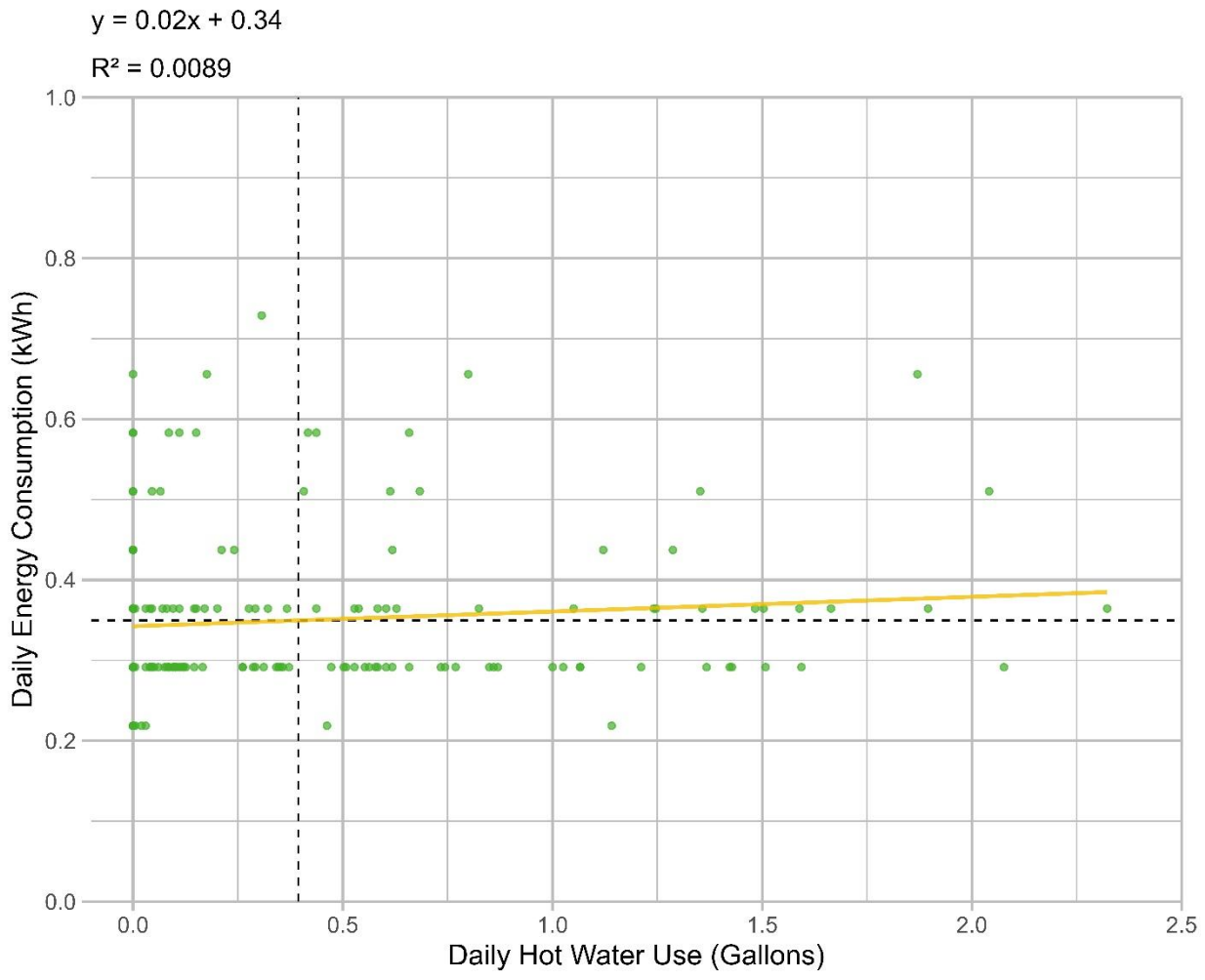


Figure 6, shown below, characterizes HPWH energy use versus daily water use. As expected, with such low hot water use, it is difficult to determine a trend, but days with higher hot water use align

with higher energy use values, indicating a relationship between draw volume and HPWH energy consumption. The dashed lines indicate the average observed water use. The R2 value is low and the trend in the data is visually scattered. Days with very low hot water use still show non-zero energy use, reflecting standby and cycling losses on low-demand days. The unit at this site was set to Heat Pump mode only throughout the monitoring period and did not have electric resistance backup.

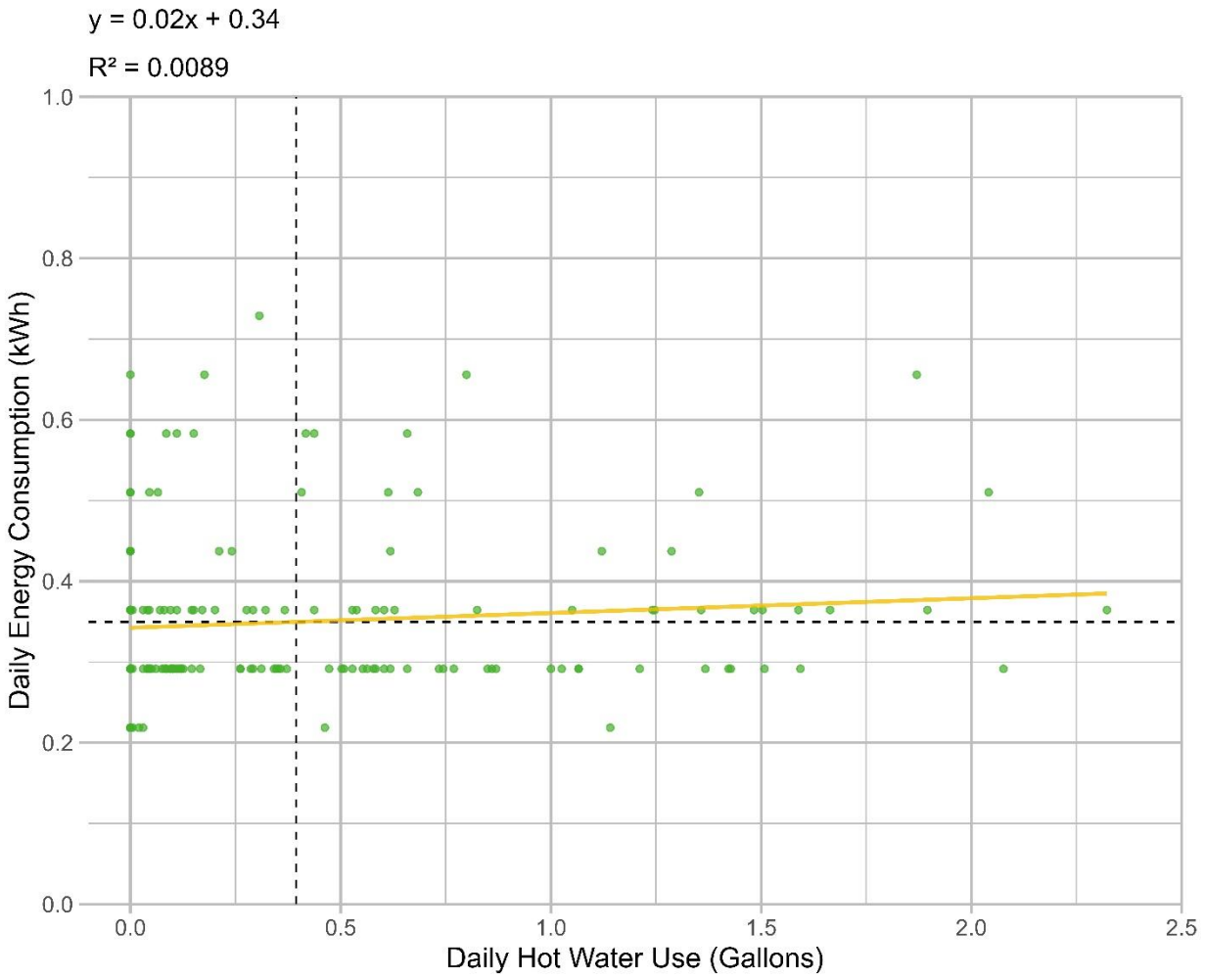


Figure 6: Site 2 water use versus energy use by day (full period).

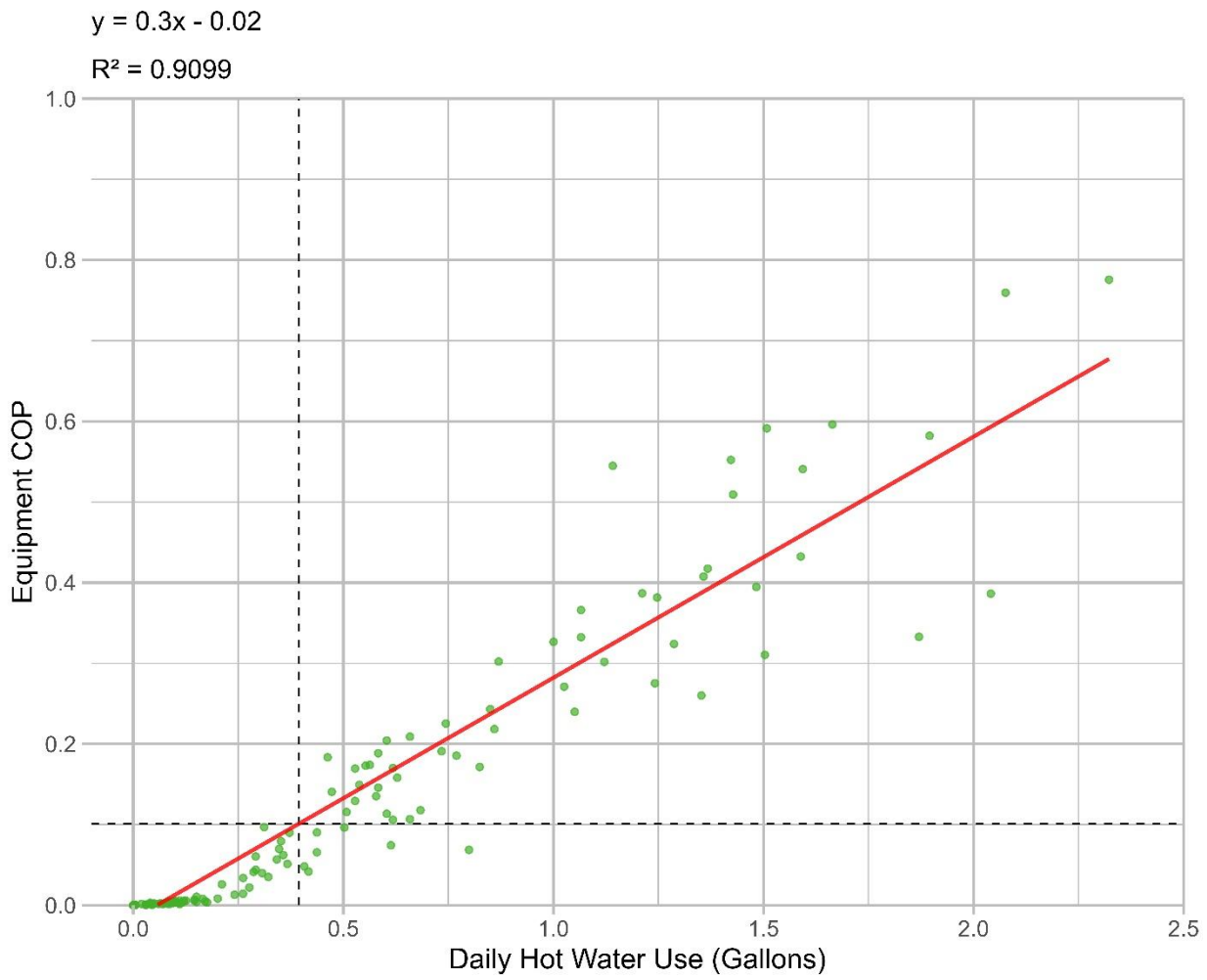


Figure 7 below illustrates equipment COP versus daily hot water use. For the entire monitoring period, the usage is below about 2.5 gallons, resulting in an equipment COP always less than 1. The dashed lines indicate the average observed water use. The figure clearly highlights a key operational insight: HPWHs at low-use commercial sites like Site 2 are better candidates for electric resistance point of use heating, given how very low-use days can erode savings due to fixed standby and cycling losses.

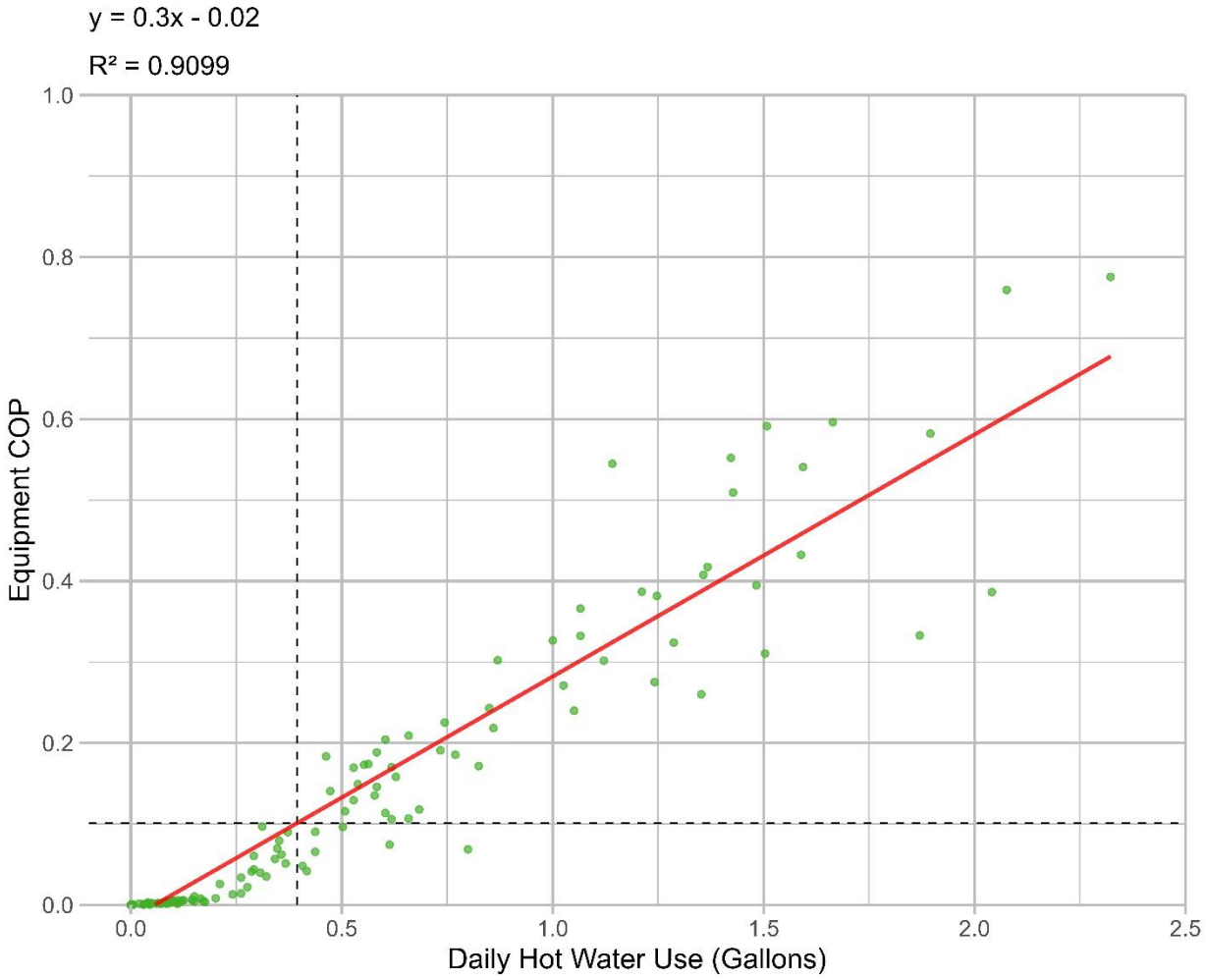


Figure 7: Site 2 COP versus daily hot water use.

Table 9 below shows the average daily hot water use and energy use. Due to low water use, the mass-weighted hot and cold water temperature were inaccurate. The team used daily maximum hot water temperature in place of mass-weighted hot water temperature and daily minimum cold water temperature in place of mass-weighted cold water temperature in all analyses. This may slightly overstate equipment COP, but the error is expected to be low. Additionally, this method only works because the team did not observe hot water runouts under normal operating conditions.

Table 9: Site 2 average daily hot water and energy use.

Site ID and Period	Average Daily Water Use (Gallons)	Average Daily Energy Use (kWh)	Hot Water Average Max Temperature (°F)	Cold Water Average Minimum Temperature (°F)
CA02 Weekdays	0.6	0.4	96.3	72.9
CA02 Weekends	0.0	0.3	79.6	73.1
CA02 All Days	0.4	0.3	91.5	73.0

From Table 9, average daily hot water use at Site 2 is extremely low. On weekdays, the office uses only about 0.6 gallons per day, reflecting a very small number of handwashing and breakroom events under normal staffing levels. On weekends, there is effectively no measured hot water use, consistent with the office being largely unoccupied. Hot water average maximum temperatures are only modestly above the cold water minimum temperatures, particularly on weekends, which indicates that the HPWH is maintaining the tank at relatively low setpoints and that many "hot" draws are either very short or do not significantly raise the delivered temperature above ambient. This combination of very low draw volumes and small temperature lift has important implications for equipment efficiency and overall system performance.

Table 10 summarizes average daily energy output, equipment COP, estimated baseline energy use, and estimated energy savings for Site 2, overall and broken out by weekdays and weekends.

Table 10: Site 2 average daily equipment COP and energy savings.

Site ID and Period	Average Daily Energy Output (Btu)	Average Daily Equipment COP	HPWH Energy Input (Btu-electric)	Estimated Baseline Energy Use (Btu)	Estimated Energy Savings (Btu)
CA02 Weekdays	166	0.14	1,205	785	-420
CA02 Weekends	0	0	1,164	Undefined*	-1,164
CA02 All Days	118	0.10	1,193	558	-635

*Undefined because water use is zero.

Overall, the results in Table 10 suggest that hot water demand is extremely limited, with usage patterns too low to support efficient operation of the HPWH. Rather than responding to meaningful draw events, the system appears to be operating primarily to maintain tank temperature, which indicates that most of its energy use is tied to standby losses and control-related cycling rather than delivery of useful hot water. Given the lack of meaningful hot water demand and the gas baseline, the actual efficiency of the water heating system at delivering useful hot water to the point of use is well below 1. In this context, a 120 V HPWH is a poor fit: the unit is oversized relative to the load, and the fixed standby and control energy required to maintain tank temperature overwhelms the minimal thermal output. For a site with such low usage, a very small point-of-use electric resistance heater would likely result in higher overall efficiency and lower energy use.

Table 11 reports estimated operating costs for the base case and retrofit systems, and energy cost savings of switching from the base case gas water heater to the retrofit case centralized HPWH.

Table 11: Site 2 operating cost and estimated energy cost savings.

Site ID and Period	HPWH Energy Cost	Baseline Fuel Type	Estimated Baseline Energy Cost	Estimated Energy Cost Savings
CA02 All Days	$37	Gas	$8	-$29

The results in Table 11 show that, on an annualized basis, the HPWH at Site 2 costs approximately $37 per year to operate, compared to an estimated $8 per year for the gas baseline. The estimated energy cost “savings” are therefore –$29 per year, indicating that the HPWH increases operating costs rather than reducing them. While the absolute dollar amounts are small, the direction of the impact is clear: in a very low-use office application with a gas baseline, the 120 V HPWH is not cost-effective. This, combined with high upfront costs, reinforces the efficiency findings from Table 11 and suggests that similar low-load office sites should not be prioritized for 120 V HPWH retrofits.

Figure 8 and **Error! Reference source not found.** are modified box plots that illustrate hourly water use in gallons for Site 2. Each figure shows the average water use (black line), the 75th percentile of water use (blue bar), and the 99th percentile of water use (top whisker), with hourly data overlaid on the box plots.
Figure 8 illustrates weekday data, and Figure 9 shows weekend data. Overall, the figures show extremely low average usage in any given hour. On weekdays, hot water use is limited to a small number of business□hour periods, with most hours showing very low or zero use, indicating that hot water demand is tied to specific office activities rather than continuous occupancy. On weekends, hot water use is effectively zero across all hours, consistent with the office being largely unoccupied. The dot plots exclude the 99th–100th percentile of data, which reduces the influence of rare, high-use events, while the box plots (based on all data) still capture the full distribution, including any occasional spikes. Together, these plots confirm that Site 2’s service hot water demand is a very low-demand, weekday-only phenomenon, with weekends characterized by no regular use.

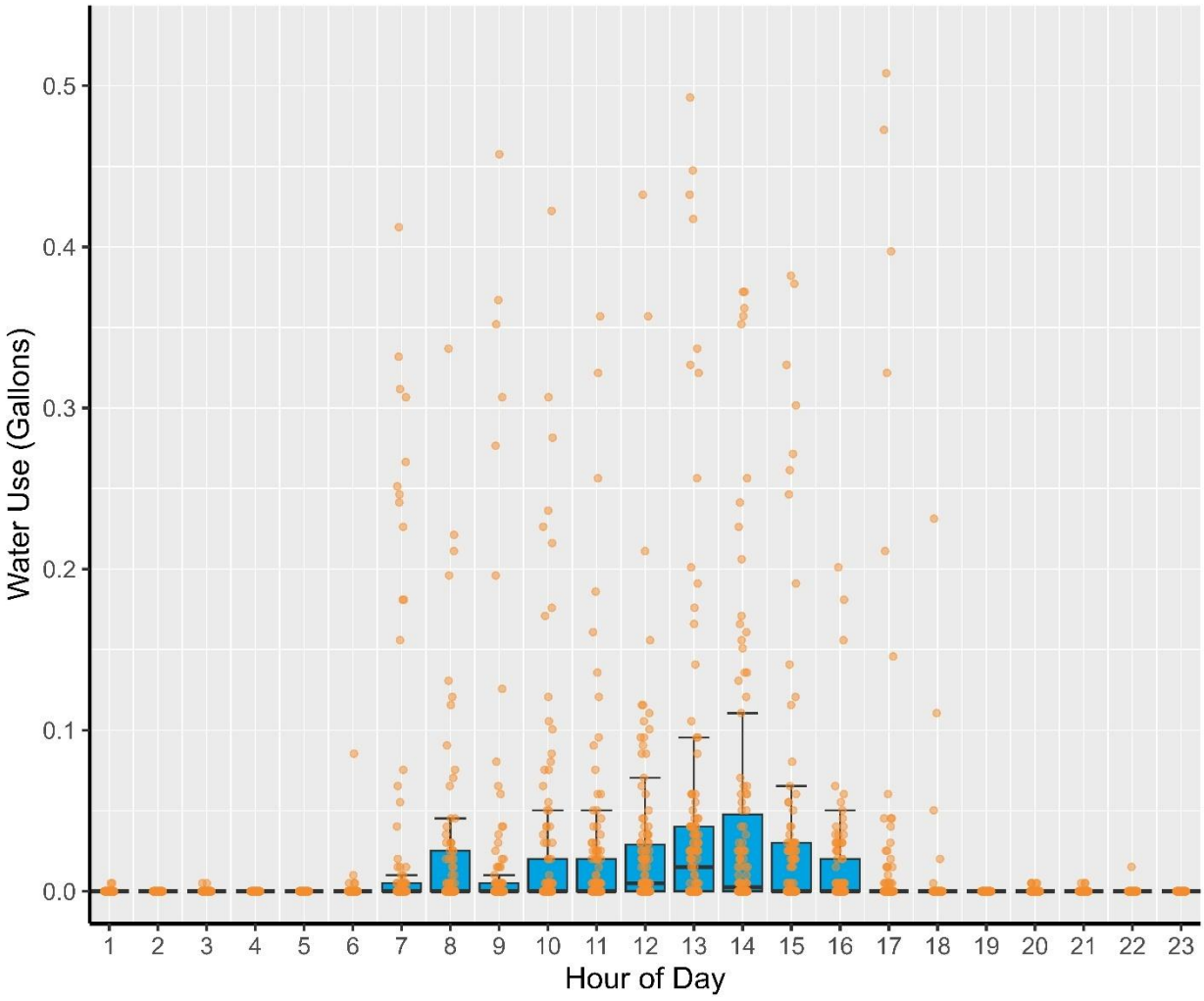


Figure 8: Site 2 weekday water use by hour of the day

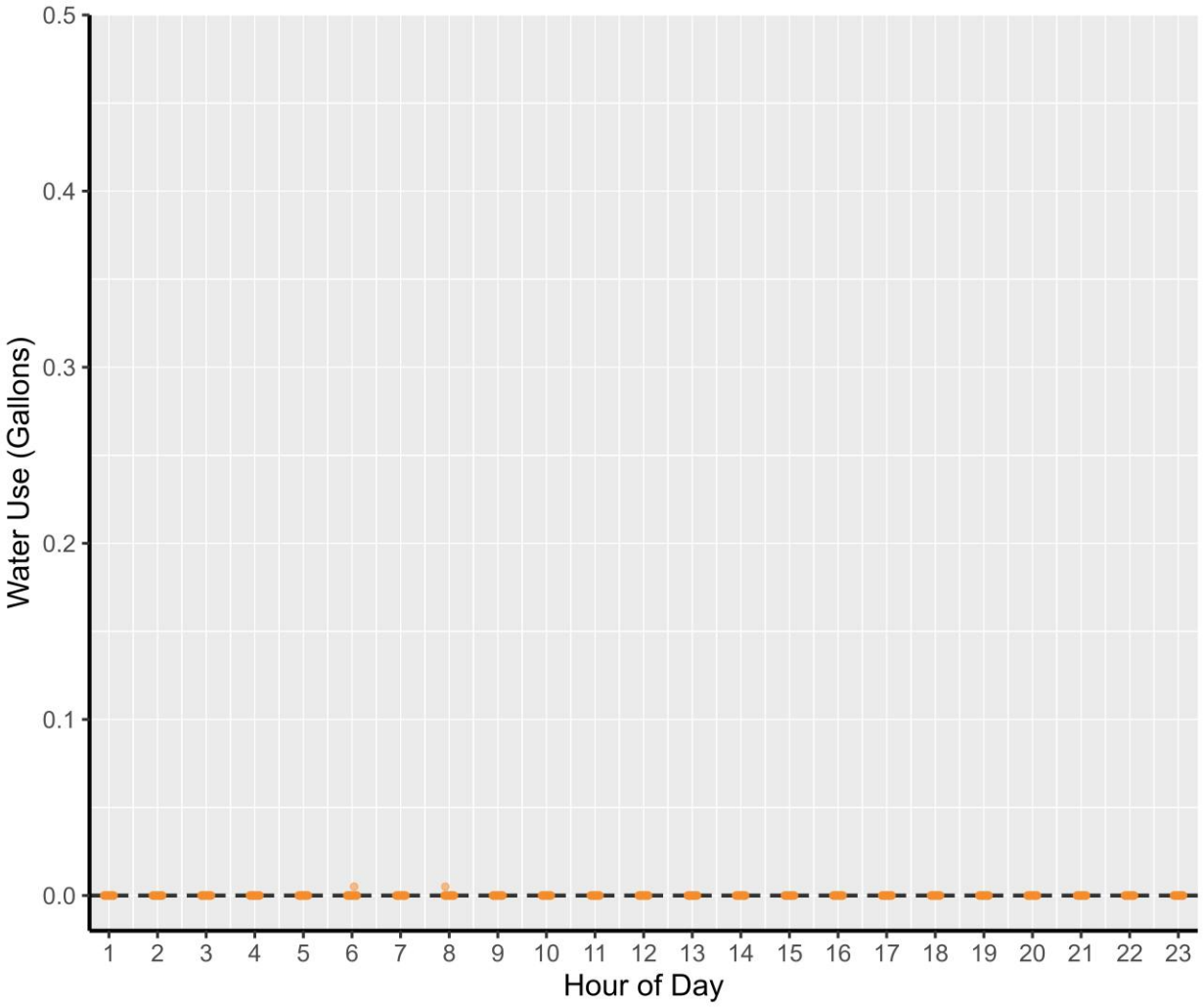


Figure 9 Site 2 weekend water use by hour of the day

*Dot plots exclude the 99th–100th percentile of data. Box plots are based on all data.

Site 3 (Small Warehouse)

Site 3 is a small warehouse used for storage and light industrial activities. Service hot water is primarily used for restroom handwashing, employee break area, and occasional janitorial tasks, resulting in intermittent and generally low hot water demand. The research team installed an 80-gallon 120 V HPWH where a 30-gallon electric resistance water heater previously served this load. The unit is in a semi-conditioned utility room adjacent to the warehouse floor.

The research team installed an 80-gallon 120 V HPWH in early September 2025 and performed monitoring until the end of March 2026. Key dates are shown in Table 12 below.

Table 12: Site 3 key dates.

Dates	Description
9/10/2025–2/8/2026	Monitoring period
9/10/2025–2/8/2026	Temperature setpoint 120°F
2/9/2026-3/26/2026	Sufficient data collected by 2/9/26 for the project. Data sampling frequency changed to 1 hour while waiting for metering retrieval on 3/26 as cost savings measure. All data dropped from analysis for this period.

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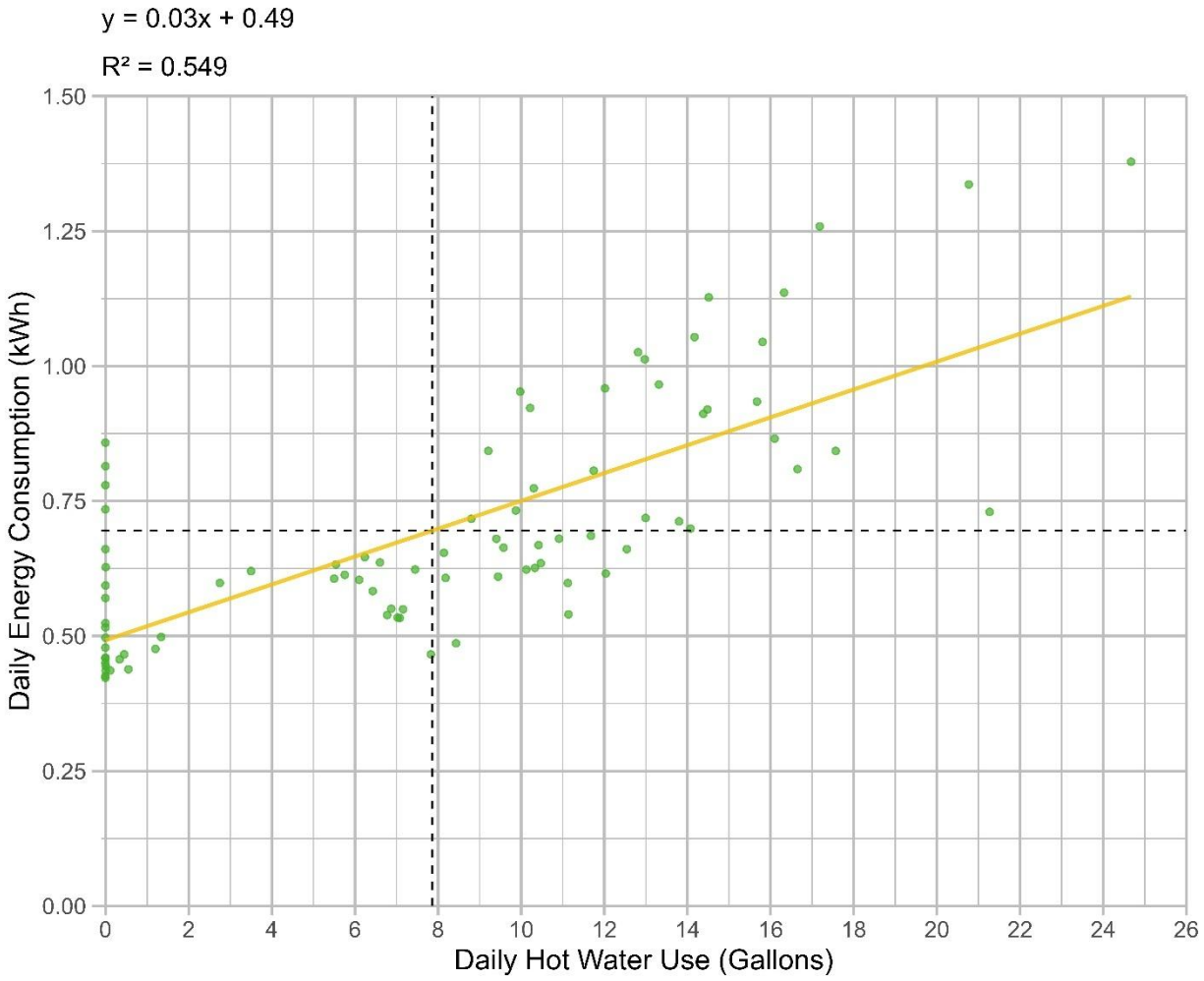


Figure 10, the scatter plot of water use versus energy use by day (full period) for Site 3 shows daily HPWH energy use (kWh) plotted against daily hot water use (gallons) for the entire monitoring period. The dashed lines indicate the average observed water use. As seen in other sites, days with higher hot water use cluster at higher energy use values, indicating a clear relationship between draw volume and HPWH energy consumption. Days with very low hot water use still show non-zero energy use, reflecting standby and cycling losses on low-demand days. The unit at this site was set to Heat Pump mode only throughout the monitoring period and did not have electric resistance backup.

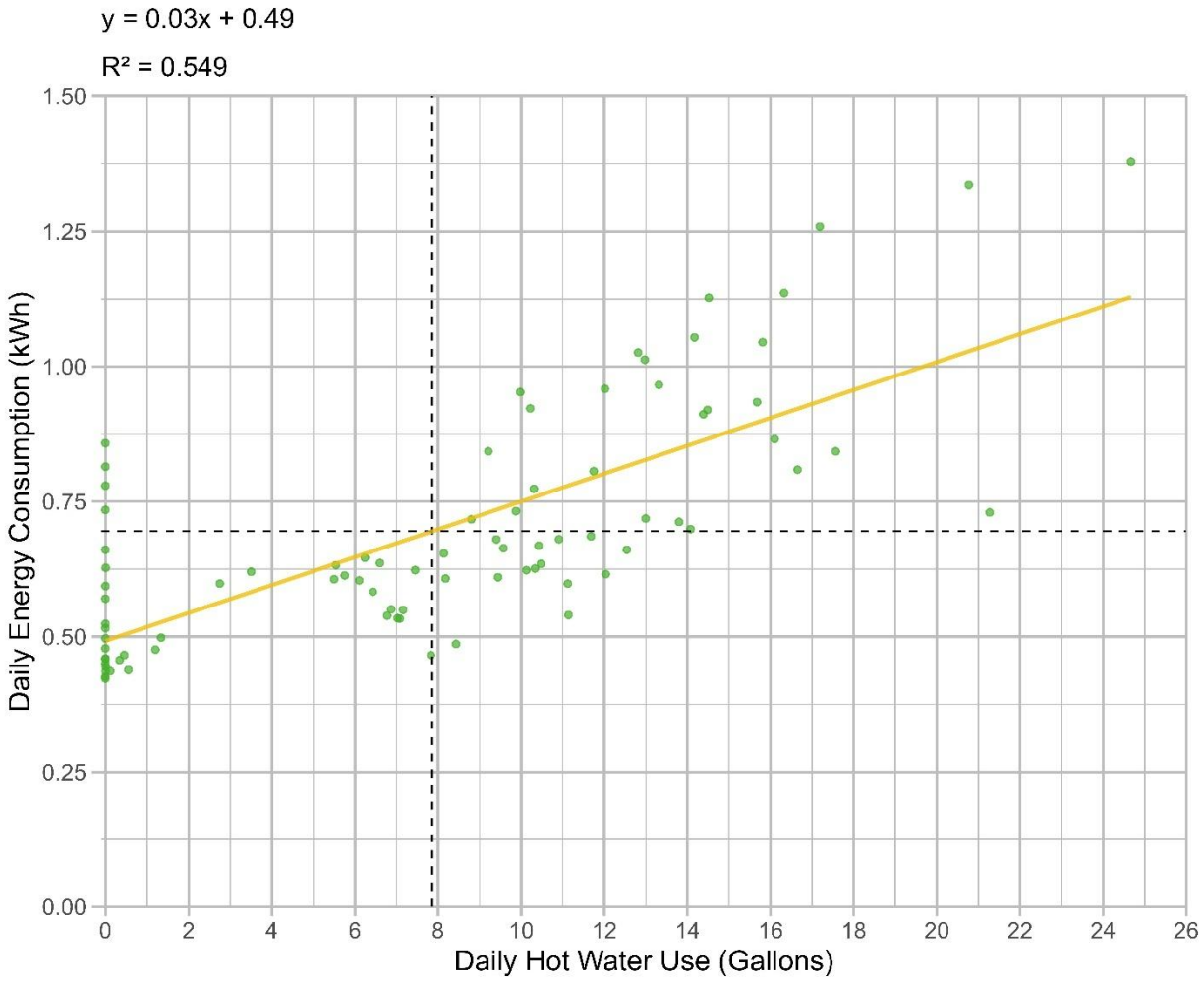

y = 0.03x + 0.49
R² = 0.549
Daily Energy Consumption (kWh)
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0
2
4
6
8
10
12
14
16
18
20
22
24
26
Daily Hot Water Use (Gallons)

Figure 10: Site 3 water use versus energy use by day (full period).

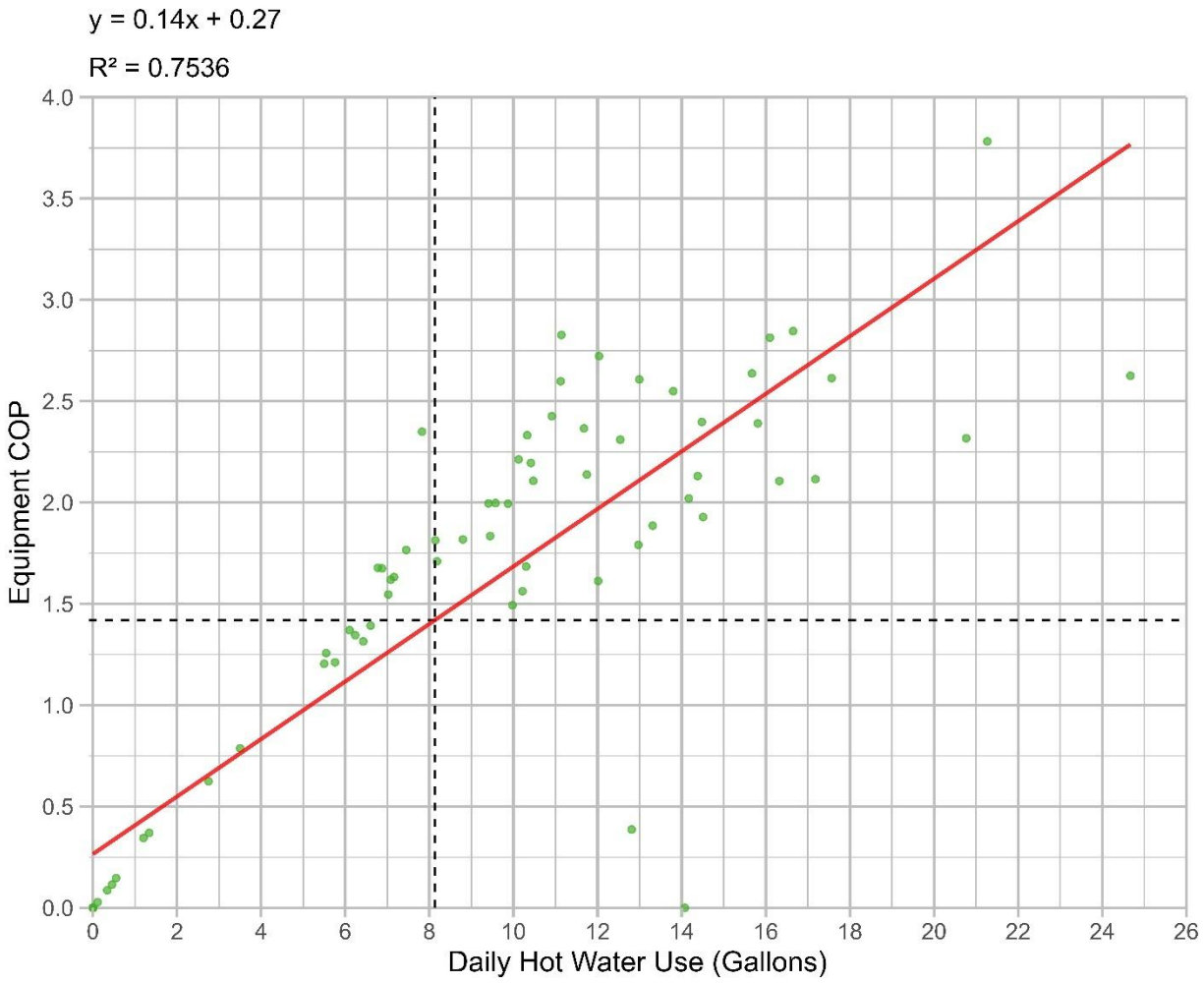


Figure 11 below illustrates equipment COP versus daily hot water use. For all days where the usage is below about 10 gallons, the equipment COP is almost always less than 1. The dashed lines indicate the average observed water use. There is some variability in the result due to when the water cycles. For example, when the water heater cycles overnight, the timing can impact the daily equipment COP calculation depending on if the cycle happens just after or just before midnight. From 10 gallons to 20 gallons per day, equipment COP ranges from just below 0.50 to almost 2.80 COP. Above 20 gallons per day, equipment COP is always observed to be above 2.25. The figure clearly highlights a key operational insight: HPWHs at low-use commercial sites like Site 3 perform

best and deliver savings on days with higher draw volumes, while very low-use days can erode savings due to fixed standby and cycling losses.

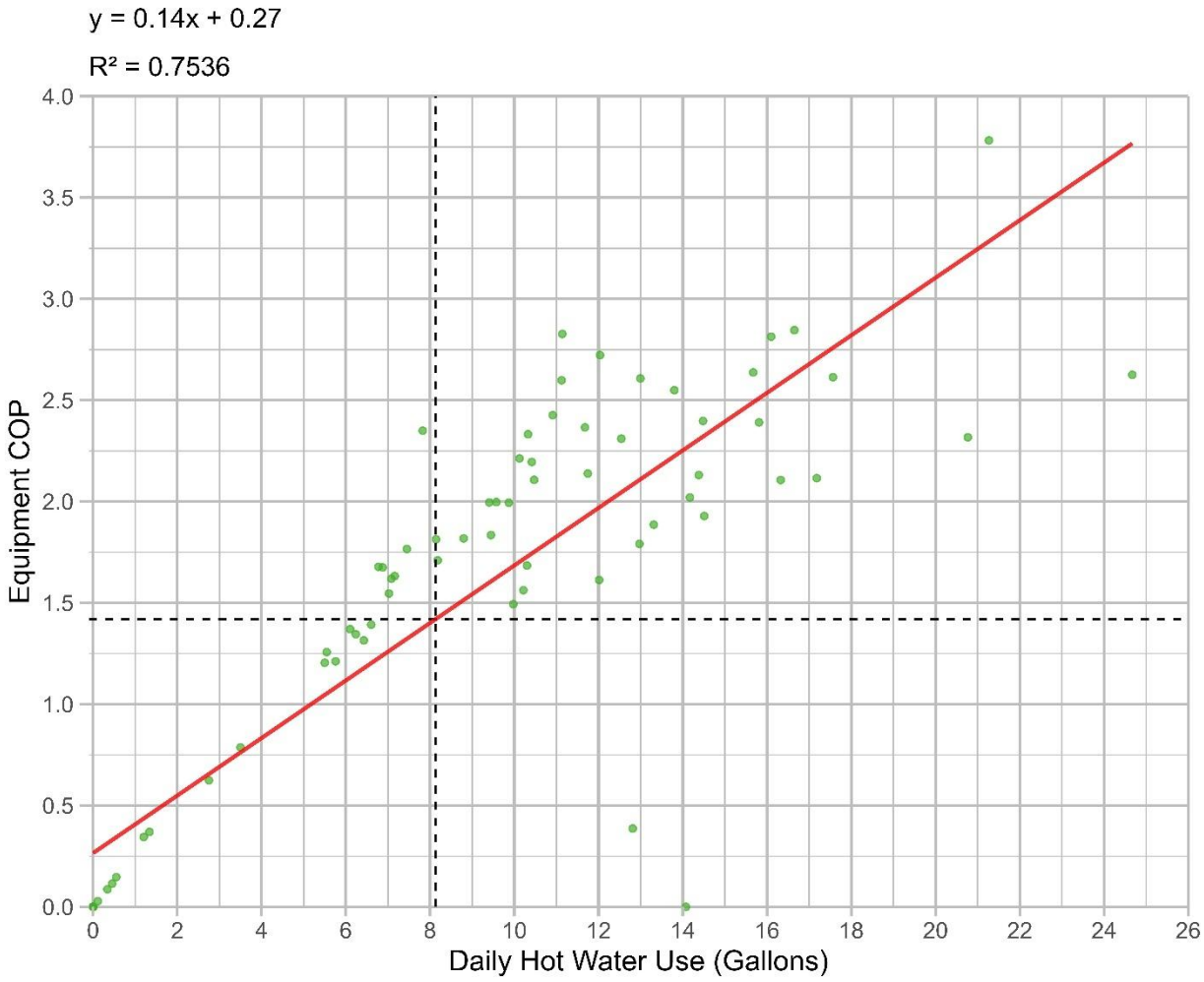


Figure 11: Site 3 COP versus daily hot water use.

Table 13 below shows the average daily hot water use and average daily energy use. Due to low water use, the mass-weighted hot and cold water temperatures were inaccurate. The team used daily maximum hot water temperature in place of mass-weighted hot water temperature and daily minimum cold water temperature in place of mass-weighted cold water temperature in all analyses. This may slightly overstate equipment COP, but the error is expected to be low. Additionally, this method only works because the team did not observe hot water runouts under normal operating conditions. At sites CA01 and CA03, a faucet was left on overnight as an isolated event. The team excluded all data from these days to ensure accuracy of this method.

Table 13: Site 3 average daily hot water and energy use.

Site ID and Period	Average Daily Water Use (Gallons)	Average Daily Energy Use (kWh)	Hot Water Average Max Temperature (°F)	Cold Water Average Minimum Temperature (°F)
CA03 Weekdays	10.7	0.8	117.8	61.3
CA03 Weekends	0.2	0.5	94.8	63.5
CA03 All Days	7.9	0.7	111.9	61.9

From Table 13, average daily hot water use at Site 3 is low overall and higher on weekdays than weekends. On weekdays, the warehouse uses about 10.7 gallons per day, reflecting typical restroom and break area use under normal staff presence. On weekends, average daily water use drops to 0.2 gallons per day, consistent with reduced occupancy and limited janitorial activity. Hot water average maximum temperatures are higher on weekdays (117.8°F) than weekends (94.8°F), while cold water minimum temperatures remain in the low 60s°F. These patterns indicate that the HPWH maintains a higher tank temperature when weekday demand is present, and that weekend operation is largely dominated by standby with occasional small draws.

Site 3's daily system performance (Table 14) summarizes average daily energy output, equipment COP, estimated baseline energy use, and estimated energy savings for Site 3, broken out by weekdays and weekends.

Table 14: Site 3 average daily equipment cop and energy savings.

Site ID and Period	Average Daily Energy Output (Btu)	Average Daily Equipment COP	HPWH Energy Input (Btu-Electric)	Estimated Baseline Energy Use (Btu)	Estimated Energy Savings (Btu)
CA03 Weekdays	4,955	1.87	2,564	5,757	3,192
CA03 Weekends	89	0.04	1,852	103	-1,749
CA03 All Days	3,738	1.48	2,372	4,356	1,984

On weekdays, the HPWH delivers 4,955 Btu per day of hot water with an average equipment COP of 1.87, reducing energy use relative to the baseline by 3192 Btu per day. This indicates that, under typical weekday operating conditions with moderate draw volumes, the HPWH is more efficient than the baseline electric resistance system and provides net energy savings. On weekends, the HPWH delivers only 89 Btu per day of hot water with an average equipment COP of 0.04, and estimated energy savings are negative (-1749 Btu per day). This suggests that on very low-use days, standby and cycling losses dominate, and the HPWH may use more energy than the baseline system would for the same small load.

When viewed together with the scatter plot of water use versus energy use by day for the full period (Figure 13), weekday points with moderate hot water use align with higher equipment COP and positive savings, while weekend points with very low hot water use align with lower equipment COP and negative savings. This pattern reinforces the conclusion that HPWHs at low-use sites like Site 3 perform best and deliver savings on days with moderate draw volumes, while very low-use days can erode savings due to fixed standby and cycling losses.

Table 15 reports estimated energy cost savings and operating costs. The HPWH reduces operating cost relative to an electric resistance baseline by about $81 per year, consistent with the positive energy savings and equipment COP > 1.

Table 15: Site 3 operating cost and estimated energy cost savings.

Site ID and Period	HPWH Energy Cost	Baseline Fuel Type	Estimated Baseline Energy Cost	Estimated Energy Cost Savings
CA03 All Days	$101	Electric resistance	$182	$81

Error! Reference source not found. and Figure 13 are modified box plots that illustrate hourly water use in gallons for Site 3. Each figure shows the average water use (black line), the 75th percentile of water use (blue bar), and the 99th percentile of water use (top whisker), with hourly data overlaid on the box plots.
Error! Reference source not found. illustrates weekday data, and Figure 13 illustrates weekend data. Overall, the figures show low average usage in any given hour. On weekdays, most hours show very low or zero hot water use, consistent with intermittent warehouse occupancy and limited-service hot water needs, while a small number of hours, likely corresponding to shift start, breaks, or cleaning periods, show higher hot water use.

On weekends, hot water use is generally lower than on weekdays, with most hours showing little or no activity; any observed weekend hot water use is likely associated with occasional weekend operations or cleaning rather than regular staff presence. The dot plots exclude the 99th to 100th percentile of data, which reduces the influence of rare, high-use events, while the box plots (based on all data) still capture the full distribution, including occasional higher-use hours. The contrast between weekday and weekend distributions confirms that the warehouse's service hot water

demand is primarily a weekday use case tied to staff schedules and operational tasks, and that hot water use is concentrated in a few key hours with long periods of almost no use where the HPWH can recover.

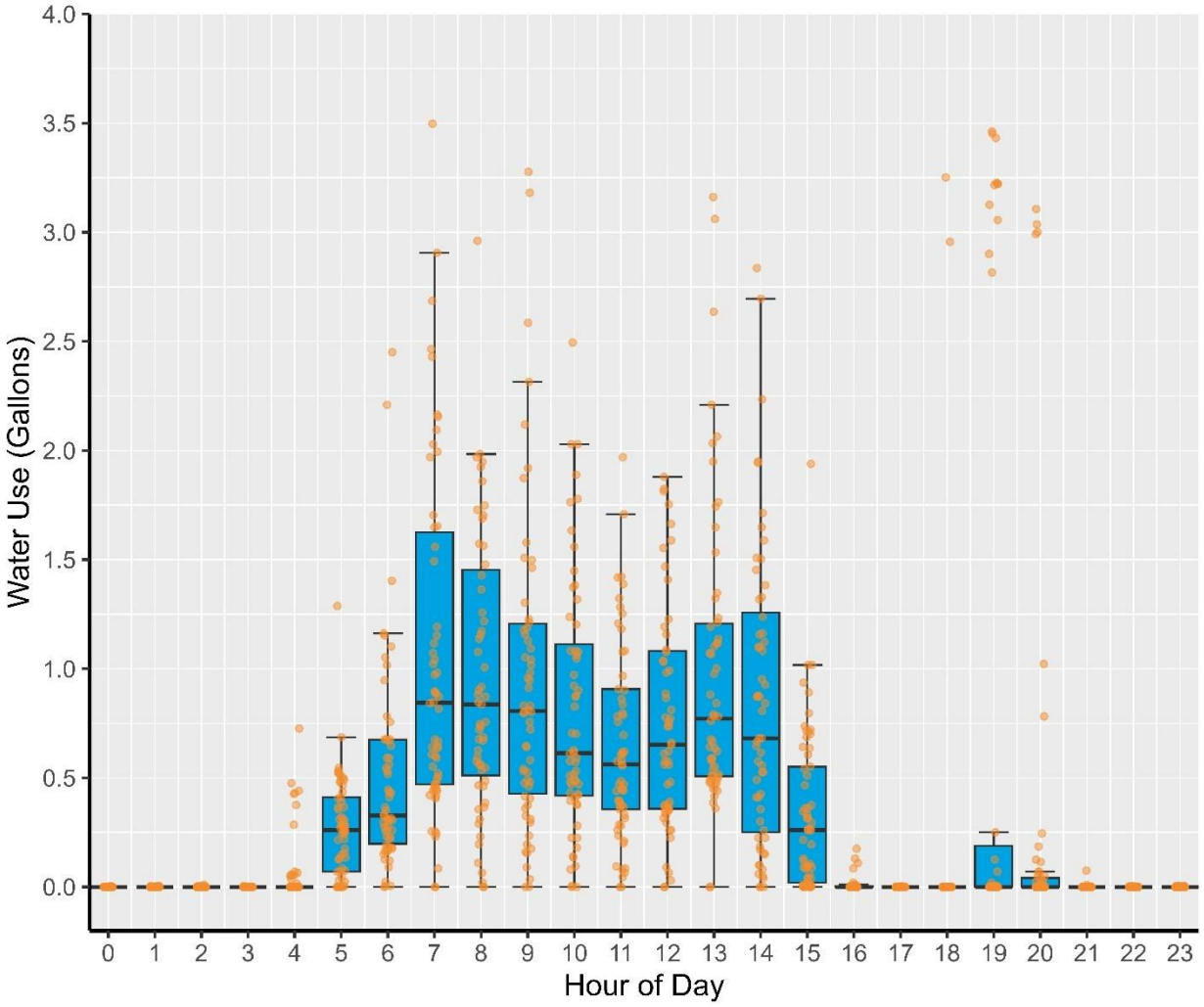


Figure 12: Site 3 weekday hot water use.

* Dot plots exclude the 99th–100th percentile of data. Box plots are based on all data.

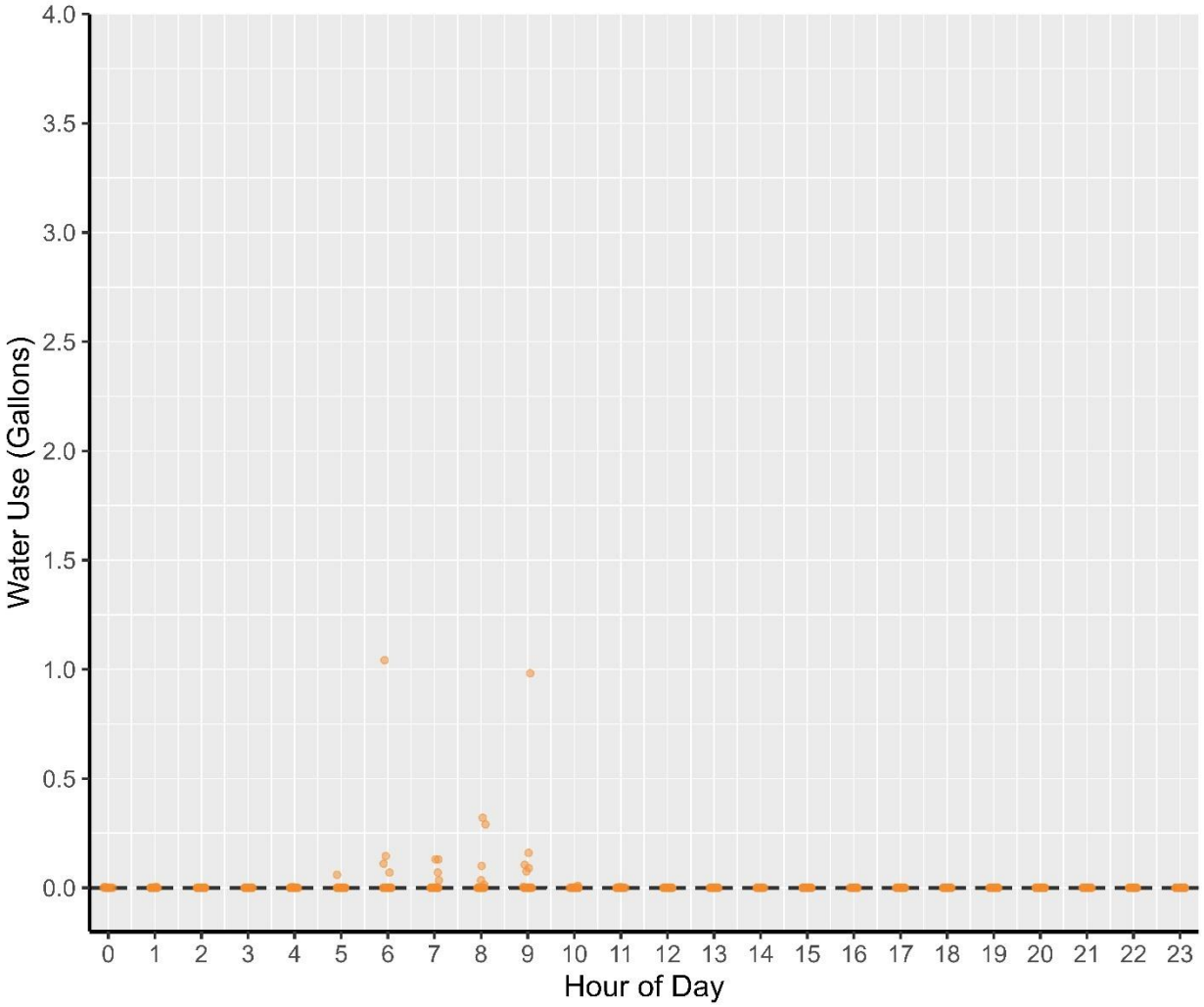


Figure 13: Site 3 weekend hot water use.

Site 4 (Non-Profit Social Service Agency)

Site 4 is a non-profit social service agency that provides community services and support. Service hot water is used for an employee restroom and an employee breakroom. The research team installed an 80-gallon 120 V HPWH to serve this load that was previously served by a 30-gallon gas water heater, located in an unconditioned outdoor mechanical room, with uninsulated outdoor pipes. The research team installed the 80-gallon 120 V HPWH in mid-September 2025 and performed monitoring until the end of January 2026. Key dates are shown in Table 16 below.

Table 16: Site 4 key dates.

Dates	Description
9/16/2025–1/22/2026	Monitoring period
9/16/2025–12/05/25	Temperature setpoint 120°F - 140°F
9/15/2025–9/25/2025	Source air sensor was not positioned correctly. Moved sensor to correct location on 9/25 and any statistics that include source air temp are from 9/25 to the end of period.
12/05/2025–1/22/2026	Temperature setpoint changed to 140°F - 150°F[4]

[4] During installation, the installers talked with the site and they agreed on 120°F setpoint. During testing, the site was unsatisfied with hot water delivery times to the point of use, so the site increased the setpoint several times during the monitoring period. The team determined the largest single change occurred on 12-05-2025, and this used this as the delimitator for the table and plots.

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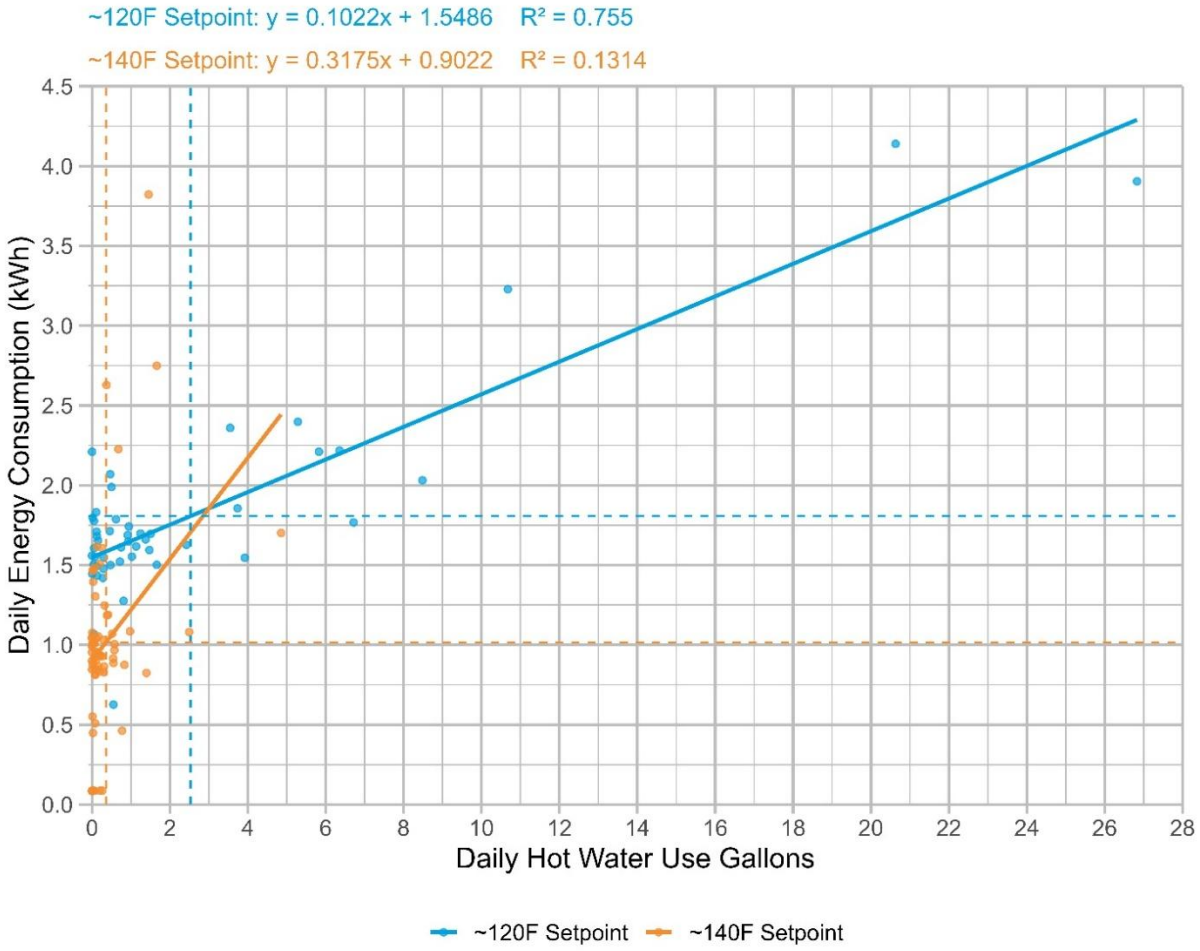


Figure 14, the scatter plot of water use versus energy use by day (full period) for Site 4 shows daily HPWH energy use plotted against daily hot water use for the entire monitoring period. The dashed lines indicate the average observed water use. The 140-degree trend line is included for consistency, but due to the sparse data, no conclusions should be drawn from it. The unit at this site was set to "heat pump mode only" throughout the monitoring period, and electric resistance never switched on during the metering period.

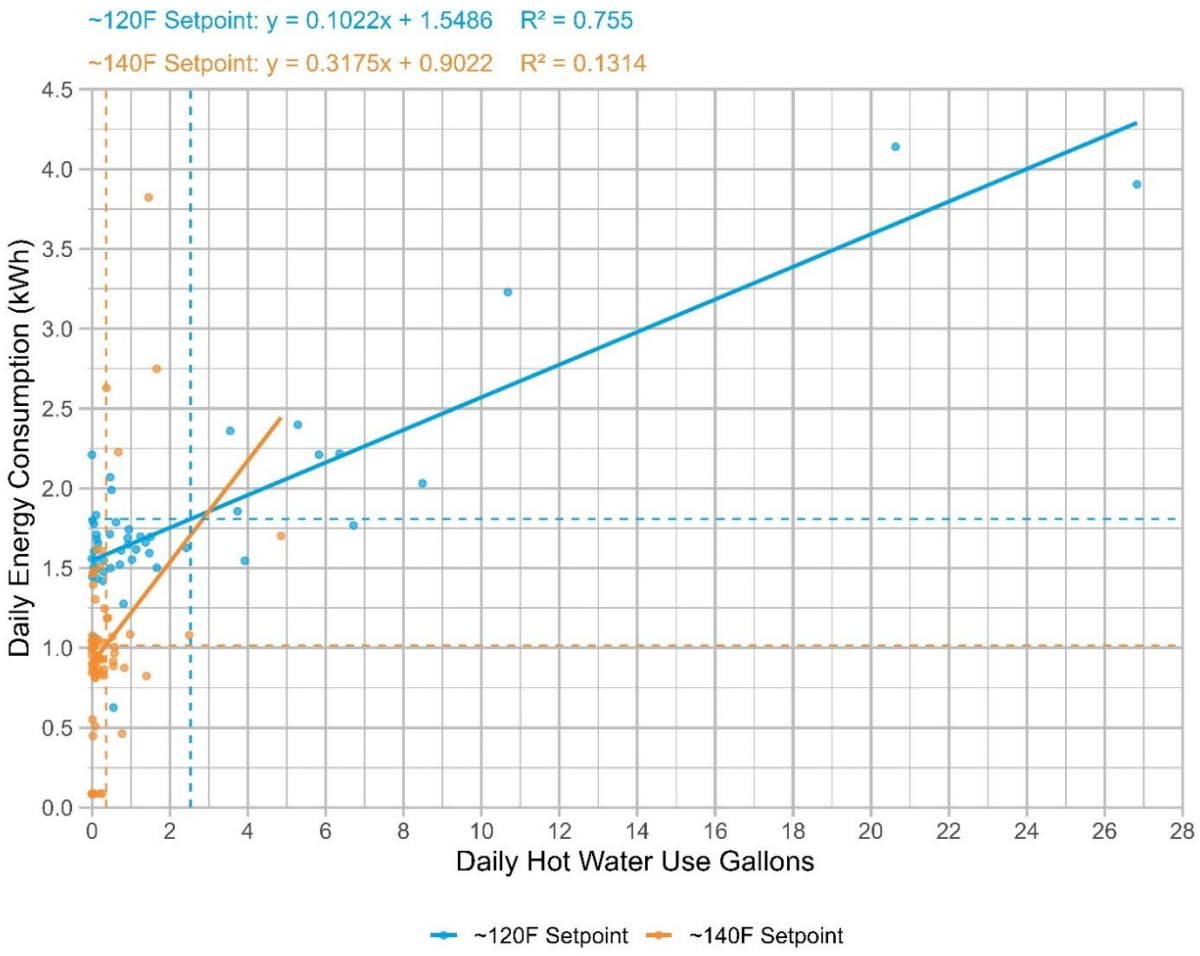

~120F Setpoint: y = 0.1022x + 1.5486 R² = 0.755
~140F Setpoint: y = 0.3175x + 0.9022 R² = 0.1314
Daily Energy Consumption (kWh)
Daily Hot Water Use Gallons
~120F Setpoint
~140F Setpoint

Figure 14: Site 4 water use versus energy use by day (full period).

From the scatter plot of water use versus energy use by day (full period) shown in

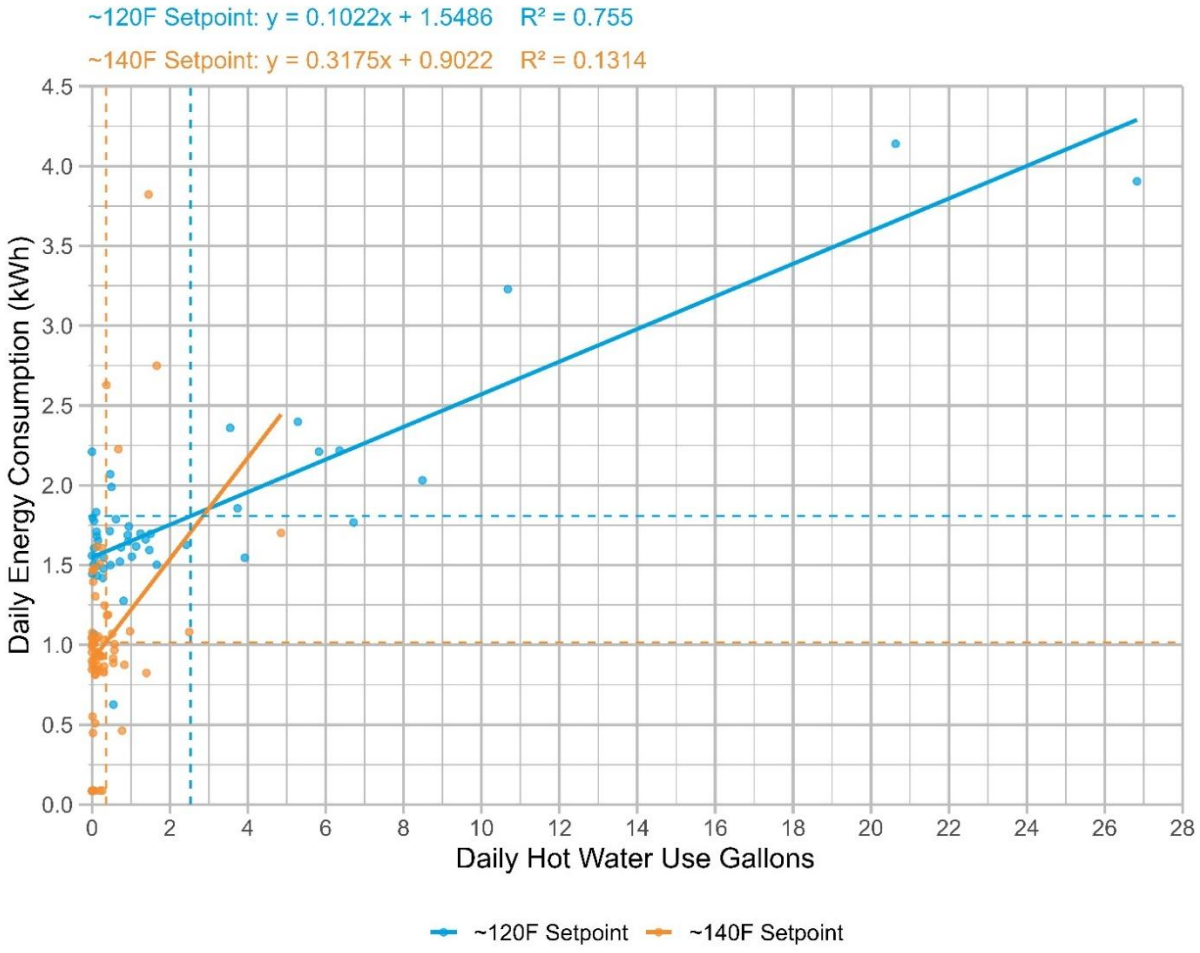


Figure 14:

- Many days cluster at very low hot water use, with HPWH energy use that is not proportionally low, indicating that the system is consuming energy even when delivering little hot water.
- The overall pattern is consistent with significant standby and cycling losses and a system that is not operating efficiently under the observed load conditions.

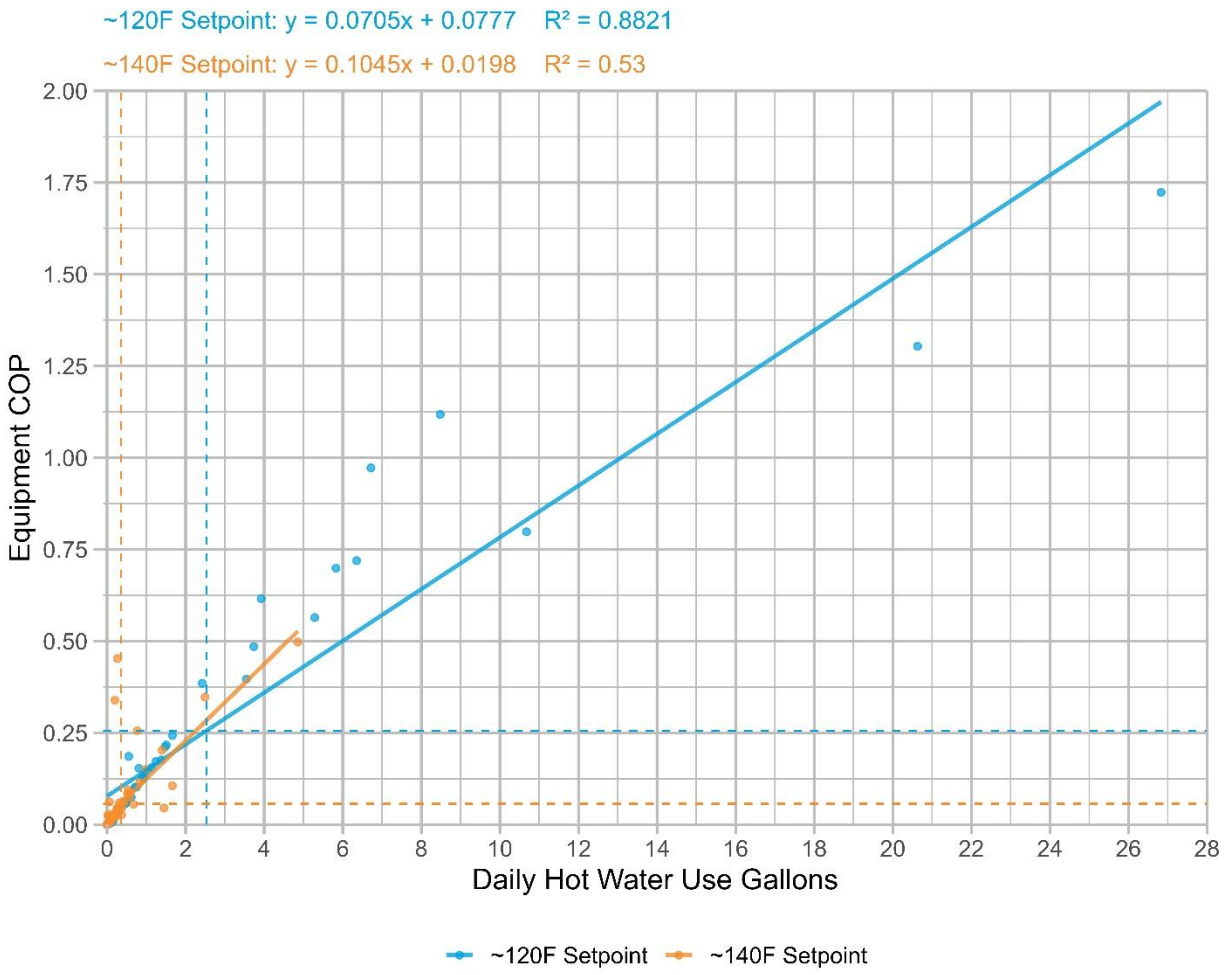


Figure 15 below illustrates equipment COP versus daily hot water use. Other than two days of the entire monitoring period, the usage is below about 12 gallons, resulting in an equipment COP that rarely climbs above 1. The dashed lines indicate the average observed water use. The dashed lines indicate the average observed water use. The 140-degree trend line is included for consistency, but due to the sparse data, no conclusions should be drawn from it. The figure highlights a key operational insight: HPWHs at low-use commercial sites like Site 4 are better candidates for electric resistance point of use heating, given how very low-use days can erode savings due to fixed standby and cycling losses. Additionally, this site had long, exterior-mounted distribution piping that is prone to high heat losses.

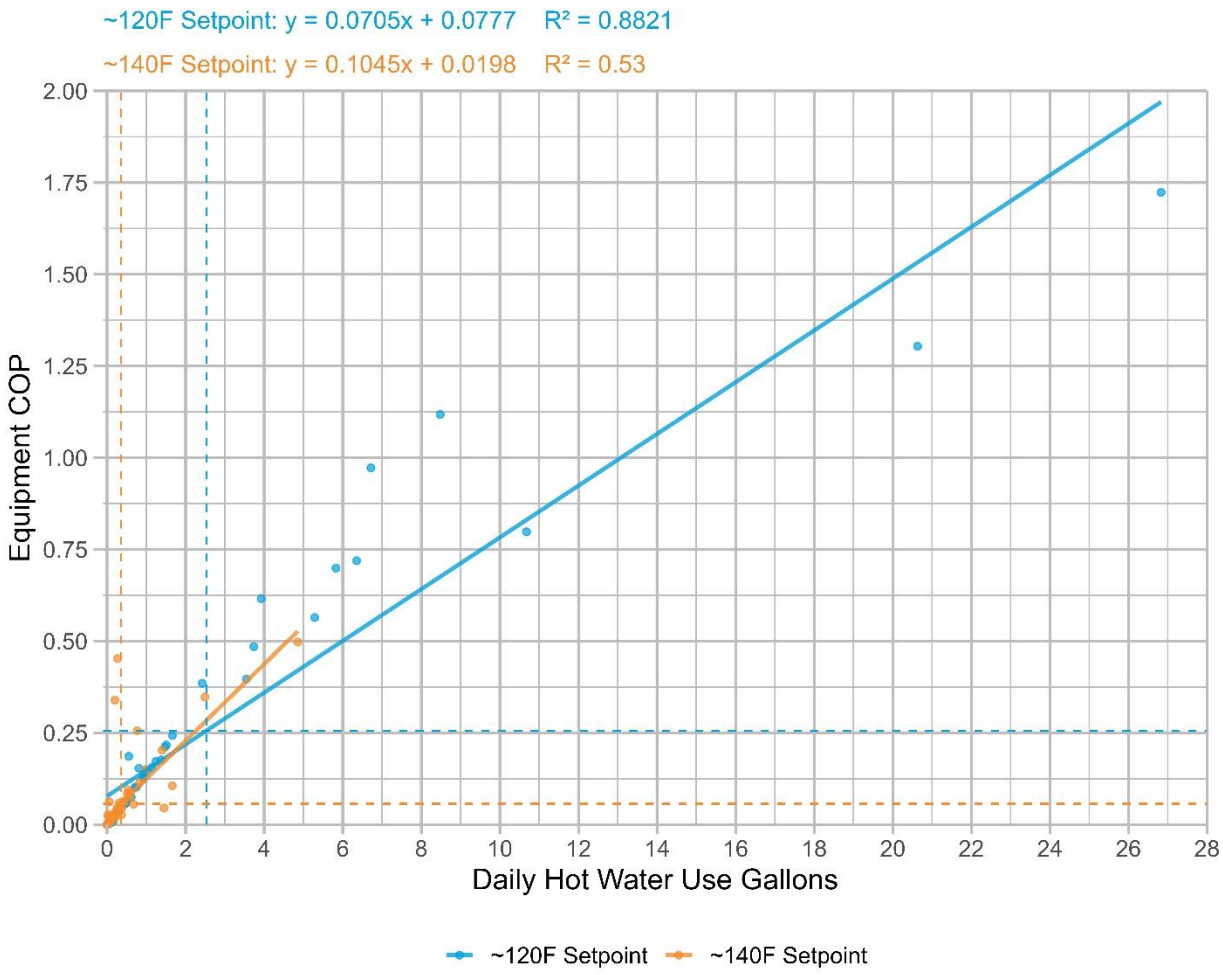


Figure 15: Site 4 COP versus daily hot water use.

Table 17 below shows the average daily hot water use and average daily energy use. Due to low water use, the mass-weighted hot and cold water temperatures were inaccurate. The team used daily maximum hot water temperature in place of mass-weighted hot water temperature and daily minimum cold water temperature in place of mass-weighted cold water temperature in all analyses. This may slightly overstate equipment COP, but the error is expected to be low. Additionally, this method only works because the team did not observe hot water runouts under normal operating conditions. Average daily hot water use at Site 4 is very low.

On weekdays, the site uses about 1.5 gallons per day, reflecting a small number of restroom and breakroom events under normal staff presence. On weekends, average daily water use drops to 0.6 gallons per day, consistent with limited or no regular program activity. Hot water average maximum temperatures are higher on weekdays (126.1°F) than on weekends (103.8°F), while cold water minimum temperatures remain in the mid-50s°F. The HPWH is installed in an uninsulated outdoor mechanical closet with long uninsulated pipes, which affects performance. These patterns indicate

that the HPWH is maintaining a relatively high tank temperature even for very small draw volumes, and that weekend operation is largely dominated by standby with occasional small draws.

Table 17: Site 4 average daily hot water and energy use.

Site ID and Period	Average Daily Water Use (Gallons)	Average Daily Energy Use (kWh)	Hot Water Average Maximum Temperature (°F)	Cold Water Average Minimum Temperature (°F)
CA04 Weekdays	1.5	1.4	126.1	53.7
CA04 Weekends	0.6	1.2	103.8	53.6
CA04 All Days	1.3	1.3	119.7	53.7

Shown in Table 18, the daily system performance for Site 4 summarizes average daily energy output, equipment COP, estimated baseline energy use, and estimated energy savings.

Table 18: Site 4 average daily equipment COP and estimated savings.

Site ID and Period	Average Daily Energy Output (Btu)	Average Daily Equipment COP	HPWH Energy Input (Btu-Electric)	Estimated Baseline Energy Use (Btu)	Estimated Energy Savings (Btu)
CA04 Weekdays	1,238	0.26	4,629	5,854	1,225
CA04 Weekends	412	0.10	4,199	1,946	-2,253
CA04 All Days	1,000	0.22	4,505	4,728	223

On weekdays, the HPWH delivers 1,238 Btu per day of hot water with an average equipment COP of 0.26. The estimated baseline energy use is 5,854 Btu per day, and the estimated energy savings are 1,225 Btu per day. Although the table shows positive “savings” relative to the modeled baseline, the very low COP indicates that most of the HPWH’s electrical input is going to standby and cycling rather than useful output. On weekends, performance is worse: the HPWH delivers only 412 Btu per day with an average equipment COP of 0.10, and estimated energy savings are negative (–2,253 Btu per

day), meaning the HPWH is modeled to use more energy than the gas baseline for the same small load. When averaged across all days, the equipment COP is 0.22 and estimated energy savings are modestly positive (223 Btu per day), but this average masks the fact that weekend operation is clearly inefficient.

Below, Table 19 calculates energy costs and estimates energy cost savings.

Table 19: Site 4 estimated operating costs and energy savings.

Site ID and Period	HPWH Energy Cost	Baseline Fuel Type	Estimated Baseline Energy Cost	Estimated Energy Cost Savings
CA04 All Days	$185	Gas	$27	-$158

On an annualized basis, the HPWH at Site 4 costs approximately $185 per year to operate, compared to an estimated $27 per year for the gas baseline. The estimated energy cost "savings" are therefore -$158 per year, indicating that the HPWH is substantially more expensive to operate than the gas baseline. These operating cost results are consistent with the energy performance findings: the HPWH at Site 4 is substantially more expensive to operate than the gas baseline on both weekdays and weekends, due to low equipment COP and high standby/cycling losses relative to the very small hot water load. For a business like Site 4, where the HPWH is less efficient and more expensive to operate than the gas baseline, the first cost premium is particularly important. Without strong operating cost savings, the economics of a 120 V HPWH relative to gas are unfavorable. These findings suggest that, at Site 4, the 120 V HPWH is not currently a cost-effective replacement for a gas-fired tank heater.

In Figure 16 and Figure 17 are modified box plots that illustrate hourly water use in gallons for Site 4. Each figure shows the average water use (black line), the 75th percentile of water use (blue bar), and the 99th percentile of water use (top whisker), with hourly data overlaid on the box plots. Figure 16 illustrates weekday data, and Figure 17 illustrates weekend data. On weekdays, hot water use is concentrated in a core set of hours, likely corresponding to operating hours and meal preparation, with those hours showing higher medians and upper quartiles that indicate regular use. Many other weekday hours have very low or zero hot water use, reflecting periods when the facility is open but not drawing hot water (for example, office work or counseling sessions).

On weekends, hot water use is generally lower than on weekdays, with fewer hours showing significant draw activity; any observed weekend hot water use is likely associated with special events or limited program operations rather than regular daily service. The dot plots exclude the 99th–100th percentile of data, which highlights typical hourly use without being dominated by rare high-use events, while the box plots (based on all data) still capture the full distribution, including occasional spikes. The contrast between weekday and weekend distributions confirms that Site 4's service hot water demand is primarily a low-demand weekday phenomenon, with weekends characterized by very low use.

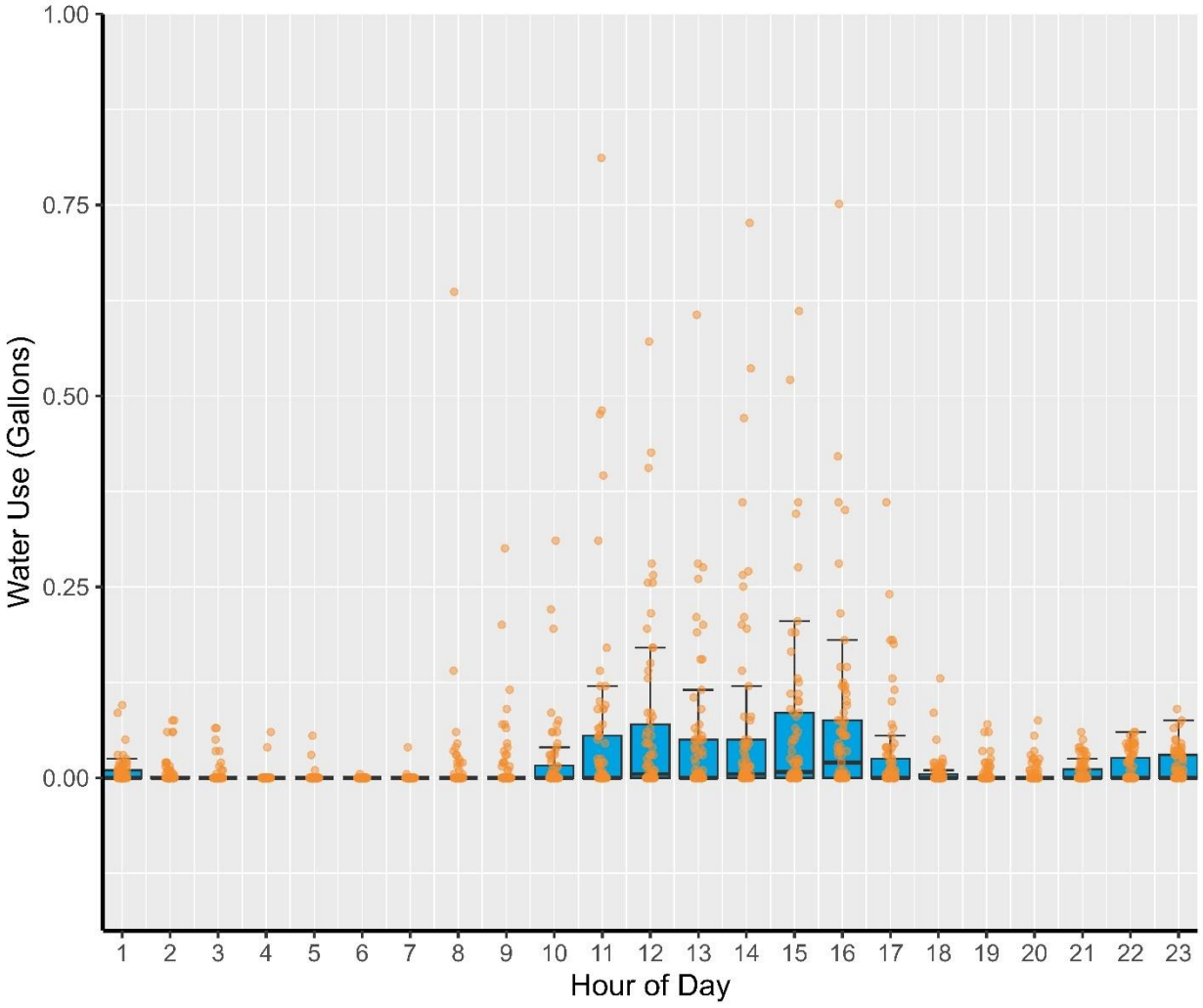


Figure 16: Site 4 weekday hot water use.

***** Dot plots exclude the 99th–100th percentile of data. Box plots are based on all data.

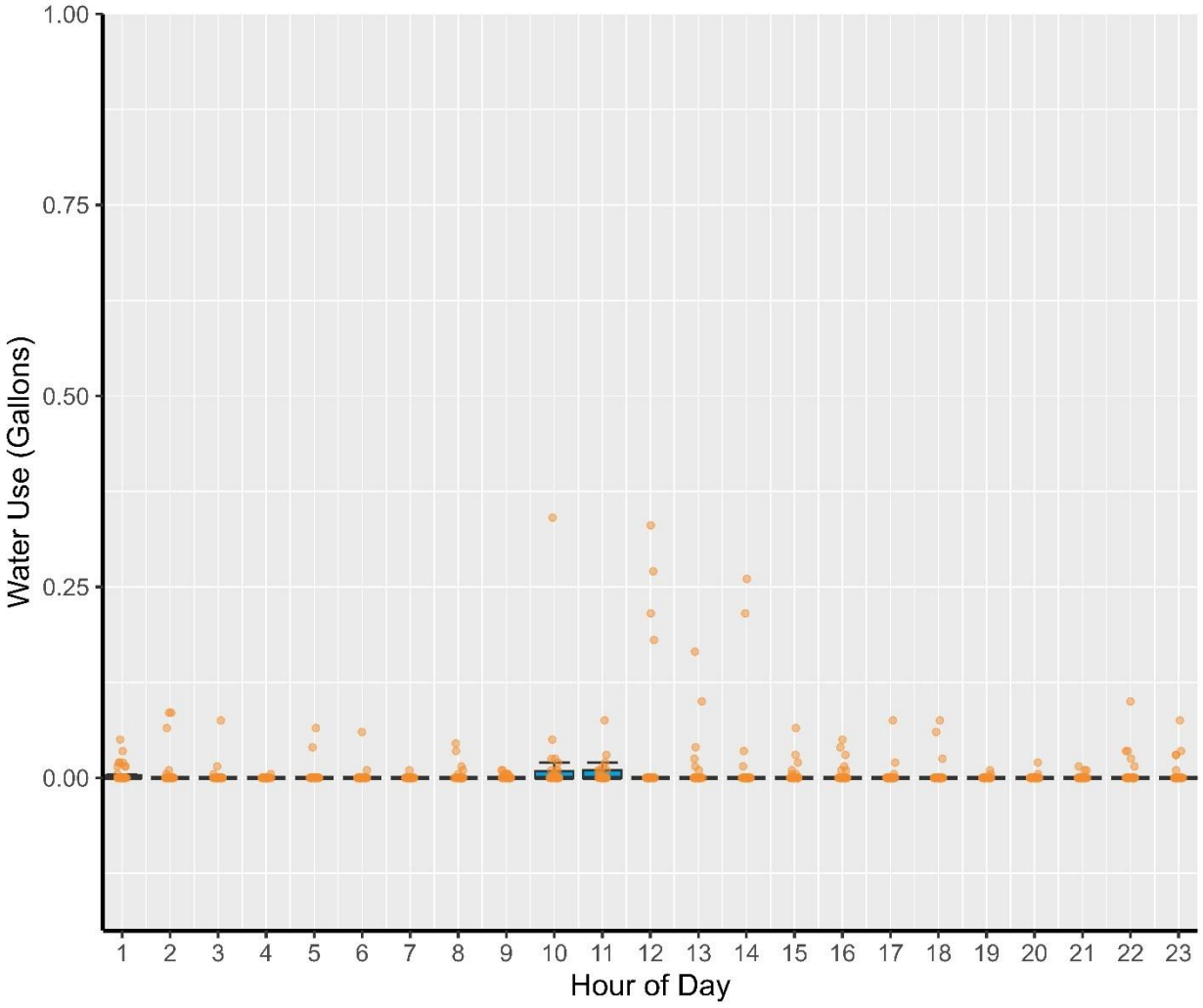


Figure 17: Site 4 weekend hot water use.

Site 5 (Religious Organization)

Site 5 is a portion of a religious organization that has a temple, office, and preschool. Service hot water is primarily used for office and preschool restroom handwashing, employee break area, and occasional mop sink usage for janitorial tasks, resulting in intermittent and generally moderate hot water demand. The research team installed a 40-gallon 120 V HPWH where a 30-gallon gas water heater previously served this load. The unit is in a conditioned utility room adjacent to the office and preschool zones.

The research team installed a 40-gallon 120 V HPWH in early February 2026 and performed monitoring until end of June 2026. Key dates are shown in Table 20 below.

Table 20: Site 5 key dates.

Dates	Description
2/12/2026–6/30/2026	Monitoring period
2/12/2026–6/30/2026	Temperature setpoint 120°F
2/11/2026–5/5/2026*	The addition of an expansion tank but no check valve resulted in bi-directional flow through the installed water meter. The team resolved the issue by installing an ultrasonic flow meter downstream of the expansion tank on 5/5/26. The team could not resolve flows prior to this date and is only using data from after this date.

*Despite a truncated metering period, the site's daily hot water consumptions were substantial with a reasonably large range of values, providing the team with a diversity of daily results. Additionally, although less seasonal impacts may have been captured, the site has a consistent operational schedule helping to normalize the results.

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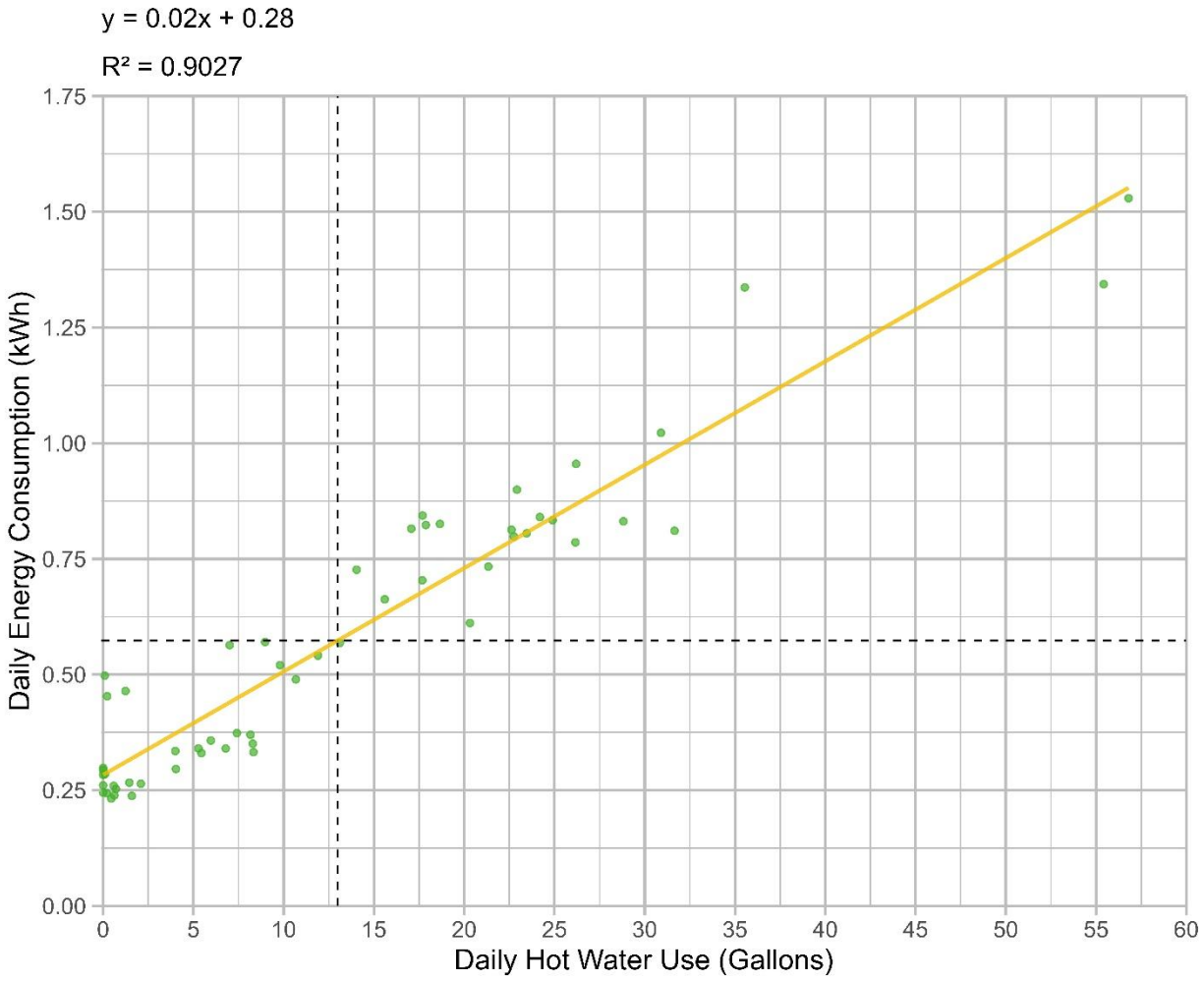


Figure 18, the scatter plot of water use versus energy use by day (full period) for Site 5 shows daily HPWH energy use plotted against daily hot water use for the entire monitoring period. The unit at this site was set to Heat Pump mode only throughout the monitoring period and did not have electric resistance backup.

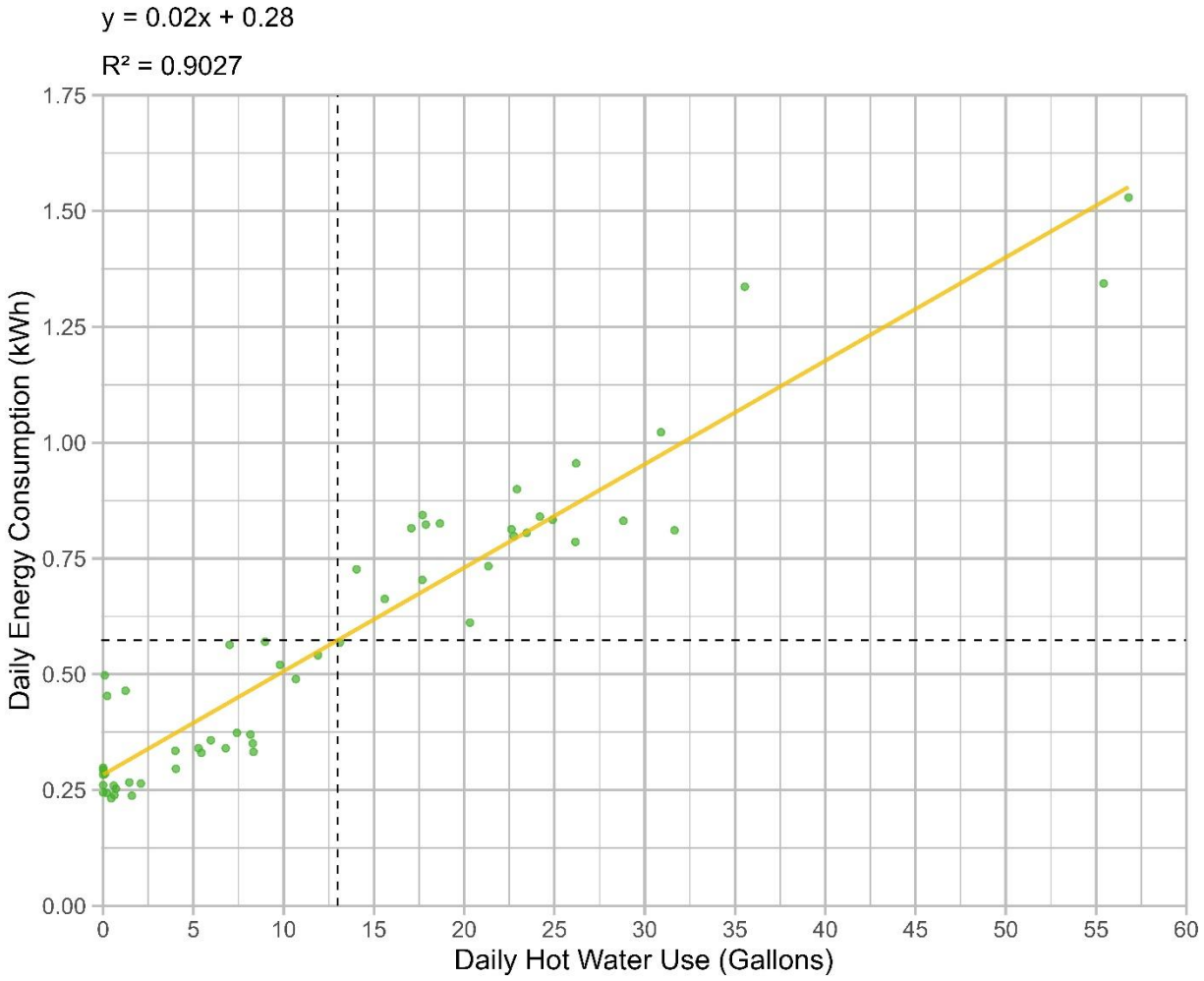


Figure 18: Site 5 water use versus energy use by day (full period).

Daily hot water use at Site 5 is typically low to moderate, with many days clustered below about 30 gallons and correspondingly low energy consumption. On moderate use days (roughly 15 gallons to 30 gallons), energy use increases proportionally, maintaining a strong linear relationship between daily water use and energy consumption. A small number of higher use outlier days (around 50 gallons to 60 gallons) also show proportionally higher energy use, indicating that the system's energy consumption scales consistently with demand.

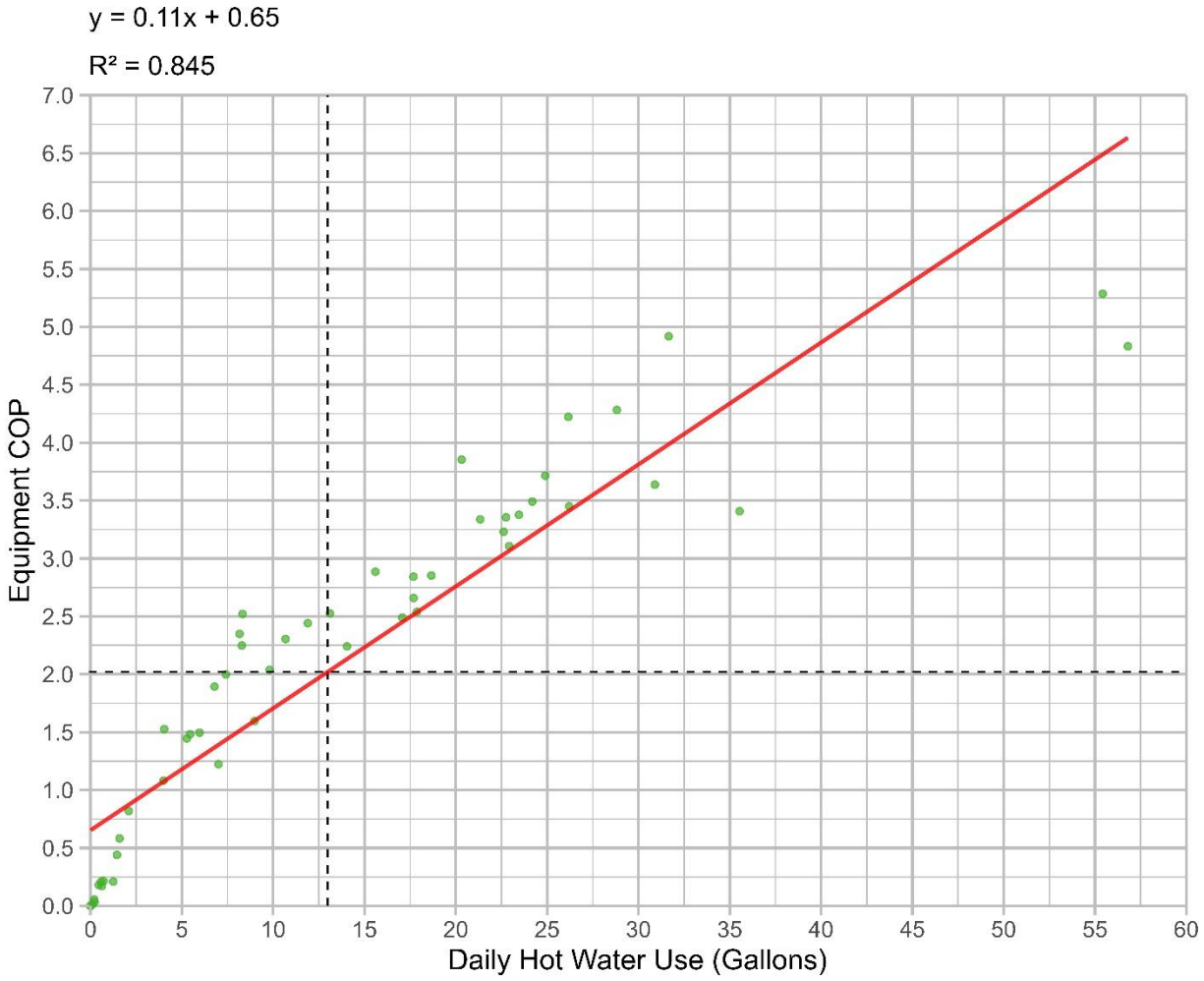


Figure 19 below illustrates equipment COP versus daily hot water use. For all days where the usage is below about 10 gallons, the equipment COP is almost always less than 2. There is some variability in the result due to when the water cycles. For example, when the water heater cycles overnight, the timing can impact the daily equipment COP calculation depending on if the cycle happens just after or just before midnight. From 10–20 gallons per day, equipment COP ranges from about 2 to 3. Above 20 gallons per day, equipment COP is always observed to be above 3. The figure clearly highlights a key operational insight: HPWHs at moderate-use commercial sites like Site 5 perform best and deliver savings on days with higher draw volumes, while very low-use days can erode savings due to fixed standby and cycling losses. Additionally, this heat pump was installed in a warm IT closet (up to 80°F) with shorter distribution piping, which improved performance.

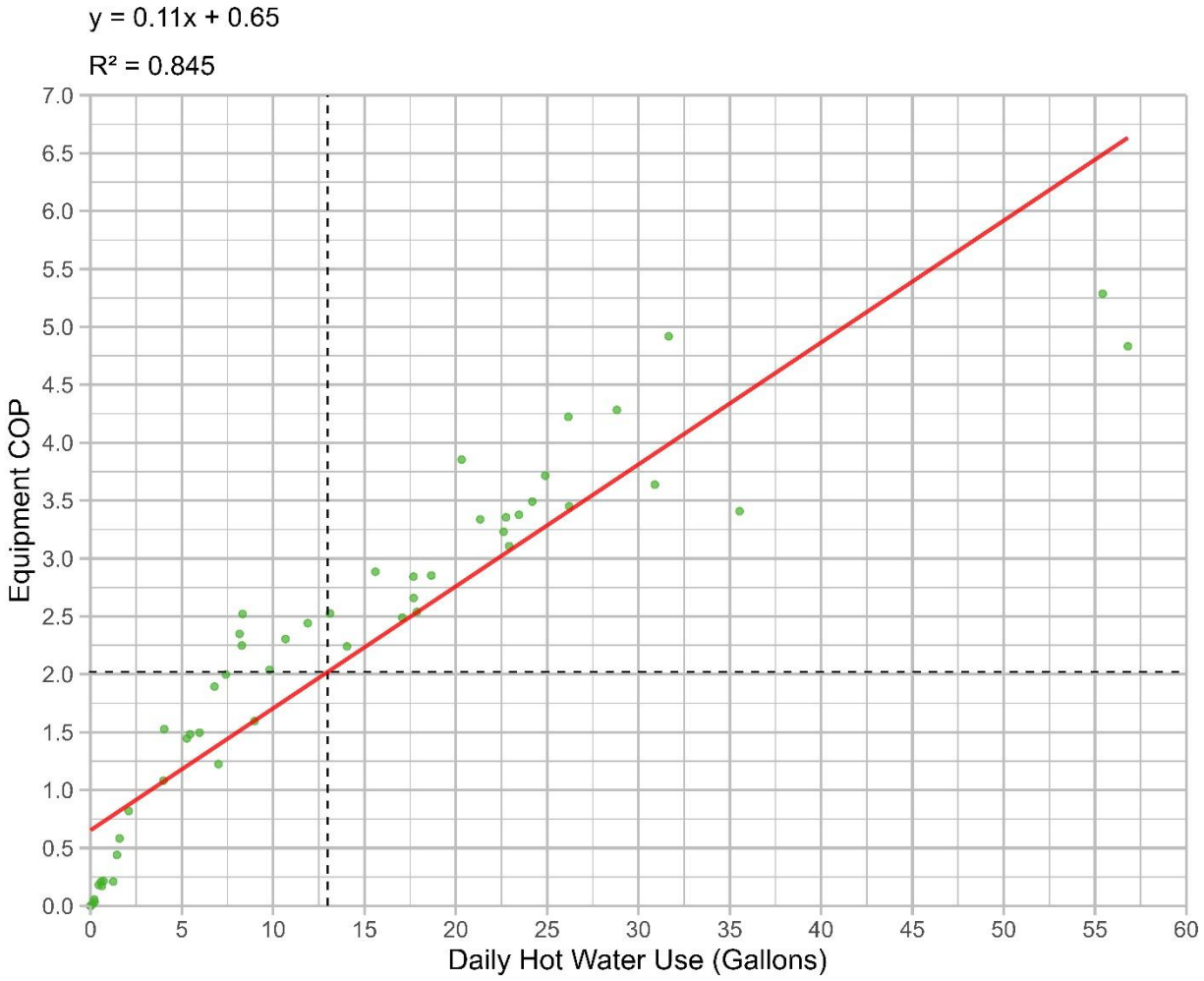


Figure 19: Site 5 COP versus daily hot water use.

Table 21 below shows the average daily hot water use and average daily energy use. Due to low water use, the mass-weighted hot and cold water temperatures were inaccurate. The team used daily maximum hot water temperature in place of mass-weighted hot water temperature and daily minimum cold water temperature in place of mass-weighted cold water temperature in all analysis. This may slightly overstate equipment COP, but the error is expected to be low. Additionally, this method only works because the team did not observe hot water runouts under normal operating conditions.

Table 21: Site 3 average daily hot water and energy use.

Site ID and Period	Average Daily Water Use (Gallons)	Average Daily Energy Use (kWh)	Hot Water Average Max Temperature (°F)	Cold Water Average Minimum Temperature (°F)
CA05 Weekdays	17.9	0.7	116.3	70.1
CA05 Weekends	0.7	0.3	99.1	72.6
CA05 All Days	13.0	0.6	111.4	70.8

From Table 21, average daily hot water use at Site 5 is moderate on weekdays and very low on weekends. On weekdays, the site uses about 17.9 gallons per day, reflecting regular restroom and breakroom use associated with office and preschool activities, as well as occasional janitorial draws. On weekends, average daily water use drops to 0.7 gallons per day, consistent with limited or no preschool operation and reduced office activity. Hot water average maximum temperatures are higher on weekdays (116.3°F) than weekends (99.1°F), while cold water minimum temperatures remain in the low 70s°F. These patterns indicate that the HPWH maintains a higher tank temperature when weekday demand is present, and that weekend operation is largely dominated by standby with only occasional small draws.

Shown in Table 22, the daily system performance for Site 5 summarizes average daily energy output, equipment COP, estimated baseline energy use, and estimated energy savings for the system we replaced. For Site 5, the average daily performance and cost metrics show a clear distinction between weekday and weekend operation, with generally favorable energy savings on weekdays and poor performance on weekends.

Table 22: Site 5 average daily equipment cop and estimated energy savings.

Site ID and Period	Average Daily Energy Output (Btu)	Average Daily Equipment COP	HPWH Energy Input (Btu-Electric)	Estimated Baseline Energy Use[5] (Btu)	Estimated Energy Savings (Btu)
CA05 Weekdays	7,273	3.13	2,325	22,708	20,382
CA05 Weekends	242	0.23	1,034	1,144	111
CA05 All Days	5,264	2.69	1,956	20,389	18,433

On weekdays, the HPWH at Site 5 delivers 7,273 Btu per day of hot water with an average equipment COP of 3.13. Against an estimated baseline energy use of 22,708 Btu per day, this corresponds to estimated daily energy savings of 20,382 Btu. This indicates that, when the system is serving its typical weekday load, it operates efficiently and displaces a substantial portion of the baseline water heating energy. On weekends, average daily energy output is only 242 Btu per day, with an average equipment COP of 0.23. Compared to an estimated baseline energy use of 1,144 Btu per day, the HPWH is modeled to save 111 Btu per day, but the very low COP suggests that most of the HPWH's electrical input is going to standby and cycling rather than useful output. When averaged across all days, the equipment COP is 2.69 and estimated energy savings are 18,433 Btu per day, but this average is driven by strong weekday performance and masks the weak performance on very low-use weekends.

[5] Baseline energy use at site 5 was calculated based on the single system that was replaced and did not consider the other two hot water systems at the site.

When viewed together with the scatter plot of water use versus energy use by day (

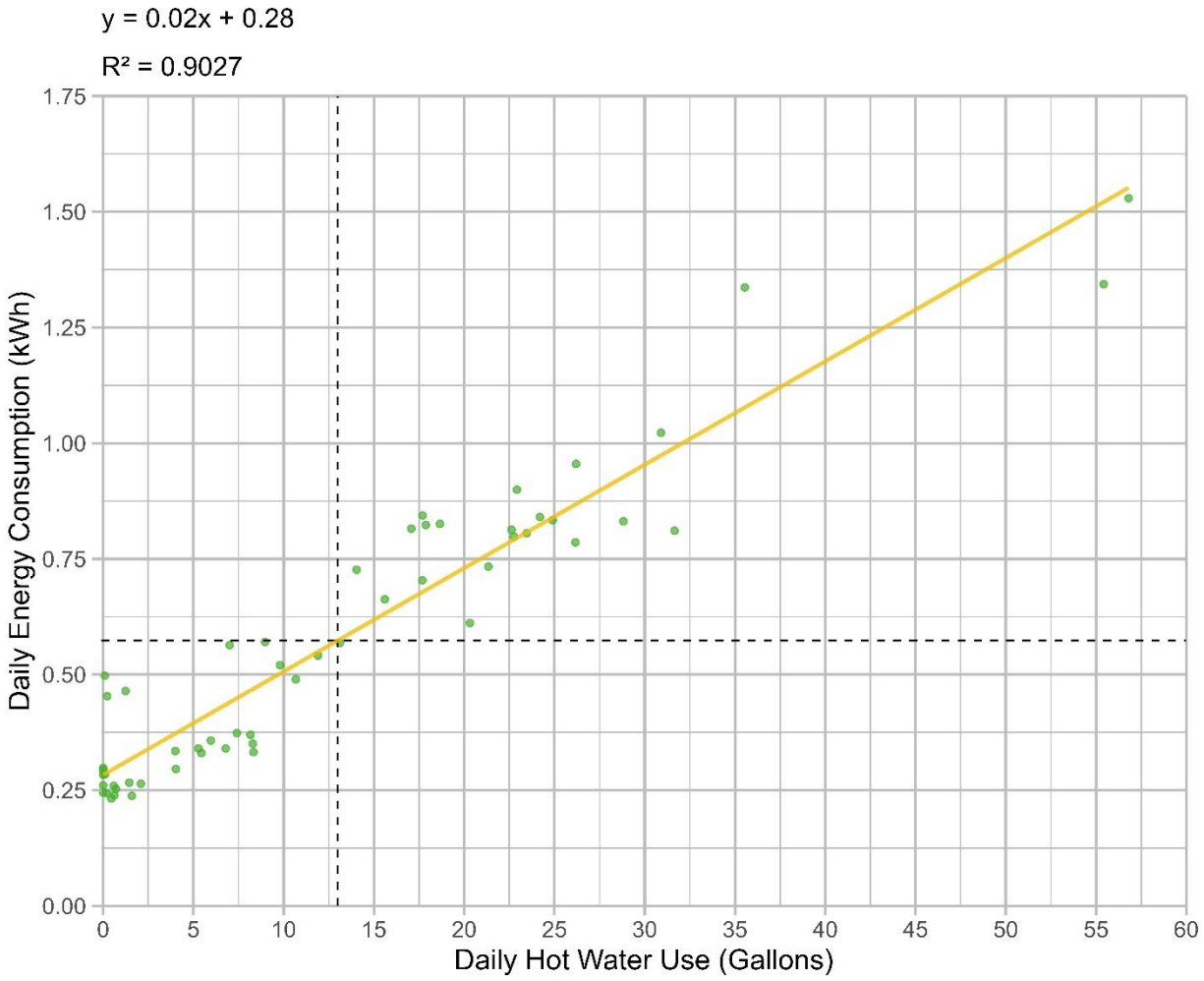


Figure 18) and the COP versus daily use plot (

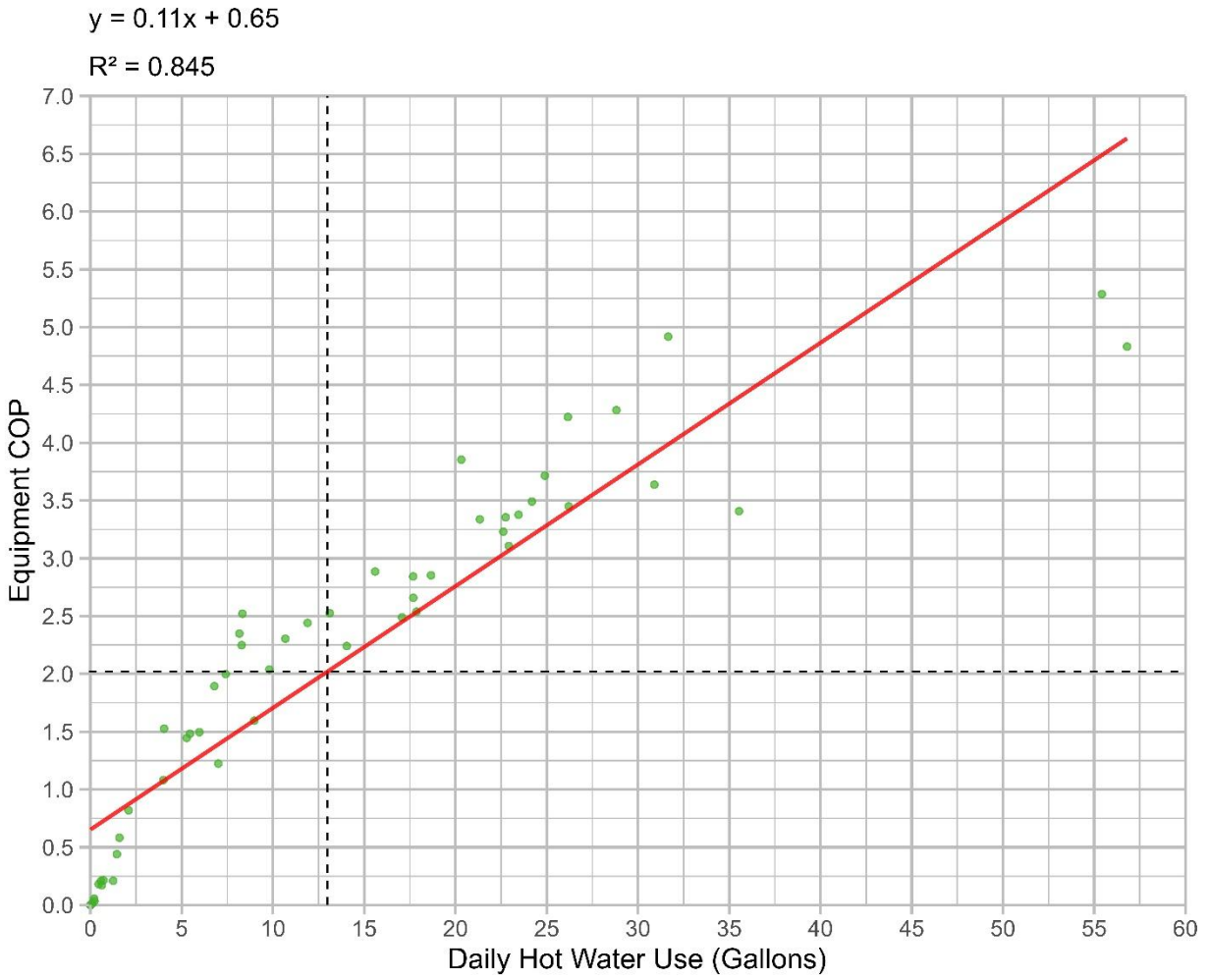


Figure 19), weekday points with moderate hot water use align with high COP and large positive savings, while weekend points with very low hot water use align with low COP and much smaller savings. Taken together, the plots and the performance table show that Site 5's HPWH performs very well on weekdays when there is meaningful hot water demand but is much less efficient on weekends when demand is minimal.

Below, Table 23 calculates energy costs and estimates energy cost savings.

Table 23: Site 5 operating costs and estimated energy cost savings.

Site ID and Period	HPWH Energy Cost	Baseline Fuel Type	Estimated Baseline Energy Cost	Estimated Energy Cost Savings
CA05 All Days	$87	Gas	$104	$17

From a cost perspective, annual operation of the HPWH at Site 5 is slightly favorable relative to the gas baseline. The HPWH's estimated annual energy cost is about $87, compared to approximately $104 for the baseline gas water heater, yielding an annual cost savings of roughly $17. In other words, the HPWH is providing meaningful energy savings (in Btu) over the year, but under current rate assumptions, those savings translate into only modest bill reductions compared to the gas baseline. Taken together with the energy performance results, these annual cost impacts indicate that Site 5's HPWH performs well and delivers substantial energy savings during periods of meaningful hot water demand, while periods of very low demand contribute little to cost savings. This pattern suggests that control strategies that limit HPWH operation during very low-load periods could further improve overall cost-effectiveness.

Site 5 illustrates several lessons that are broadly applicable to other mixed-use, low-to-moderate load sites. First, aligning HPWH operation with actual demand is critical. At Site 5, the system performs well and delivers substantial energy savings when office, preschool, and temple activities drive regular hot water use, but contributes little benefit when demand is minimal. This underscores the importance of controls and scheduling that limit operation during off-hours and very low-load periods to avoid standby and cycling losses.

Second, the representative day and week plots show that even relatively small tanks and 120 V HPWHs can reliably meet clustered morning peaks and scattered daytime draws, provided that setpoints and recovery behavior are tuned to the site's specific load shape. Finally, the strong correlation between daily water use and energy consumption, combined with annual cost results that are only modestly better than a gas baseline, suggests that program success at sites like Site 5 depends as much on operational strategies, such as weekend setbacks, temperature maintenance logic, and careful meter placement/commissioning, as on equipment selection. These lessons can inform design and control approaches at similar religious, educational, and office facilities where hot water demand is concentrated in predictable weekday windows and drops sharply outside core operating hours.

Figure 20 and Figure 21 are modified box plots that illustrate hourly water use in gallons for Site 5. Each figure shows the average water use (black line), the 75th percentile of water use (blue bar), and the 99th percentile of water use (top whisker), with hourly data overlaid on the box plots. Figure 20 illustrates weekday data, and Figure 21 illustrates weekend data. On weekdays, hot water use is present across many hours of the day, indicating more regular and distributed usage compared to sites with very intermittent occupancy. Certain hours show noticeably higher water use, likely corresponding to peak activity periods such as morning start-up, midday breaks, or end-of-day cleaning, while other hours exhibit more moderate but still nonzero use. On weekends, hot water use is generally lower than on weekdays, with many hours showing little or no activity across the 24-hour period; any observed weekend hot water use is likely associated with limited or occasional weekend operations (such as cleaning or sporadic staff presence) rather than a consistent, full staff schedule. The dot plots exclude the 99th to 100th percentile of data, which limits the visual influence of rare, very high use events, while the box plots (based on all data) still represent the full distribution of hot water use, including occasional high use hours. This contrast between weekday and weekend

distributions at Site 5 indicates that the site's service hot water demand is primarily a weekday use case tied to staff and program schedules, with only minor, intermittent use on weekends.

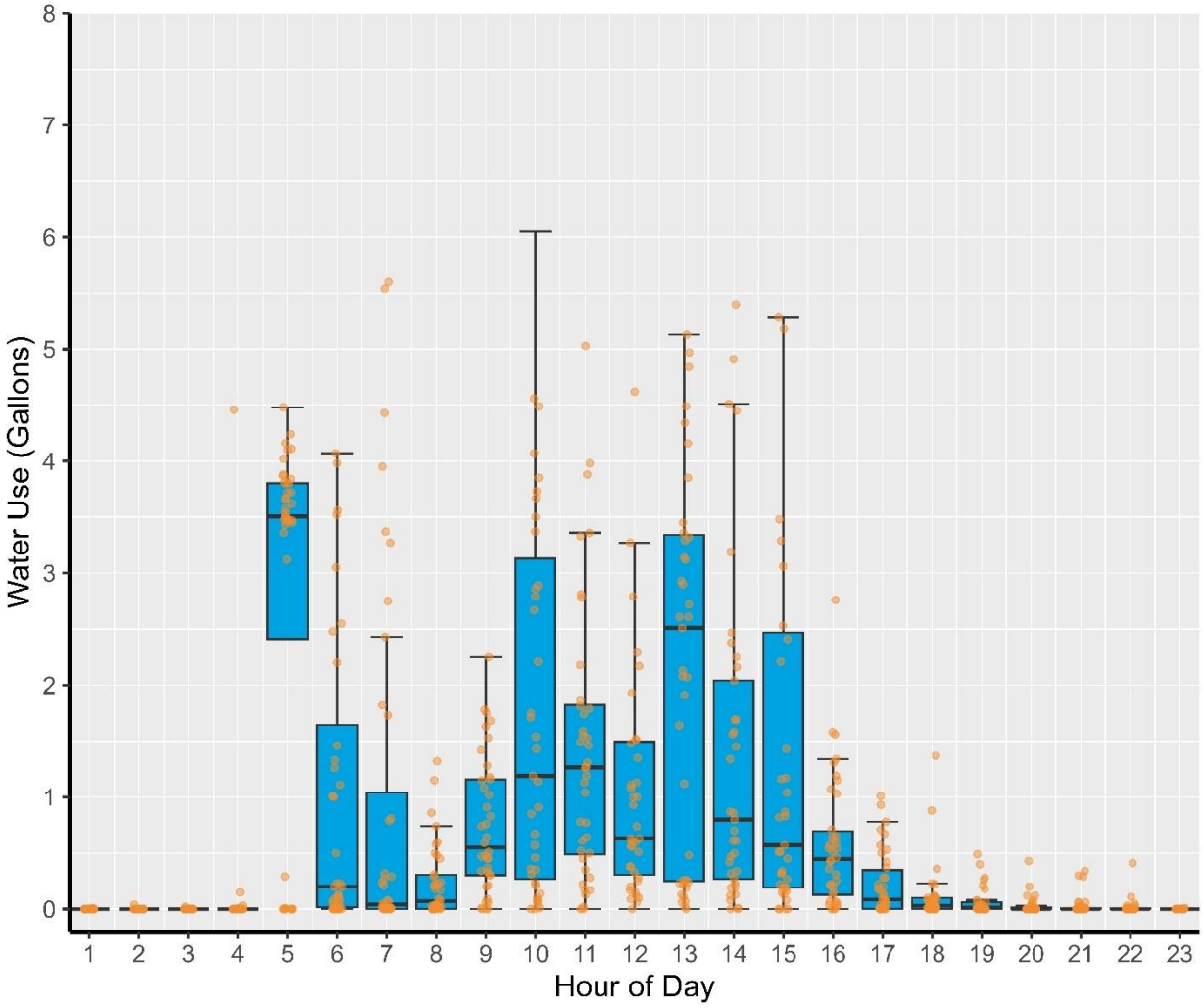


Figure 20: Site 5 weekday water use.

*Dot plot excludes the 99th–100th percentile of data. Box plots are based on all data.

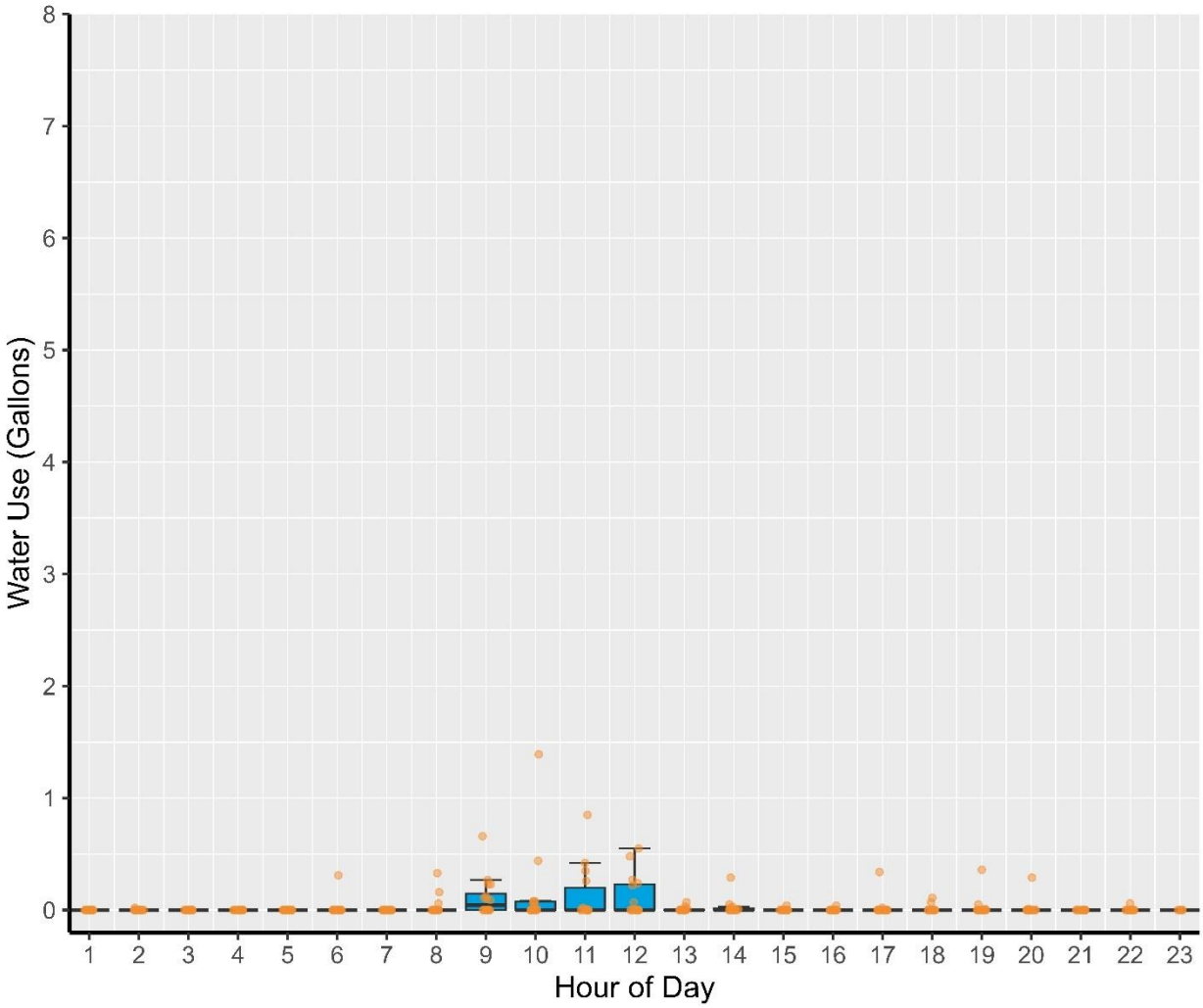


Figure 21: Site 5 weekend water use.

Survey Findings and Interpretation

This section summarizes the findings from the site surveys. Overall, site staff were generally happy with the project, but their attitudes may reflect a low sensitivity to the performance of the hot water system in the SMB segment rather than indicating that the 120 V HPWH are a good fit in this segment.

Before installation, customers were generally moderately satisfied with their existing water heaters; however, this includes three sites that had no water heater/had broken and decommissioned water heaters. These sites were low-risk for the use of 120 V HPWH, especially given the observed overly conservative predictions of industry standard sizing methods, contractors, and equipment suppliers. Ultimately, the overall results show that the sites got a low value from the retrofit. Most respondents were not very engaged with their energy use or bills. At the same time, they were open to improvements and expressed interest in both energy efficiency and environmental benefits, especially if newer technology could reduce costs or improve reliability. Taken together, the findings

indicate that SMB sites are open to new technologies and methods and present a low-risk segment for decarbonization. However, water heating equipment is not viewed as mission-critical in this segment and self-reported satisfaction may fail to capture key performance considerations such as whether hot water is ever delivered to the point of use.

The installation experience showed that 120 V HPWHs are technically feasible in these settings and can avoid the need for electrical panel upgrades. Across sites, installation cost and time for a 120V HPWH tended to fall between a conventional gas-fired tank water heater at the low end and a 240 V HPWH at the high end, which reflects a true cost compression from 240 V HPWH. The most significant challenges were related to contractor processes and permitting, such as quote iterations, confusion about permit requirements, and one instance of the wrong equipment being ordered, rather than any inherent limitation of the 120 V HPWH technology itself.

Over three to eight months of operation, customers reported high satisfaction with the 120 V HPWHs. They described the units as reliable and easy to operate. Maintenance needs were minimal, and any issues that did arise, such as a leak or an error code, were resolved quickly. It's important to note that these positive responses may reflect on the project implementation more than on the reliability of the equipment, since two HPWH required warranty repair or replacement within the first four months of installation. This is a high failure rate given the short monitoring period. Furthermore, the manufacturer warranty presents a challenge to the site and contractor due to what contractors perceive as a lack of sufficient reimbursement for labor to replace the equipment. Other warranty challenges include potential ineligibility for the manufacturer's warranty since the equipment is not intended for use in commercial buildings, even at such low uses.

The main recurring complaint was that hot water could take longer to reach the faucet at some sites. However, this reflects the inherent limitation of central water heating systems without recirculation, rather than a performance problem with the HPWH itself. Most customers did not closely track their energy bills or consumption, so they were unable to provide clear feedback on cost savings. The fact that bills did not stand out to them, combined with the absence of cost-related complaints, suggests that operating costs were not perceived as problematic.

Reviews were mostly positive overall, but one customer captured the adoption calculus particularly well, stating, "I like the idea of the technology and feel it has the potential to save money but with the limited amount of hot water we use it is hard to say if it is worthwhile for our business."

Across the five sites, installation cost and time data show a consistent pattern: 120 V HPWHs sit between gas-fired tank heaters and 240 V HPWHs. At the two sites with direct contractor survey responses, 120 V HPWHs took 2–3 hours longer to install than a gas-fired tank heater, but two to 10 hours less than a 240 V HPWH, largely because they avoided panel upgrades. In terms of cost, 120 V HPWHs were $2,000 to $3,000 more expensive than gas-fired tanks, but $2,000 to $10,000 less expensive than 240 V HPWHs.

For the remaining sites, the team combined site-specific quotes and market data to construct a consistent comparison. Using published cost ranges for gas equipment (about $3,500 for an 80-gallon tank, $1,000 for permits, and $1,250 for gas/water line work, or roughly $5,750 total), and contractor quotes for 120 V and 240 V HPWHs, the same pattern emerged: 240 V HPWHs were the highest-cost option (with 240 V units $1,950–$4,200 more than 120 V HPWHs before adding an

assumed $4,000 panel upgrade), gas-fired tanks were the lowest-cost option, and 120 V HPWHs fell in the middle. At Sites 3–5, 120 V HPWHs were $2,600–$4,200 less than 240 V HPWHs (before panel upgrades) but $15,200–$19,900 more than the assumed gas baseline. These estimates are directional rather than precise, and they reflect the fact that the utility is limited to highly certified ISN contractors; in particular, one contractor was relatively risk-averse and less experienced with 120 V HPWHs and appears to have factored that uncertainty into their pricing. Even so, the consistent pattern across sites suggests that 120 V HPWHs can be a cost-effective electrification option compared to 240 V HPWHs, while still carrying a cost premium relative to gas-fired tank heaters.

Additional electrical or plumbing work was minimal and did not affect feasibility. One site required about $300 of plumbing work, and another needed only a simple electrical modification (adding a plug). The main challenges were process and logistics rather than technical barriers: multiple quote iterations and change orders due to uncertainty about 120 V performance and permitting requirements, confusion and delays around permit costs and responsibilities, and one case where the contractor arrived with the wrong equipment (240 V instead of 120 V), causing a one-month delay. These issues were driven by contractor familiarity, internal processes, and permitting practices, not by the 120 V HPWH technology itself. For any future emergency-replacement offering, the program will need to address these soft barriers directly: training contractors on 120 V HPWH applications and sizing (and compensating them at fair market value for that training), providing clear references and a support hotline, and ensuring product availability by working with distributors, potentially including pre-purchasing units and directing trade allies to reliable stocking locations. Contractors also need simple sizing tools they trust so they can quickly determine whether a 120 V HPWH will maintain hot water demand at a given site. Without that confidence, they are likely to price in risk or default to familiar gas or 240 V options, undermining the speed and reliability required in true emergency replacement scenarios.

Key Findings

The field demonstration of 120 V plug-in HPWHs in commercial settings has surfaced a range of operational, technical, and customer-related insights. While much of the early work focused on overcoming deployment barriers, data from the initial installations has begun to illustrate the feasibility of using 120 V HPWHs in light commercial applications. The following findings summarize lessons learned to date and emerging themes that will inform final analysis and recommendations.

Overall, the field experience suggests that 120 V HPWHs are an option for the right subset of small and medium businesses that need reliable hot water, want to avoid panel upgrades, and place value on efficiency and decarbonization.

COP is low at low uses where we were confident the HPWH would work. This ties into the problem with sizing methods that seem to overstate water use.

1. **Overly conservative sizing methods and contractor perceptions cause misalignment between calculated loads and equipment capabilities, given the modest hot water loads observed in SMBs.**

The project team selected sites where we had high confidence that a 120 V HPWH would meet the load, based on traditional prescriptive American Society of Heating, Refrigerating, and Air-Conditioning (ASHRAE) sizing methods, more advanced sizing approaches, and consultation with the installing contractor and their equipment suppliers. These methods, and contractor perceptions, predicted that several sites would be undersized or would barely have their loads met by a 120 V HPWH. Metered data, however, show that many SMB sites have relatively modest and intermittent hot water demand, typically limited to handwashing and periodic cleaning, and that actual usage at the demonstration sites was much lower than expected. In practice, the HPWHs were appropriately sized from a capacity standpoint, but the low and sporadic usage resulted in low equipment COPs due to shell losses and cycling. The sites we targeted are, in many cases, more appropriate for distributed point-of-use electric resistance water heating based on low and sporadic usage and very low observed equipment COPs. This points to a gap in sizing methods that needs to be addressed to enable 120 V HPWHs at sites with higher actual use, as well as a need for further demonstration at larger SMB facilities where centralized HPWHs may be a better fit.

2. **Low use applications are not suited for centralized water heating systems, and 120 V HPWH cannot solve this problem.**

   The survey results indicate that several facilities didn't receive hot water at the fixtures, due to how distant the fixtures are from the water heater. One customer captured the adoption calculus particularly well, stating, "I like the idea of the technology and feel it has the potential to save money but with the limited amount of hot water we use it is hard to say if it is worthwhile for our business." This ties into the first key finding and suggests that 120 V HPWHs are most compelling for sites with meaningful or concentrated hot water loads where the points of use are also close to the water heater. The results underscore the importance of considering the hot water system as a whole; in many SMB facilities, centralized water heating leads to poor energy performance and poor hot water delivery performance. These sites would be better served by ER POU heating.

3. **Recirculation systems have complex screening criteria in existing buildings, with major implications for performance.**

   The project team screened out sites with recirculation systems because they add significant complexity and risk for 120 V HPWHs, which have low recovery rates. Because recirculation systems are often concealed, and the degree of insulation quality can be highly variable, it is challenging to accurately predict the heat loss in an existing recirculation system short of installing metering to observe the heat loss. Furthermore, common issues like crossover can further complicate the equation. As a result of this screening decision, the team observed that some sites did not receive hot water at the fixtures. The key implication is that retrofits that include new piping or significant tenant improvements, such as changes in occupancy that allow redesign of the distribution system, are more promising contexts for 120 V HPWHs than retrofits into legacy piping layouts with hidden recirculation and long runs.

4. **SMB deployment challenges and knowledge gaps highlight the need for targeted education and careful emergency program design.**

Site recruitment and survey results revealed that many SMBs do not view water heating as a priority and may be reluctant to switch to electric alternatives, particularly in the context of rising electricity prices. Even among interested sites, existing systems were often oversized, featured complex configurations like recirculation loops, or lacked the recovery capacity to support 120 V HPWHs. Site contacts frequently lacked detailed knowledge about their existing water heating systems, including sizing, usage patterns, delivery layout, and available electrical capacity, which complicated equipment selection and sizing. TRC developed project-specific tools to assess hot water demand, energy use, and GHG emissions, which proved essential for site engagement and helped reduce the risk of under-sizing.

Additional resources, such as recovery rate charts and interactive sizing guides, would further support successful installations and help bridge the gap between residential specifications and commercial needs. Importantly, participants were willing to move forward with 120 V HPWH retrofits when offered at no upfront cost, even when modeled operating costs were slightly higher than baseline, indicating that SMB customers may accept small operating cost increases in exchange for avoided capital costs and clear environmental benefits. At the same time, the project encountered contractual and administrative requirements, such as site access agreements, municipal approvals, and internal procurement processes, that were difficult to navigate in a timely manner, along with installation-related hiccups (for example, door replacements to move equipment, verifying that units could be installed on shared circuits, and confusion around permitting requirements).

One site experienced a one-month delay when the contractor arrived with the wrong equipment (240 V instead of 120 V). These issues were driven by contractor familiarity, internal processes, and permitting practices, not by the 120 V HPWH technology itself. Any utility program that frames 120 V HPWHs as a fast-track emergency replacement option must design around these real-world barriers by training contractors on 120 V HPWH applications and sizing (and compensating them at fair market value for that training), providing clear references and a support hotline, and ensuring product availability through reliable distributors and pre-purchased stock.

5. **Manufacturer data gaps on recovery rates and performance conditions limit measure development and confidence in 120 V HPWHs.**

   A particularly critical gap is the lack of published recovery rate data from manufacturers. Current product literature is geared toward residential installations, where first hour rating is more relevant, but this is insufficient for commercial use cases that rely on understanding sustained hot water delivery. Further, there is limited published performance data across different ambient and inlet air conditions, which are essential to accurately model energy savings and reliability in real-world commercial installations. For broader market acceptance, manufacturers must make these datasets readily available. In the interim, program administrators should plan for independent field metering at a subset of sites and support future projects that develop and validate sizing and impact calculators using real SMB data.

6. **Customer feedback highlights perception gap and value proposition.**

Customer surveys revealed that customers were generally satisfied with their existing hot water systems, even when those systems were aging or underperforming or nonexistent and serving non-critical equipment. None had a clear understanding of energy use or efficiency, and some expressed interest in features like improved consistency, lower utility bills, and app-based controls. These findings, though unrelated to HPWH experience directly, suggest a need to reframe the HPWH value proposition around tangible benefits such as performance reliability, energy savings, and app-based controls. However, a key concern for future sites may be the reduction in manufacturer warranty coverage when 120 V HPWHs are used in commercial settings. Since these units are technically categorized as residential products, their warranties typically drop from 10 years to just 1 year in commercial applications despite the much lower use with no recirculation than residential applications. This issue may limit uptake unless programs can provide extended warranty coverage or negotiate support from manufacturers to close the gap.

7. **Competitive installation costs and simpler electrical requirements strengthen 120 V HPWHs' fit relative to 240 V HPWHs.**

Installation data from the first two sites and cost comparisons at Sites 3–5 indicate that 120 V HPWHs offer a simpler and more cost-effective path to electrification than 240 V alternatives. The units required no electrical panel upgrades or extensive wiring work, and installation was relatively fast and low-disruption. Across sites, 240 V HPWHs were consistently the highest-cost option, gas-fired tank water heaters were the lowest-cost option, and 120 V HPWHs fell in the middle. Under the assumptions used, 120 V HPWHs were several thousand dollars less expensive than 240 V HPWHs (especially once panel upgrades were considered) but carried a noticeable first-cost premium relative to gas-fired tanks. These attributes, combined with compatibility with standard outlets, make 120 V HPWHs particularly attractive in retrofit scenarios where panel upgrades are infeasible or cost-prohibitive, and support future positioning as a minimally invasive electrification option, provided that programs account for the cost premium relative to gas and target sites where decarbonization benefits are valued.

Overall, 120 V HPWHs can meet SMB hot water needs in the right contexts, but success depends on site selection, distribution design, and program support. Together, the field results show that 120 V plug-in HPWHs can reliably meet hot water needs in many SMB applications, particularly where loads are modest but meaningful, fixtures are reasonably close to the water heater, and panel upgrades are difficult or undesirable. At the same time, low-use, dispersed-fixture applications, complex recirculation systems, and limited warranty coverage pose significant challenges. The demonstration highlights that measure success will depend on careful site selection, attention to distribution system design (including whether recirculation, heat trace, or ER point-of-use solutions are needed), and strong program support for contractors and customers. With these elements in place, 120 V HPWHs can serve as a viable emergency replacement and decarbonization measure for a targeted subset of SMBs; without them, the technology risks being misapplied in contexts where centralized water heating is inherently inefficient and customer value is limited.

Stakeholder Feedback

Throughout the project, the project team coordinated with a range of stakeholders to guide site selection, installation planning, and outreach strategies. These stakeholders included our primary installation contractors, other trade allies, SDG&E's CEMS program staff, heat pump water heater manufacturers, and non-governmental organizations focused on small business engagement.

Our coordination took place through a mix of email and phone communication, with the frequency varying by stakeholder. The project team engaged contractors most regularly, particularly during installation planning and site-level troubleshooting. Communication with other stakeholders occurred on an as-needed basis, depending on the project phase.

Stakeholder feedback played a central role in shaping our field deployment strategy. Contractors and CEMS staff noted that many of their customer sites used larger water heating systems with significant hot water demand and often included recirculation loops—configurations that fall outside the capabilities of 120 V plug-in HPWHs. This feedback helped us sharpen our screening criteria and underscored the need for tools to assess site suitability.

Non-governmental organizations provided helpful introductions to small and medium businesses, though they were generally less familiar with the technical or operational characteristics of water heating systems, limiting their influence on equipment decision-making. Manufacturer coordination proved to be challenging; despite signing a non-disclosure agreement with one manufacturer, the project team was ultimately unable to obtain the performance data targeted for use. Both manufacturers eventually disengaged, prompting us to shift to a more robust field metering approach.

These coordination efforts, though sometimes constrained, provided valuable insights into market barriers and real-world implementation issues. They also highlighted the need for clearer performance data from manufacturers and stronger collaboration pathways between technical decision-makers and small business advocates.

Recommendations

This field study shows that 120 V plug-in HPWHs can reliably serve many small and medium business hot water loads, but only when applied in the right contexts and with appropriate program support. The recommendations below synthesize the technical, programmatic, and market lessons from the demonstration and are intended to inform measure readiness, program design pathways, and market transformation efforts in California.

1. Develop modern sizing and screening tools for SMB applications.

A central finding from this study is that existing sizing tools substantially overestimated hot water needs at the participating sites. The SMBs in the sample had modest, intermittent hot water loads dominated by handwashing, employee breakroom, and light janitorial use, yet conventional tools, largely adapted from residential or large commercial contexts, suggested much larger systems than

were actually required. At the same time, contractors and sites expressed concern about under-sizing and recovery capacity, particularly for sites with occasional higher-than-average peak draws.

To address this, future programs should support the development of a simple, standardized sizing and screening tool specifically tailored to 120 V plug-in HPWHs in SMB settings. This tool should be grounded in measured draw profiles from this and similar field studies and should distinguish between common SMB use cases (for example, handwashing-only, breakroom plus janitorial, or light breakroom usage). It should also incorporate a screening step that flags sites with very low loads, where standby losses are likely to dominate and savings are limited, and sites with high or highly peaky loads, where 120 V HPWHs may not be appropriate without additional backup.

The sizing and screening tool should be developed in coordination with industry stakeholders and integrated into measure development and workpaper processes. Doing so would modernize sizing practices, reduce oversizing and under-sizing risk, and give contractors and program staff a practical steppingstone for assessing 120 V HPWH suitability in SMB applications.

2. **Target appropriate sites and address distribution system losses.**

The field results indicate that 120 V HPWHs can align with low-to-moderate hot water loads, but that distribution system design can make or break overall performance. In several sites, equipment-level COP gains were offset by high distribution losses. In some cases, this led to both reduced efficiency and inadequate hot water delivery at remote fixtures.

Early program deployments should therefore focus on SMBs with low-to-moderate hot water demand, no recirculation, and the ability to locate the HPWH close to the primary fixtures. Conversely, sites with extensive recirculation loops or long, uninsulated distribution runs should either be deprioritized or subjected to additional design review, as the combination of 120 V HPWHs and conventional recirculation can erode savings and compromise performance.

Where recirculation is currently used to maintain hot water at remote fixtures, simply removing the loop is not always acceptable, as it can lead to long wait times and user dissatisfaction. At the same time, maintaining a traditional recirculation loop with a 120 V HPWH increases distribution losses, reduces effective COP, and disrupts tank stratification. Future program design and research should therefore evaluate alternatives such as heat trace systems and advanced recirculation controls. Heat trace, which activates based on pipe temperature rather than continuous flow, has the potential to reduce both distribution losses and destratification, improving overall system COP while maintaining acceptable delivery times. Demand-controlled or schedule-based recirculation may also offer benefits, although any such approach must be evaluated against ASHRAE Guideline 12 and other health and safety guidance.

For very remote or rarely used fixtures, ER POU water heaters may be a more practical solution than extending central HPWH distribution or installing multiple small HPWHs. A hybrid approach, central 120 V HPWH for primary loads, supplemented by ER POU units at outlying fixtures, could reduce both first cost and complexity while preserving user experience. This study suggests that relying solely on a central HPWH without recirculation is often insufficient for dispersed fixtures, yet maintaining

conventional recirculation undermines performance; hybrid strategies and alternative distribution concepts will be critical to resolving this tension.

3. Refine program design for emergency replacement and direct install offerings.

One of the study's core questions was whether 120 V plug-in HPWHs can serve as a viable emergency replacement option for SMBs. Technically, the units are well suited to this role: they plug into standard outlets, avoid panel upgrades, and can be installed relatively quickly. However, the field experience revealed that contractual and administrative requirements, such as site access agreements, municipal approvals, and internal procurement processes, can significantly delay installation. These barriers are not technical, but they are real and recurring in commercial settings.

Programs that position 120 V HPWHs as fast-track replacements need to design around these real-world constraints. This includes streamlining contracting and approvals through standardized agreements, pre-negotiated templates, and clear guidance for municipal permitting. It also means aligning program timelines with realistic field conditions, recognizing that same-day or next-day replacements may only be feasible in certain customer segments or building types where administrative hurdles are minimal.

The study also found that participants were willing to move forward with 120 V HPWH retrofits when they were offered at no upfront cost, even when modeled operating costs were slightly higher than the baseline. This suggests that SMB customers may accept small operating cost increases if capital costs are fully or largely covered and if environmental and decarbonization benefits are clearly communicated. For program design, this points toward direct install and hard-to-reach offerings where the program bears most of the capital cost and positions the HPWH as a low-disruption, no-upfront-cost electrification option. In these cases, the value proposition should emphasize reliability, decarbonization, and future-proofing, rather than immediate bill savings alone.

4. Strengthen tools, data, and manufacturer engagement for measure development.

One of the study's objectives was to generate field data that could inform future measure development and eventual inclusion of 120 V HPWHs in the California eTRM. The results highlight both the value of decision-support tools and the current gaps in available data.

During this project, the team used simple, project-specific calculations to estimate hot water demand, energy use, and greenhouse gas impacts for candidate sites. These were limited internal tools rather than fully developed program resources, but they proved useful for framing the value proposition with customers and contractors and for reducing the risk of under-sizing. The field data collected in this study provide a foundation for a future effort to formalize such tools.

A logical next step is a follow-on project focused on developing and validating screening and sizing tools, particularly a bill and GHG impact calculator and screening/sizing aid, for broader program use. That future project could:

- Use the metered draw profiles and performance data from this study as seed datasets.

- Expand the tool to cover a wider range of SMB archetypes and rate structures.
- Package the outputs in a form suitable for Cal TF, IOUs, and other utilities to use in measure development, workpapers, and customer-facing decision support.

In parallel, this study underscores the need for stronger data support from manufacturers. The project initially anticipated relying on in-unit "smart" data, but key performance metrics, such as hot water draws, standby losses, and heat pump operation cycles, were not made available in a form suitable for measure development. Recovery rate data and performance across ambient and inlet conditions were similarly limited, with most product literature geared toward residential applications and first-hour ratings rather than sustained commercial delivery.

For early program phases, program administrators should plan for independent field metering at a subset of sites to validate savings assumptions and characterize performance under real-world conditions. At the same time, future program and measure development efforts should explicitly engage manufacturers to:

- Publish recovery rate data suitable for commercial use.
- Provide performance maps across relevant ambient and inlet water conditions.
- Clarify warranty terms for commercial applications of 120 V HPWHs.

These steps, combining future tool development, targeted field metering, and improved manufacturer data—will be important to support robust deemed savings values, transparent workpapers, and ultimately the inclusion of 120 V HPWHs as a well-defined measure in the eTRM.

5. **Address customer and contractor experience to enable scale.**

The field demonstration underscored that customer and contractor experience will be critical to scaling 120 V HPWH adoption. Many site contacts lacked detailed knowledge of their existing systems, including sizing, usage patterns, and available electrical capacity. Contractors were often uncertain about appropriate applications for 120 V HPWHs, concerned about recovery capacity, and unfamiliar with permitting and warranty implications for using residential-classified equipment in commercial settings.

Future programs should embed targeted education and support for both contractors and customers. This includes providing simple, visual tools, such as recovery rate charts, interactive sizing guides, and bill/GHG calculators, to help contractors quickly assess fit and to support customer conversations about tradeoffs and benefits. Training should emphasize appropriate site selection (including load magnitude, recirculation, and distribution considerations), installation best practices (location, ventilation, condensate management, and controls), and the implications of using residential-rated equipment in commercial applications.

Warranty coverage is a particular concern. Because many 120 V HPWHs are marketed as residential products, warranty coverage often drops from ten years to one year when used in commercial settings. This can be a significant barrier for SMB adoption. Programs should work with manufacturers to clarify warranty terms and explore extended warranty options for program participants. Where manufacturer support is limited, programs may need to consider program-funded warranty extensions or service agreements, especially in early deployments, to build market confidence.

6. Measure readiness and program pathways.

Taken together, the field results suggest that 120 V HPWHs are technically feasible and can perform well in low-to-moderate load SMB applications without complex recirculation, but that their cost-effectiveness relative to gas baselines is highly context-dependent. They offer meaningful first-cost advantages over 240 V HPWHs by avoiding panel upgrades and simplifying installation, yet they remain more expensive than conventional gas-fired tank heaters and may not always deliver operating cost savings under current rate structures.

From a measure readiness perspective, 120 V HPWHs should be positioned as a targeted measure in the eTRM rather than a universal replacement for all commercial water heating. Applicability conditions should be clearly documented, including load magnitude, distribution system characteristics, electrical capacity, and ambient conditions. The data from this study can support initial deemed savings values and workpapers, with the understanding that additional metering and refinement will be needed as programs scale.

Once adopted into the eTRM, 120 V HPWH measures can be used by utilities to serve hard-to-reach and disadvantaged community customers through direct install and same-day installation offerings, particularly where panel upgrades are infeasible or cost-prohibitive. In these contexts, 120 V HPWHs offer a practical, minimally invasive path to electrification and decarbonization, provided that programs carefully screen sites, support contractors, and address the distribution and warranty challenges identified in this study.

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Appendix A Survey 1: Site Pre-Screener

Taken by customers on the flyer

1. Please provide your business name, address, phone number and email below.
    - Business name:
    - Address:
    - Phone number:
    - Email:

2. How old is your existing water heater? (in years) [OPEN END]

3. Please provide a photo of your existing hot water system.
4. Please provide a photo of your hot water system nameplate.
5. Please provide a photo of your hot water system location.

6. Is the room where the water heater is stationed at least 70 sqft?
    - Yes
    - No

7. Please provide a copy of your recent electric bill.
8. Please provide a copy of your recent gas bill.

9. Does your company have any climate, electrification or decarbonization goals? If so, please explain.
    - Yes [OPEN END]
    - No

10. Are you satisfied with the hot water delivery of your current water heater?
    - I am satisfied with my hot water delivery.

- I am neither satisfied nor dissatisfied with my hot water delivery.
- I am dissatisfied with my hot water delivery. Please explain why: [OPEN END]

11. Do you ever run out of hot water?
    - Only during winter months
    - Throughout the year
    - Never

Appendix B Survey 2: Customer Pre-Installation Satisfaction

1. Please provide your contact name and business name below.

- Contact name: _____
- Business name: _____

2. On a scale of 1 to 5, how satisfied are you with the performance of your previous water heater?

- 1 - Extremely dissatisfied
- 2 - Somewhat dissatisfied
- 3 - Neither satisfied nor dissatisfied
- 4 - Somewhat satisfied
- 5 - Extremely satisfied

3. Why did you rate the performance of your previous water heater as above? [OPEN END]

4. What issues, if any, have you experienced with your previous water heater? [ALLOW MULTIPLE]

- Insufficient hot water
- Slow heating
- High energy bills
- Other, please specify: [OPEN END]
- None [EXCLUSIVE]

5. How satisfied are you with the time it takes for your previous water heater to deliver hot water after turning on the tap?

- 1 - Extremely dissatisfied
- 2 - Somewhat dissatisfied
- 3 - Neither satisfied nor dissatisfied
- 4 - Somewhat satisfied

- 5 - Extremely satisfied

6. Did you experience any fluctuations in water temperature during usage?

- Only during winter months
- Throughout the year
- Never
- DK

7. How often do you need to perform maintenance on your previous water heater?

- Multiple times a year
- Once a year
- Once every 2-3 years
- Once every 3-5 years
- Once every 5+ years
- Never
- I don’t know

8. Have you experienced any breakdowns or failures of your previous water heater in the past year?

- Yes
- No
- I don’t know

9. How aware are you of the energy consumption of your previous water heater?

- Not aware at all
- Slightly aware
- Moderately aware
- Very aware
- Extremely aware

10. How important is energy efficiency to you in a water heater?

- Not at all important
- Slightly important
- Moderately important
- Very important
- Extremely important

11. How important are carbon emissions to you in a water heater?

- Not at all important
- Slightly important
- Moderately important
- Very important
- Extremely important

12. Regarding energy bills, how would you rate the cost of operating your previous water heater?

- Extremely unreasonable
- Somewhat unreasonable
- Neither reasonable nor unreasonable
- Somewhat reasonable
- Extremely reasonable

13. Regarding maintenance costs, how would you rate the cost of operating your previous water heater?

- Extremely unreasonable
- Somewhat unreasonable
- Neither reasonable nor unreasonable
- Somewhat reasonable
- Extremely reasonable

14. Are you looking for a water heater that will reduce your overall costs?

- Yes
- No
- Indifferent

15. What improvements do you hope to see with your new 120 V heat pump water heater? [ALLOW MULTIPLE]

- More consistent hot water delivery
- Lower energy bills
- Lower maintenance cost
- Other, please specify: [OPEN END]
- I don't know

16. Are there any specific features or benefits you are looking forward to? [ALLOW MULTIPLE]

- Wi-Fi enabled
- Smart phone application
- Ability to participate in demand response events
- Other, please specify: [OPEN END]
- I don't know

Appendix C Survey 3: Pre-Installation Site Screening Walk-Through (Completed by contractor)

1. How many hot water fixtures are served by this water heater?
    - 1
    - 2-4
    - 5-10
    - 10+

2. Please provide photos of each fixture served by the water heater (e.g., sinks, showers, dishwashers). [MAXIMUM 15 PHOTOS]

3. What are the primary uses of hot water besides washing hands served by this water heater? [ALLOW MULTIPLE]
    - Showers
    - Dishwashing
    - Laundry
    - Other [OPEN END]

[ASK Q4 – Q6 IF Q3 = SHOWERS]

4. How is this shower used throughout the year? [OPEN END]

5. How many times is this shower used per day?
    - Multiple times a day
    - Once a day
    - Less than once a day

6. How many minutes is this shower used per day?
    - 5 minutes or less

- 5 to 10 minutes
- 10 to 20 minutes

7. What is the material of the pipes connected to the current water heater?
    - Copper
    - CPVC (Chlorinated polyvinyl chloride)
    - PEX (cross-linked polyethylene)
    - Corrugated Stainless-Steel (CSST)
    - Steel pipe

8. What is the diameter of the cold-water pipe connected to the current water heater? (in inches)
    - 3/8”
    - ½”
    - ¾”
    - 1”
    - Greater than 1” (please specify): [OPEN END]

9. Please provide several photos of the existing plumbing layout so we can confirm the metering solution will work with our flow and temperature meters (i.e. length of straight pipe).
    - Please attach a photo of the hot water and cold-water intake supply.
    - Please provide the length of straight pipe of hot water before the pipe branches out (in inches). [OPEN END]
    - Please provide the length of straight pipe of cold water before the pipe branches out (in inches). [OPEN END]

10. Is there a check valve and/or expansion tank serving the existing system?
    - Both
    - Check valve only
    - Expansion tank only

- None

11. Are the pipes insulated?
    - No
    - Yes, partial/some
    - Yes, well insulated

12. What is the volume of the room where the water heater is located?
    - Equal to or greater than 700 cubic feet
    - Less than 700 cubic feet

[ASK Q13 IF Q12 = LESS THAN 700 CUBIC FEET]

13. Please provide photo of any sidewall ventilation with dimensions.

14. Please provide a photo of the wall outlet for the current water heater.

15. What are the amps of the circuit that serves the water heater?
    - 15
    - 20
    - Other, (please specify): [OPEN END]

16. What other appliances share the circuit with the water heater?
    - [OPEN END]
    - None

17. Is there an existing drain available near the water heater?
    - Yes
    - No
    - Not existing, but can be easily added

Appendix D Survey 4: Installation Experience and Cost Survey

18. Please provide your contact name and name of the site for which you installed the 120 V heat pump water heater for.

- Contact name: _____
- Site name: _____

19. How long did it take to install the 120 V plug-in heat pump water heater (in minutes)? Please exclude travel time. [NUMERIC OPEN END]

20. Was any additional electrical work required? If yes, please estimate the cost:

- [NUMERIC OPEN END]
- There was no additional cost for electrical work.

21. Was any additional plumbing work required? If yes, please estimate the cost:

- [NUMERIC OPEN END]
- There was no additional cost for plumbing work.

22. If the final invoice significantly changed from the initial quote received, please upload an updated itemized invoice for parts and labor.

- [OPTIONAL FILE UPLOAD]
- The final invoice reflected the original quote received.

23. In the next series of questions, we are going to ask you to compare installation time and cost between 120 V heat pump water heaters and 240 V heat pump water heaters.

a. How does the installation time compare to a 240 V heat pump water heater?

- Installation time is shorter than a 240 V heat pump water heater
- Installation time is longer than a 240 V heat pump water heater
- Installation time is about the same as a 240 V heat pump water heater

[IF Q6a = 1]

a_1. How much shorter is the installation time of a 120 V heat pump water heater compared to a 240 V heat pump water heater (in hours)? [NUMERIC OPEN END]

[IF Q6a = 2]

a_2. How much longer is the installation time of a 120 V heat pump water heater compared to a 240 V heat pump water heater (in hours)? [NUMERIC OPEN END]

b. How does the installation cost compare to a **240 V heat pump water heater**?

- Installation cost is less than a 240 V heat pump water heater
- Installation cost is higher than a 240 V heat pump water heater
- Installation cost is about the same as a 240 V heat pump water heater

[IF Q6b = 1]

b_1. How much cheaper is the installation of a 120 V heat pump water heater compared to a 240 V heat pump water heater? [NUMERIC OPEN END]

[IF Q6b = 2]

b_2. How much more expensive is the installation cost of a 120 V heat pump water heater compared to a 240 V heat pump water heater? [NUMERIC OPEN END]

24. In the next series of questions, we are going to ask you to compare installation time and cost between 120 V heat pump water heaters and conventional gas-fired tank water heaters.

a. How does the installation time compare to a conventional gas-fired tank water heater?

- Installation time is shorter than a conventional gas-fired tank water heater
- Installation time is longer than a conventional gas-fired tank water heater
- Installation time is about the same as a conventional gas-fired tank water heater

[IF Q7a = 1]

a_1. How much shorter is the installation time of a 120 V heat pump water heater compared to a conventional gas-fired tank water heater (in hours)? [NUMERIC OPEN END]

[IF Q7a = 2]

a_2. How much longer is the installation time of a 120 V heat pump water heater compared to a conventional gas-fired tank water heater (in hours)? [NUMERIC OPEN END]

b. How does the installation cost compare to a conventional gas-fired tank water heater?

- Installation cost is cheaper than a conventional gas-fired tank water heater
- Installation cost is more expensive than a conventional gas-fired tank water heater
- Installation cost is about the same as a conventional gas-fired tank water heater

[IF Q7b = 1]

b_1. How much cheaper is the installation cost of a 120 V heat pump water heater compared to a conventional gas-fired tank water heater? [NUMERIC OPEN END]

[IF Q7b = 2]

b_2. How much more expensive is the installation cost of a 120 V heat pump water heater compared to a conventional gas-fired tank water heater? [NUMERIC OPEN END]

25. Did you face any challenges throughout the installation process?

- Yes
- No

[ASK Q9 IF Q8 = YES]

26. What were the main challenges you faced during the installation of the 120 V heat pump water heater? *Select all that apply.* [ALLOW MULTIPLE]

- Preparing the quote
- Coordinating with the site team
- Coordinating with the metering team

- Physical installation of the water heater
- Managing overall project logistics
- Other (please specify): [OPEN END]

27. Please provide details on the challenges you selected in the previous question.

- Preparing the quote: [OPEN END]
- Coordinating with the site team: [OPEN END]
- Coordinating with the metering team: [OPEN END]
- Physical installation of the water heater: [OPEN END]
- Managing overall project logistics: [OPEN END]
- [PIPED ENTRY TEXT FROM Q9 for Other]: [OPEN END]

Appendix E Survey 5: 3-Month Post-Installation Customer Satisfaction

Intro. Please provide your contact name and business name below.

Contact Name: _____

Business Name: _____

1. Overall Satisfaction:

a. On a scale of 1 to 5, how satisfied are you with the performance of the 120 V heat pump water heater (HPWH) so far?

- 1 – Extremely dissatisfied
- 2 – Somewhat dissatisfied
- 3 – Neither satisfied nor dissatisfied
- 4 – Somewhat satisfied
- 5 – Extremely satisfied

b. Why did you rate your overall satisfaction with your heat pump water heater as above?

[OPEN END]

2. Performance:

a. How does the hot water availability compare to your previous water heater?

- Better, the new HPWH has more hot water available for use
- Worse, the new HPWH has less hot water available for use
- They both have the same level of performance
- I could not tell / Unsure

b. Have you noticed any changes in your energy bills?

- Yes, my energy bills have decreased
- Yes, my energy bills have increased
- No, my energy bills remained the same
- Not sure, I have not looked into my energy bills yet

3. Issues and Improvements:

a. Have you encountered any issues with the HPWH?

- Yes
- No

[IF 3a = YES]

b. What issues have you encountered with the HPWH?

[ALLOW MULTIPLE]

[RANDOMIZE]

- Water leaks
- Lack of hot water
- Inconsistent water temperature
- Long heating time to refill hot water tank
- Equipment malfunction
- Electrical overload
- Strange noises
- Weird odor
- Vibration
- Ambient temperature near the heat pump water heater
- Humidity near the heat pump water heater
- It takes too long for hot water to come out of the tap
- Other (please specify): [OPEN END]
- I have not encountered any issues [EXCLUSIVE]

[ASK 3b_2 IF 3b = It takes too long for hot water to come out of the tap]

b_2. Approximately, how many seconds does the faucet run before hot water is delivered?

[OPEN END]

c. What improvements, if any, would you suggest for the HPWH?

[ALLOW MULTIPLE]

[RANDOMIZE]

- Better electrical efficiency and power management
- Faster hot water heating time
- Smart features and grid integration
- Quieter noise

- Solar thermal or PV assist integration
- Other (please specify): [OPEN END]
- I am satisfied and have no suggestions for improvement [EXCLUSIVE]

4. Impact on Business:

a. How has the HPWH impacted your business operations? Please indicate the impact for the following factors.

[MATRIX]

COLUMNS:

- Positive
- Neutral
- Negative
- Not Applicable

ROWS:

- Monthly energy bills
- Operational productivity
- Corporate Environmental, Social and Governance (ESG) goals
- Managing energy use
- Level of maintenance required
- Water Heater Functionality and Accessibility
- Other (please specify): [OPEN END]

[IF POSITIVE OR NEGATIVE FOR EACH FACTOR]

- Please explain how the HPWH has impacted your monthly energy bills.
- Please explain how the HPWH has impacted your operational productivity.
- Please explain how the HPWH has impacted your corporate ESG goals.
- Please explain how the HPWH has impacted your management of energy use.
- Please explain how the HPWH has impacted the level of maintenance required.
- Please explain how the HPWH has impacted your equipment operability.
- Please explain how the HPWH has impacted your **<PIPED TEXT FROM OTHER>**.

5. Do you have any additional comments or suggestions regarding the HPWH?

[OPEN END]

Appendix F Survey 6: 8-Month Post-Installation Customer Satisfaction

Intro. Please provide your contact name and business name below.

Contact Name: _____

Business Name: _____

1. Overall Satisfaction:

a. On a scale of 1 to 5, how satisfied are you with the performance of the 120 V heat pump water heater (HPWH) after eight months of use?

- 1 – Extremely dissatisfied
- 2 – Somewhat dissatisfied
- 3 – Neither satisfied nor dissatisfied
- 4 – Somewhat satisfied
- 5 – Extremely satisfied

b. Why did you rate your overall satisfaction with your HPWH as above?

[OPEN END]

2. Long-Term Performance:

a. Has the performance of the HPWH been consistent over the past eight months?

- Yes, performance has been consistent
- No, performance has not been consistent

b. What issues have you encountered with the HPWH?

[ALLOW MULTIPLE]

[RANDOMIZE]

- Water leaks
- Lack of hot water
- Inconsistent water temperature
- Long heating time to refill hot water tank
- Equipment malfunction
- Electrical overload
- Strange noises
- Weird odor

- Vibration
- Ambient temperature near the heat pump water heater
- Humidity near the heat pump water heater
- It takes too long for hot water to come out of the tap
- Other (please specify): [OPEN END]
- I have not encountered any issues [EXCLUSIVE]

[ASK 2b_2 IF 2b = It takes too long for hot water to come out of the tap]

b_2. Approximately, how many seconds must the faucet run before hot water is delivered?

[OPEN END]

c. Have you noticed any long-term changes in monthly energy costs (i.e. total $ combined gas and electric bills)?

- My monthly energy costs (gas + electric) are lower
- My monthly energy costs (gas + electric) are the same
- My monthly energy costs (gas + electric) are higher
- I am unsure of changes to my energy costs (gas + electric)

c_2. How would you rate your satisfaction with the changes to your energy costs after the 120 V HPWH was installed?

- 1 – Extremely dissatisfied
- 2 – Somewhat dissatisfied
- 3 – Neither satisfied nor dissatisfied
- 4 – Somewhat satisfied
- 5 – Extremely satisfied

D_1 Have you noticed any long-term changes in monthly energy consumption (i.e. total kWh + total Therms billed)?

- My energy consumption (total kWh + total Therms) is lower
- My energy consumption (total kWh + total Therms) is the same
- My energy consumption (total kWh + total Therms) is higher
- I am unsure of changes to my energy consumption (total kWh + total Therms)

d_2. How would you rate your satisfaction with the changes to your energy consumption after the 120 V HPWH was installed?

- 1 – Extremely dissatisfied
- 2 – Somewhat dissatisfied
- 3 – Neither satisfied nor dissatisfied
- 4 – Somewhat satisfied
- 5 – Extremely satisfied

3. Reliability:

a. How would you rate your satisfaction with the reliability of the HPWH?

- 1 – Extremely dissatisfied
- 2 – Somewhat dissatisfied
- 3 – Neither satisfied nor dissatisfied
- 4 – Somewhat satisfied
- 5 – Extremely satisfied

[ASK 3b IF 3a = 4 or below]

b. Have there been any reliability issues with the HPWH?

- Yes, please specify: [OPEN END]
- No

4. Customer Support:

a. How satisfied are you with the support and service provided **after** the installation?

- 1 – Extremely dissatisfied
- 2 – Somewhat dissatisfied
- 3 – Neither satisfied nor dissatisfied
- 4 – Somewhat satisfied
- 5 – Extremely satisfied

5. Overall Impact:

a. Has the 120 V HPWH met your expectations and needs?

- Yes, it met my expectations and needs
- Yes, it even exceeded my expectations and needs
- No, it did not meet my expectations and needs

[ASK 5b IF 5a = NO]

b. Why did the 120 V HPWH not meet your organization's expectations and needs?

[OPEN END]

c. Would you recommend this technology to other businesses? Please explain your reasoning.

- Yes (please specify): [OPEN END]
- No (please specify): [OPEN END]

Appendix G Scatter plot of Raw HPWH Flow and Power for five sites

Figure 22 below shows the heat map of whole period by time of day, water use, and energy for Site 1 provides a high-level view of HPWH operation at the shopping center over the entire monitoring period. The heat map displays hot water use and HPWH energy use by hour of day, with color intensity indicating the magnitude of activity.

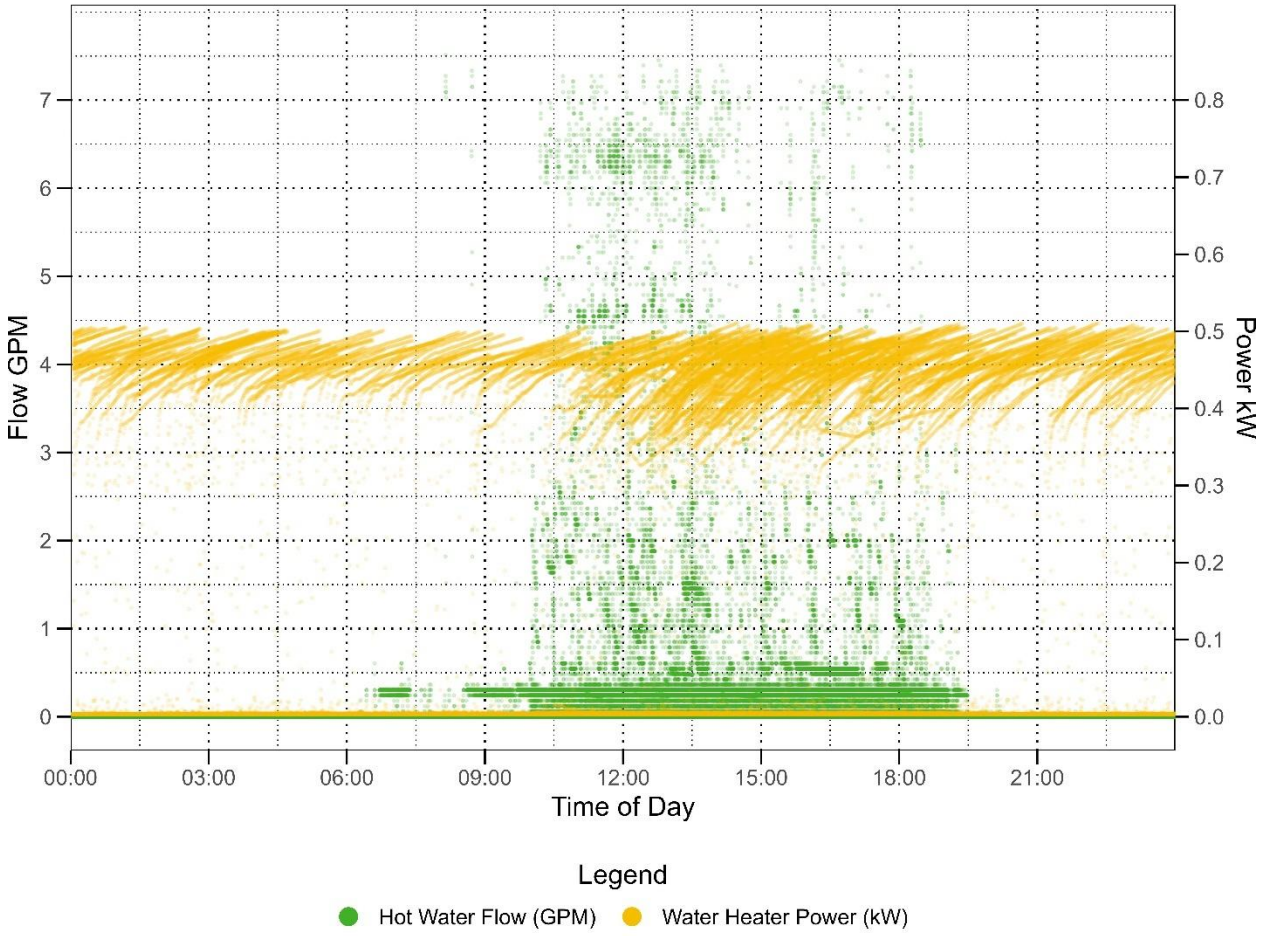


Figure 22: Site 1 heat map of whole period by time of day, water use and energy.

Figure 23 shows the heat map of the whole period by time of day, water use, and energy for Site 2 provides a high-level view of HPWH operation at the small office over the entire monitoring period. The heat map displays hot water use and HPWH energy use by hour of day, with color intensity indicating the magnitude of activity.

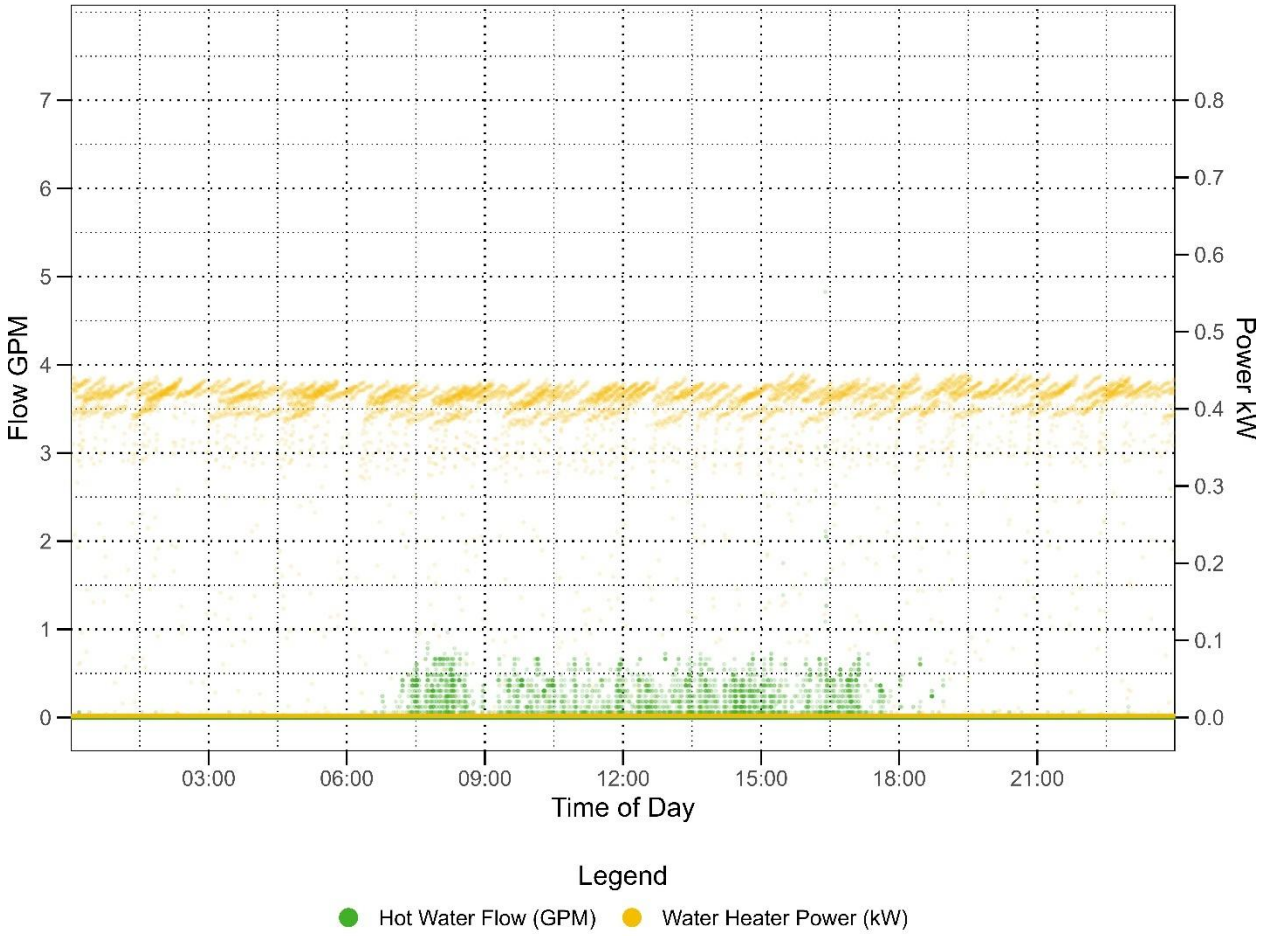


Figure 23: Site 2 heat map of whole period by time of day, water use and energy.

Figure 24 shows the heat map of whole period by time of day, water use, and energy for site 3 provides a high-level view of HPWH operation at the warehouse over the entire monitoring period. The heat map displays hot water use and HPWH energy use by hour of day, with color intensity indicating the magnitude of activity.

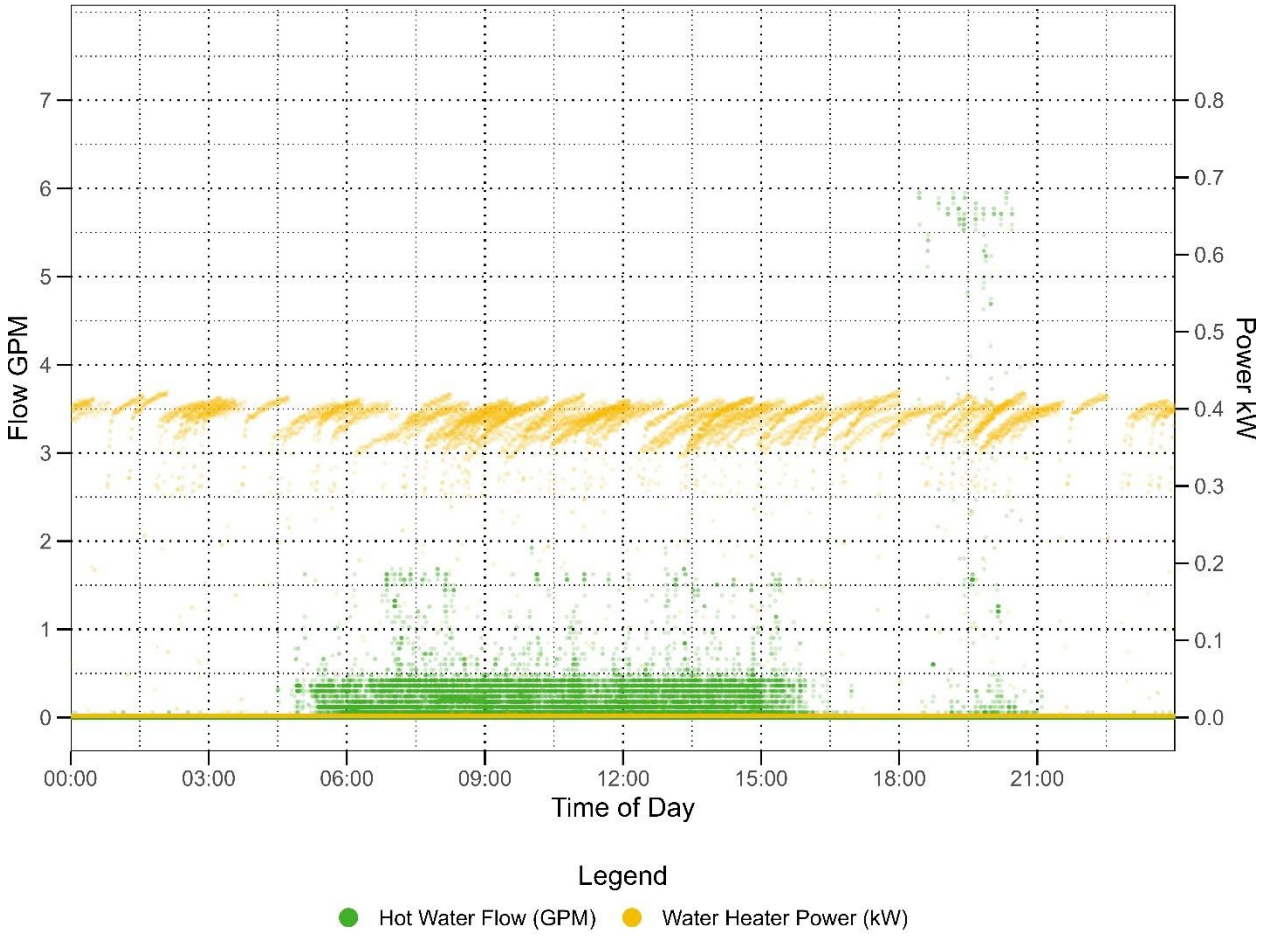


Figure 24: Site 3 heat map of whole period by time of day, water use, and energy.

In Figure 25 below, the heat map for Site 4 shows how hot water use and HPWH energy use vary by hour of day over the full monitoring period. Color intensity indicates the magnitude of activity.

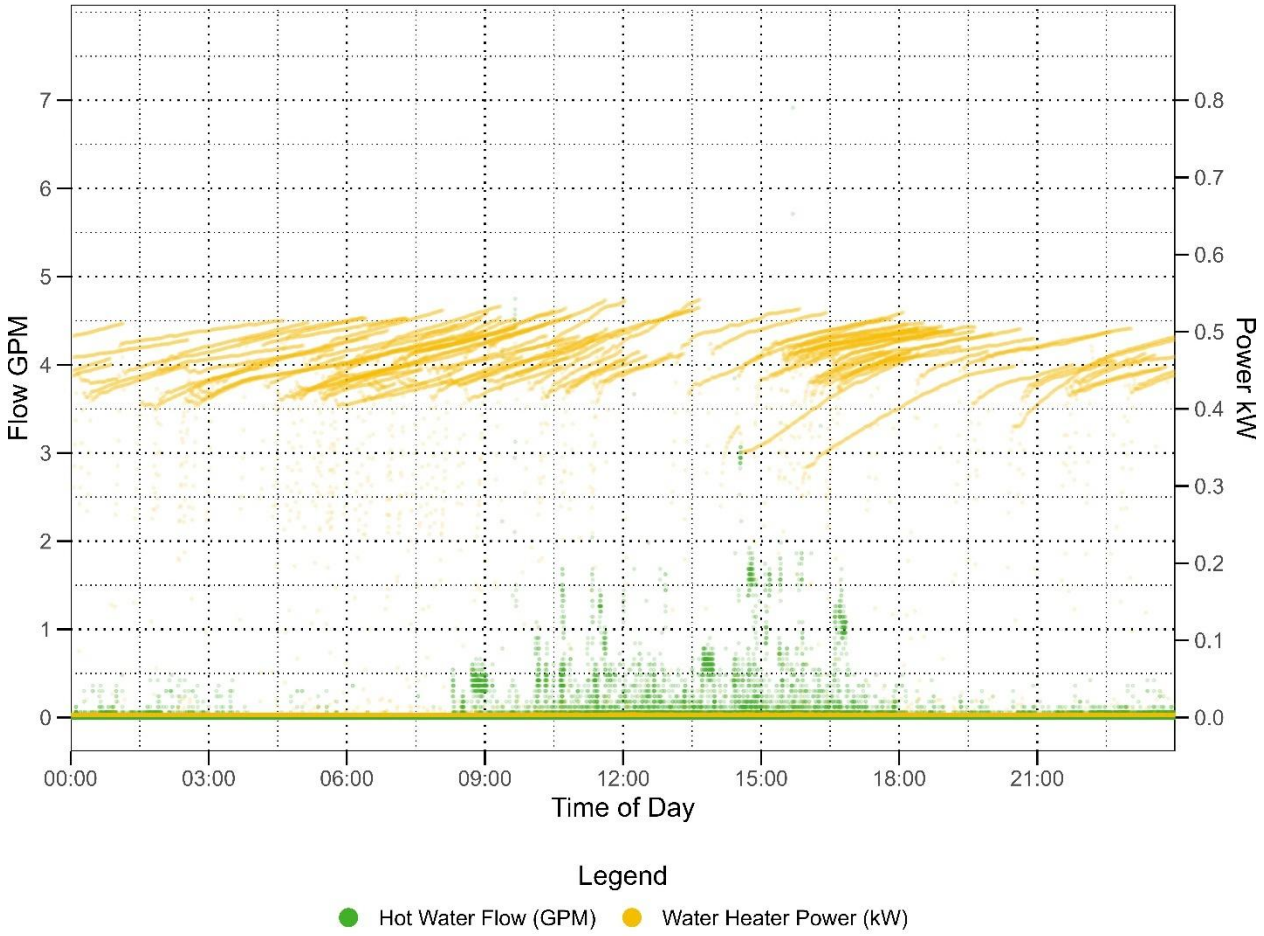


Figure 25: Site 4 heat map of whole period by time of day, water use, and energy.

In Figure 26 below, the heat map for Site 5 shows how hot water use and HPWH energy use vary by hour of day over the full monitoring period. Color intensity indicates the magnitude of activity, with separate legends for Hot Water Flow (GPM) and Water Heater Power (kW).

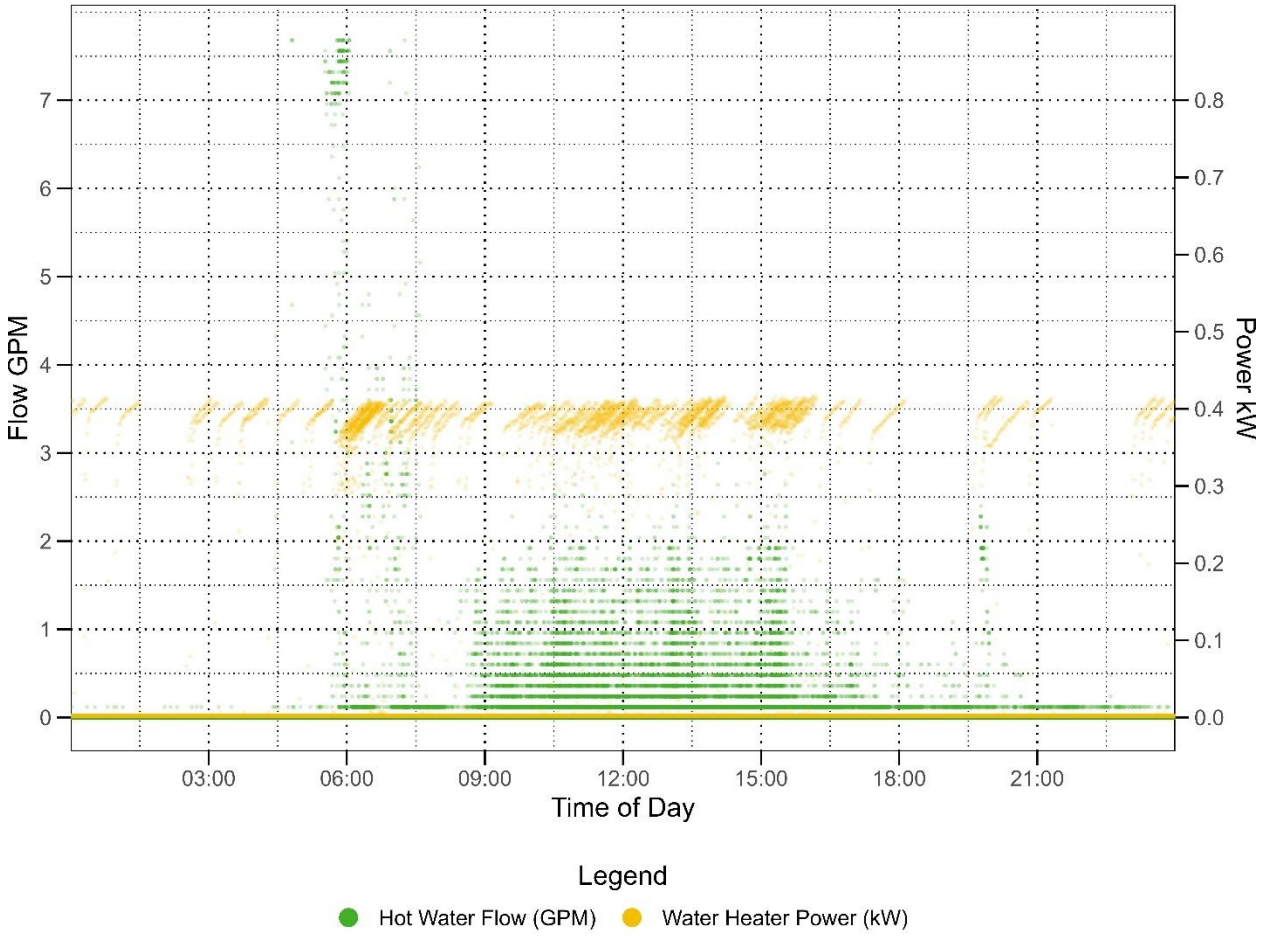


Figure 26: Site 5 heat map of whole period by time of day, water use, and energy.

Appendix H Line Plot of Representative Week and Day Data for Five Sites

Site 1

In Figure 27, the representative week plot (three days before and four days after median water use day) for Site 1 shows a seven-day window centered on the median water use day. This plot provides a more intuitive view of how daily hot water use and HPWH energy use vary over a typical week.

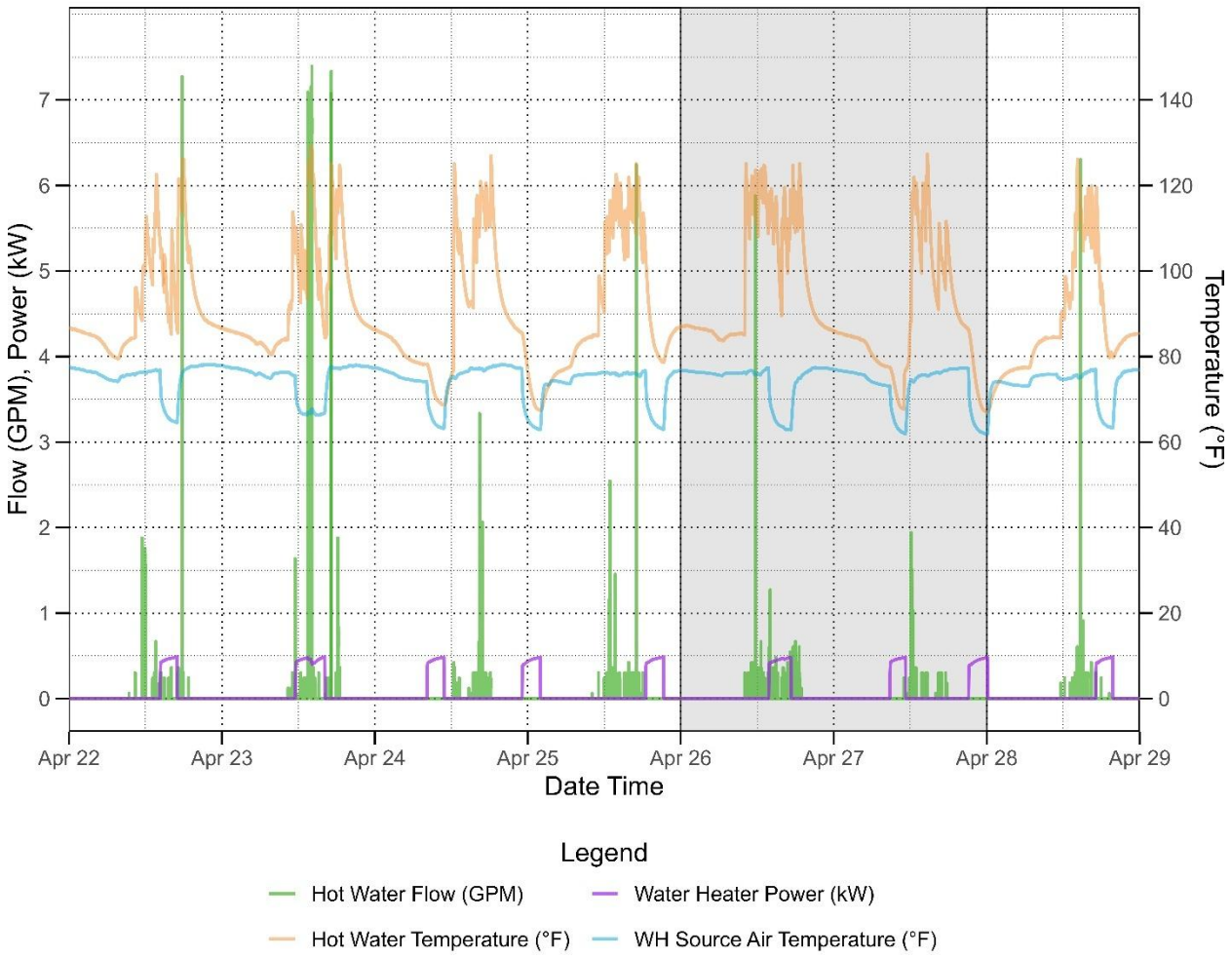


Figure 27: Site 1 representative week plot.

*Weekend days are shaded.

From the representative week plot shown in Figure 27:

- The median water use day sits within the week, with days before and after showing lower or higher use relative to that median, reflecting normal variation in shopping center activity.

- Weekend days in the representative week show higher hot water use and corresponding higher HPWH energy use, consistent with the weekend averages.
- Weekday days show more modest hot water use and lower HPWH energy use, with at least one day exhibiting relatively low use and energy dominated by standby.

This representative week illustrates the mix of low-use weekdays and moderate-use weekends that the HPWH must accommodate at Site 1.

In Figure 28, the representative day plot for Site 1 zooms in on the median water use day, showing hot water flow and HPWH power over a 24-hour period.

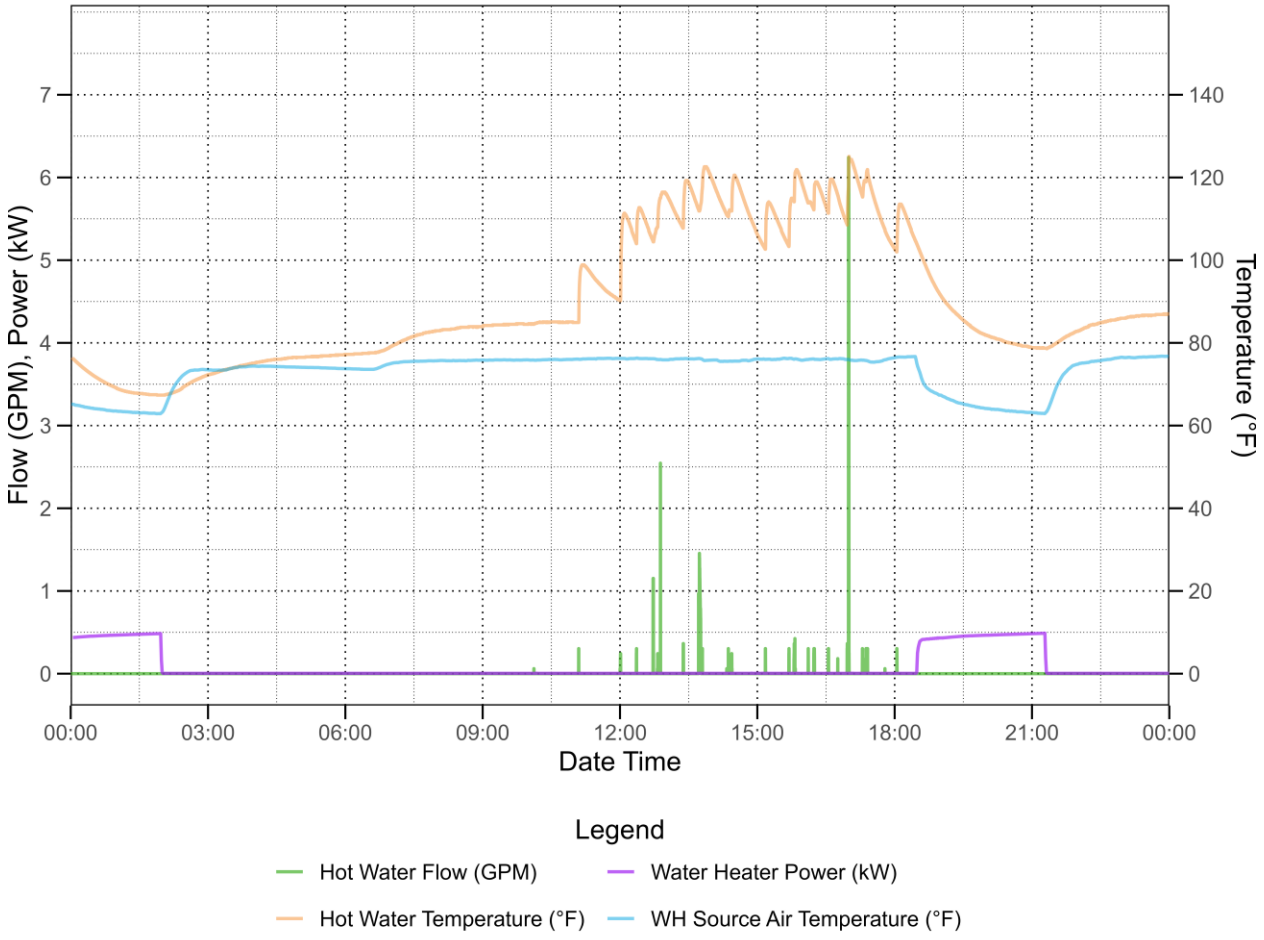


Figure 28: Site 1 representative day Saturday 4/25/26 (median water use day).

From the representative day (median water use) shown in Figure 28:

- Hot water draws occur in a series of discrete events, likely aligned with opening hours, peak customer periods, and end-of-day cleaning.
- HPWH power ramps up in response to these draws, with short periods of operation followed by longer idle periods between events.
- Outside of these draw events, HPWH power is present, indicating standby cycling on the median day.

This representative day confirms that the HPWH at Site 1 is primarily responding to a handful of daily draw events, with little continuous operation, consistent with the low daily water use.

Site 2

Shown in Figure 29, the representative week plot (three days before and four days after median water use day) for Site 2 shows a seven-day window centered on the median water use day. This plot provides an intuitive view of how daily hot water use and HPWH energy use vary over a typical week.

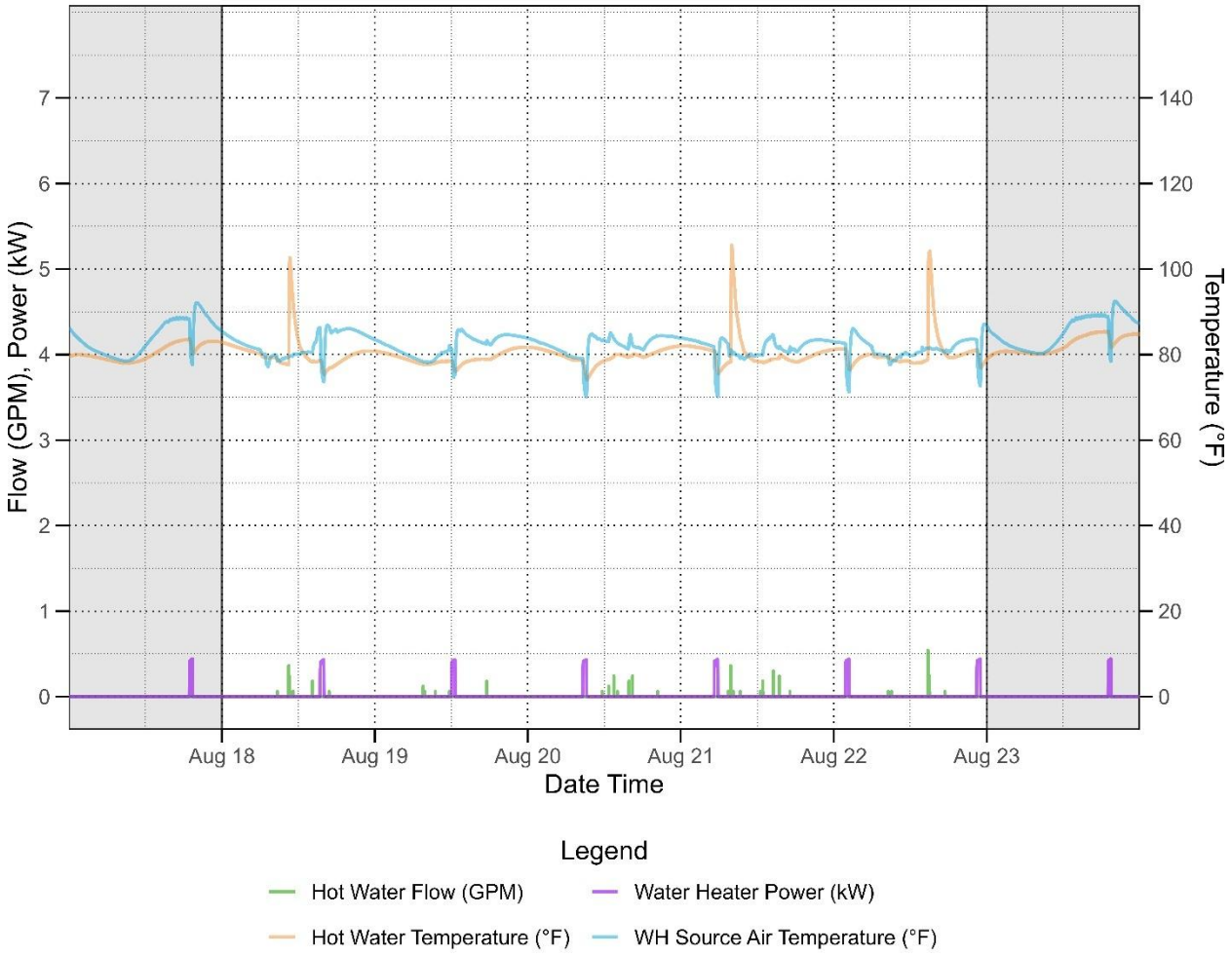


Figure 29: Site 2 representative week plot.

*Weekend days are shaded.

From the representative week plot (3 days before and 4 days after median water use day) shown in Figure 29:

- Several days in the representative week show very low hot water use, particularly on weekends, with HPWH energy use that is still nonzero due to standby and cycling.
- On the median day and other higher use weekdays, hot water consumption is very low but clearly above zero, and HPWH energy use increases accordingly.

In Error! Reference source not found., the representative day (median water use day) plot for Site 2 zooms in on the median water use day, showing hot water flow and HPWH power over 24 hours.

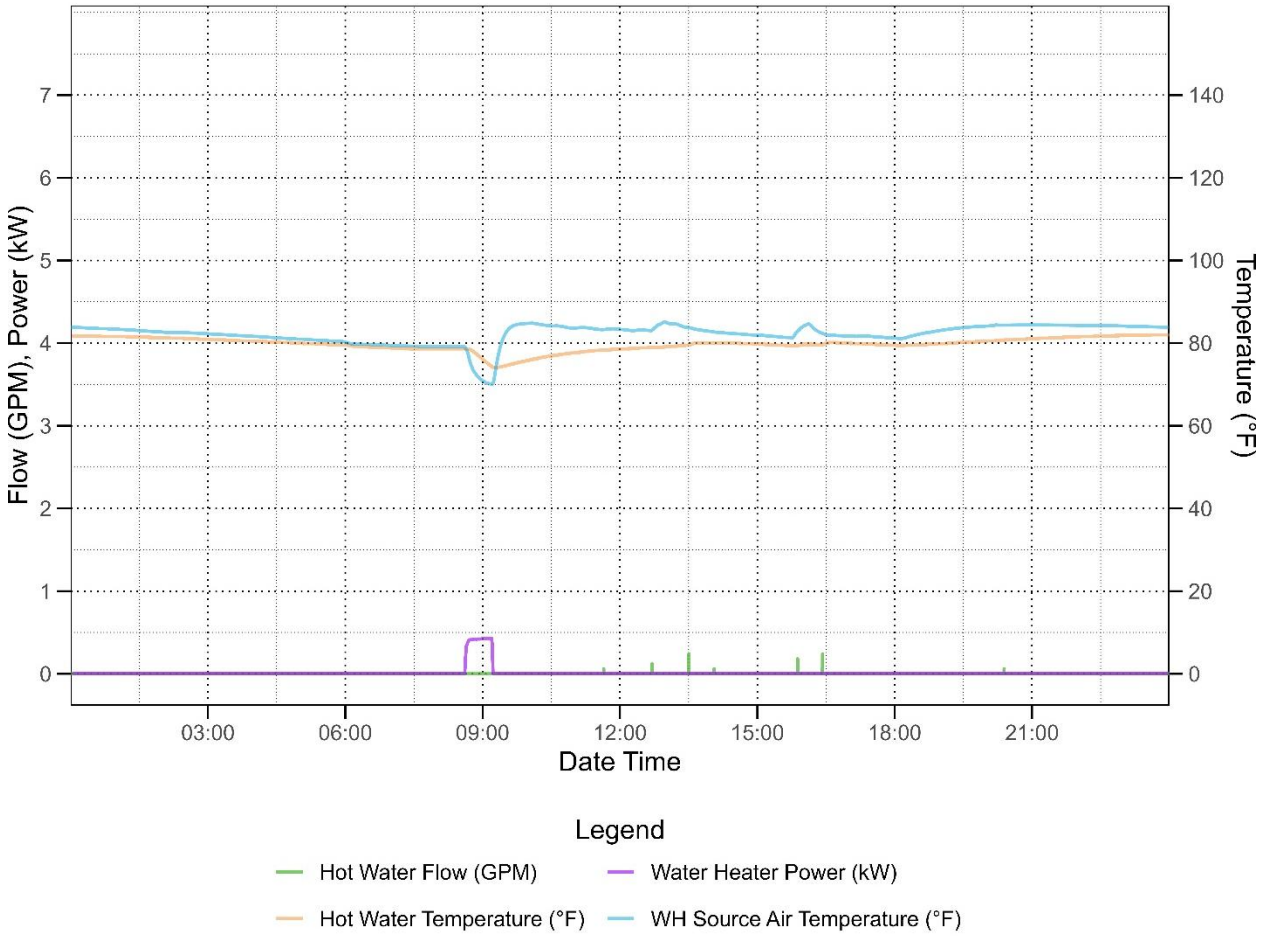


Figure 30: Site 2 representative day (median water use day) 8/20/25.

Site 3

In Figure 31, the representative week plot (three days before and four days after the median water use day) for Site 3 shows a seven-day window centered on the median water use day. This plot provides a more intuitive view of how daily hot water use and HPWH energy use vary over a typical week.

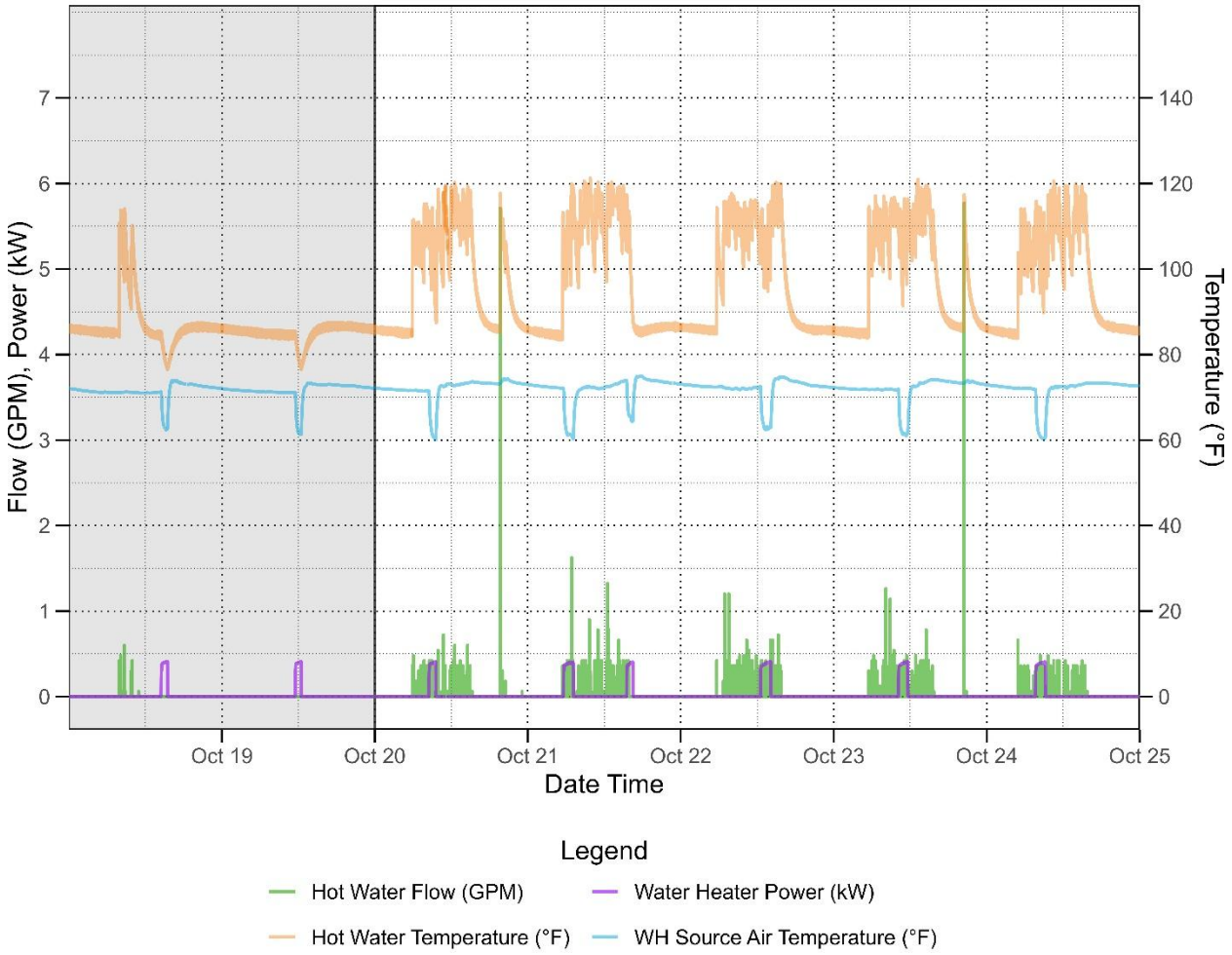


Figure 31: Site 3 representative week plot.

From the representative week plot shown in Figure 31:

- The median water use day sits in the beginning of the week (Tuesday), with days before and days after showing lower or higher use relative to that median.
- Weekend days in the representative week show very low or near-zero hot water use, with corresponding low HPWH energy use dominated by standby.
- One or two days show higher hot water use, with HPWH energy use increasing accordingly.

This representative week illustrates the intermittent nature of hot water demand at Site 3 and highlights the mix of low-use and moderate-use days that the HPWH must accommodate.

In Figure 32, the representative day plot for site 3 zooms in on the median water use day, showing hot water flow and HPWH power over 24 hours.

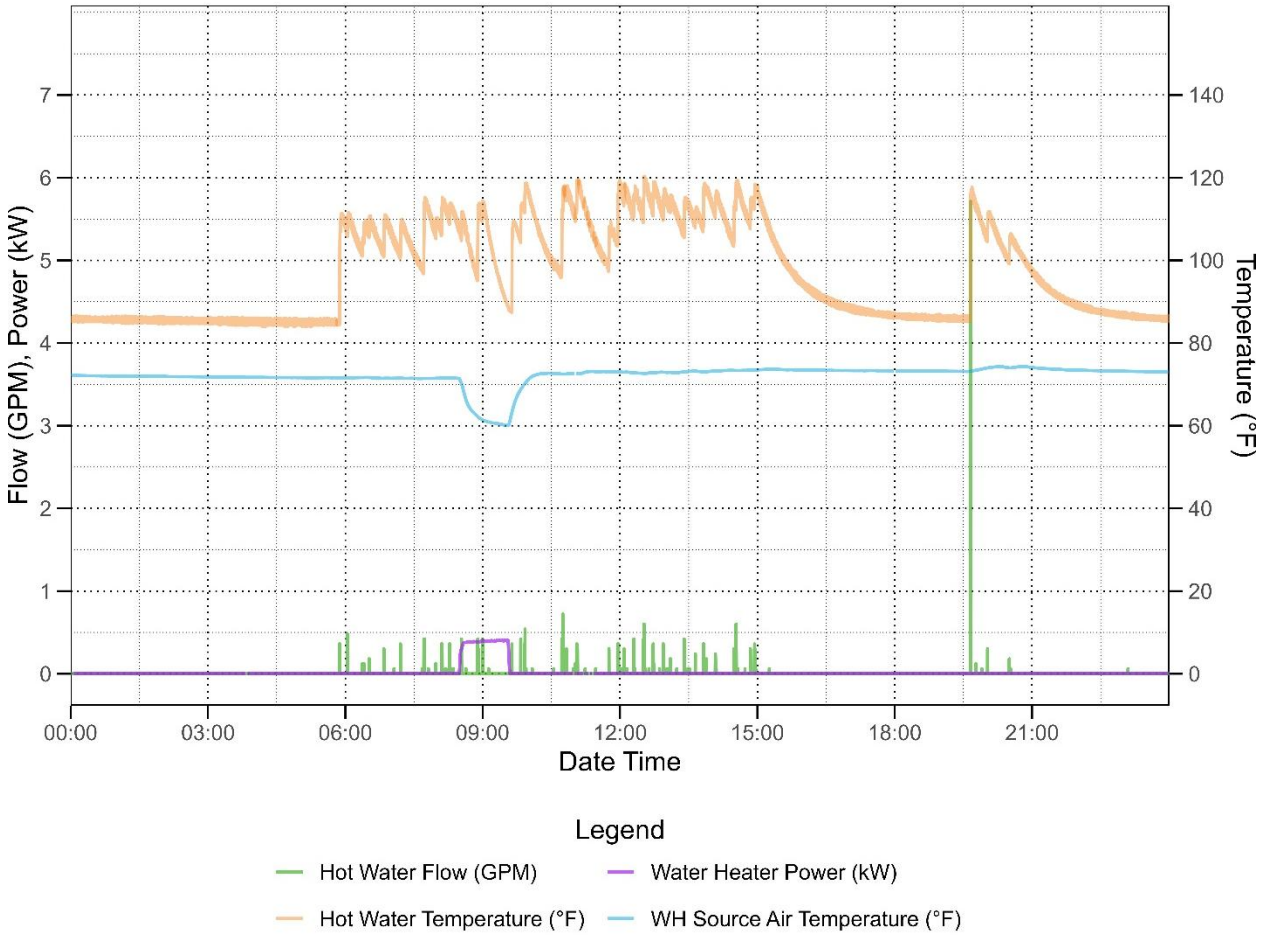


Figure 32: Site 3 representative day 10/20/25 Tuesday (median water use day).

From the representative day (median water use) shown in Figure 32:

- Hot water draws occur in a small number of discrete events, likely aligned with staff arrival, breaks, and cleaning activities.
- HPWH power ramps up in response to these draws, with short periods of operation followed by longer idle periods.
- Outside of these draw events, HPWH power is minimal, indicating limited standby cycling on the median day.

This representative day confirms that the HPWH at Site 3 is primarily responding to a handful of daily draw events, with little continuous operation.

Site 4

Shown in Figure 33, the representative week plot (three days before and four days after median water use day) for Site 4 shows a seven-day window centered on the median water use day. This plot provides an intuitive view of how daily hot water use and HPWH energy use vary over a typical week.

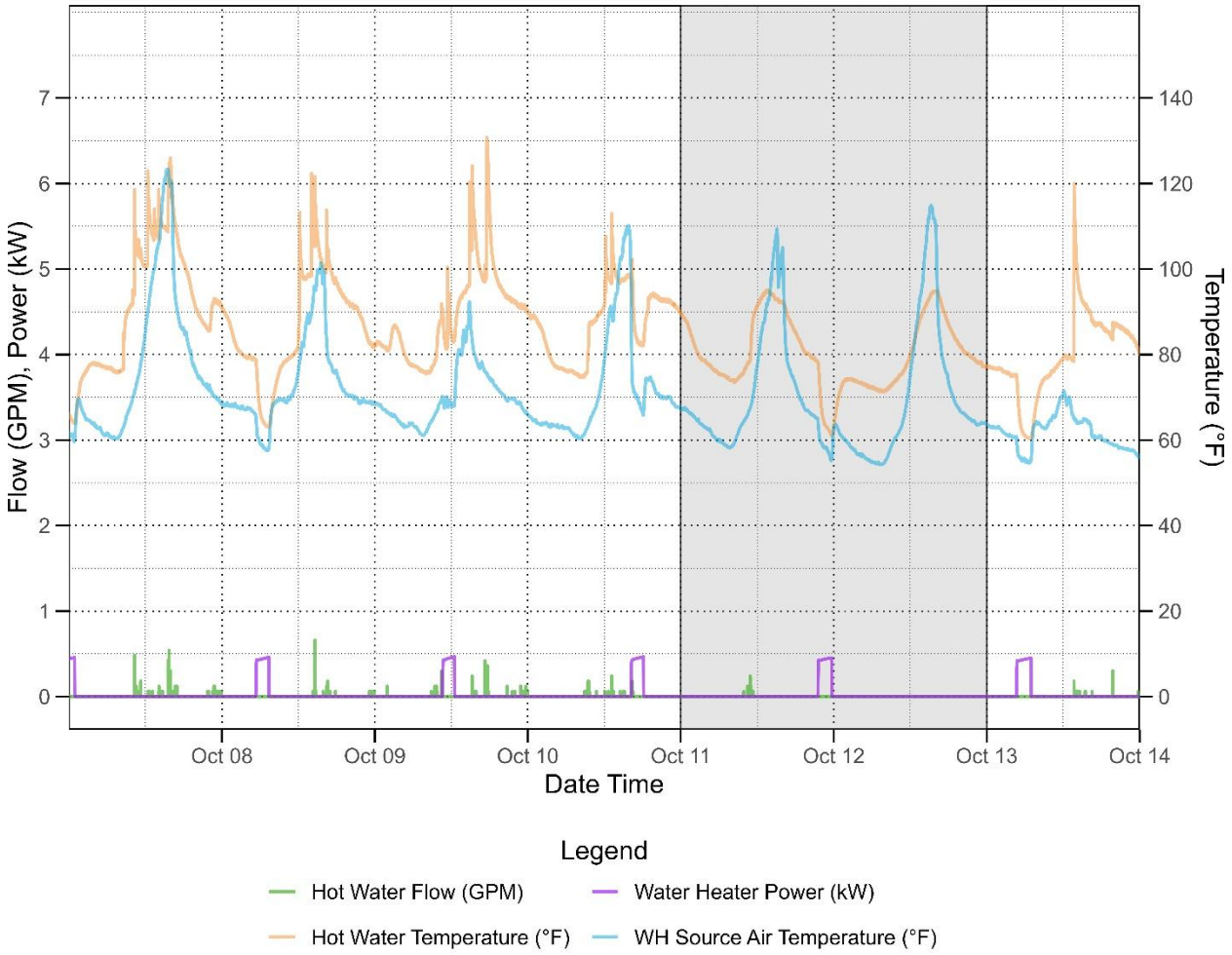


Figure 33: Site 4 representative week.

From the representative week plot (three days before and four days after median water use day) shown in Figure 33:

- Several days in the representative week show very low hot water use, particularly on weekends, with HPWH energy use that is still nonzero due to standby and cycling.
- On the median day and other higher use weekdays, hot water consumption is very low but clearly above zero, and HPWH energy use increases accordingly.

In Figure 34, the representative day (median water use day) plot for Site 4 zooms in on the median water use day, showing hot water flow and HPWH power over a 24-hour period.

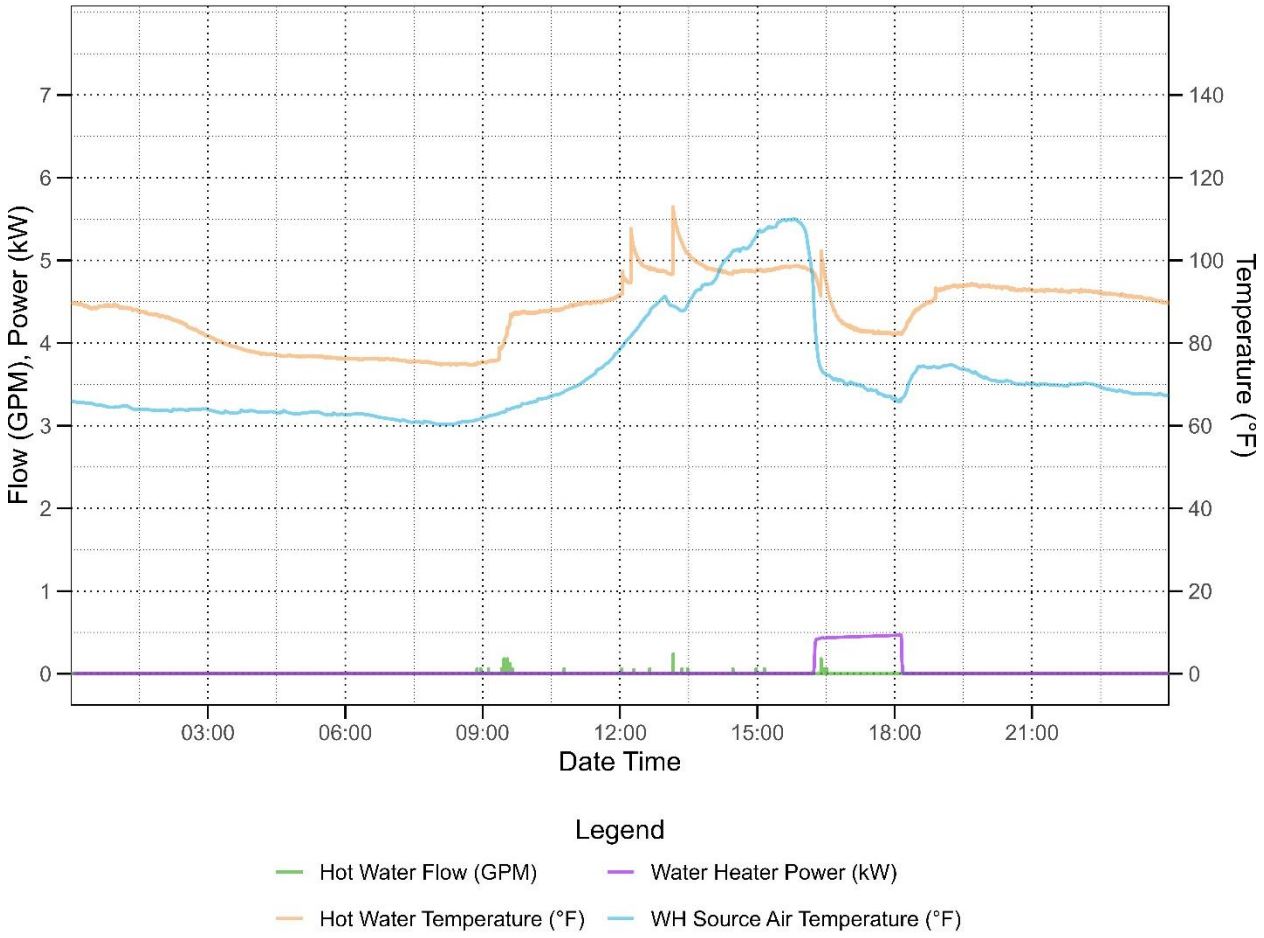


Figure 34: Site 4 representative day (median water use day) 10/10/25.

From the representative day (median water use day) shown in Figure 34:

- Hot water draws occur in a limited number of discrete events, likely aligned with staff activities and breakroom use.
- HPWH power ramps up in response to these draws, but the plot also shows periods of HPWH operation when hot water flow is minimal or absent, indicating cycling or temperature maintenance.
- Overall, the median day is characterized by very low hot water use and HPWH operation that is not limited to draw events.

This representative day suggests that the HPWH at Site 4 is cycling to maintain tank temperature even when hot water demand is low, contributing to low equipment COP and negative savings.

Site 5:

In Figure 35, the representative week plot (three days before and four days after the median water use day) for Site 5 shows a seven-day window from May 30 through June 5. This plot provides a

more intuitive view of how daily hot water use and water-heater power use vary over a typical week at this site

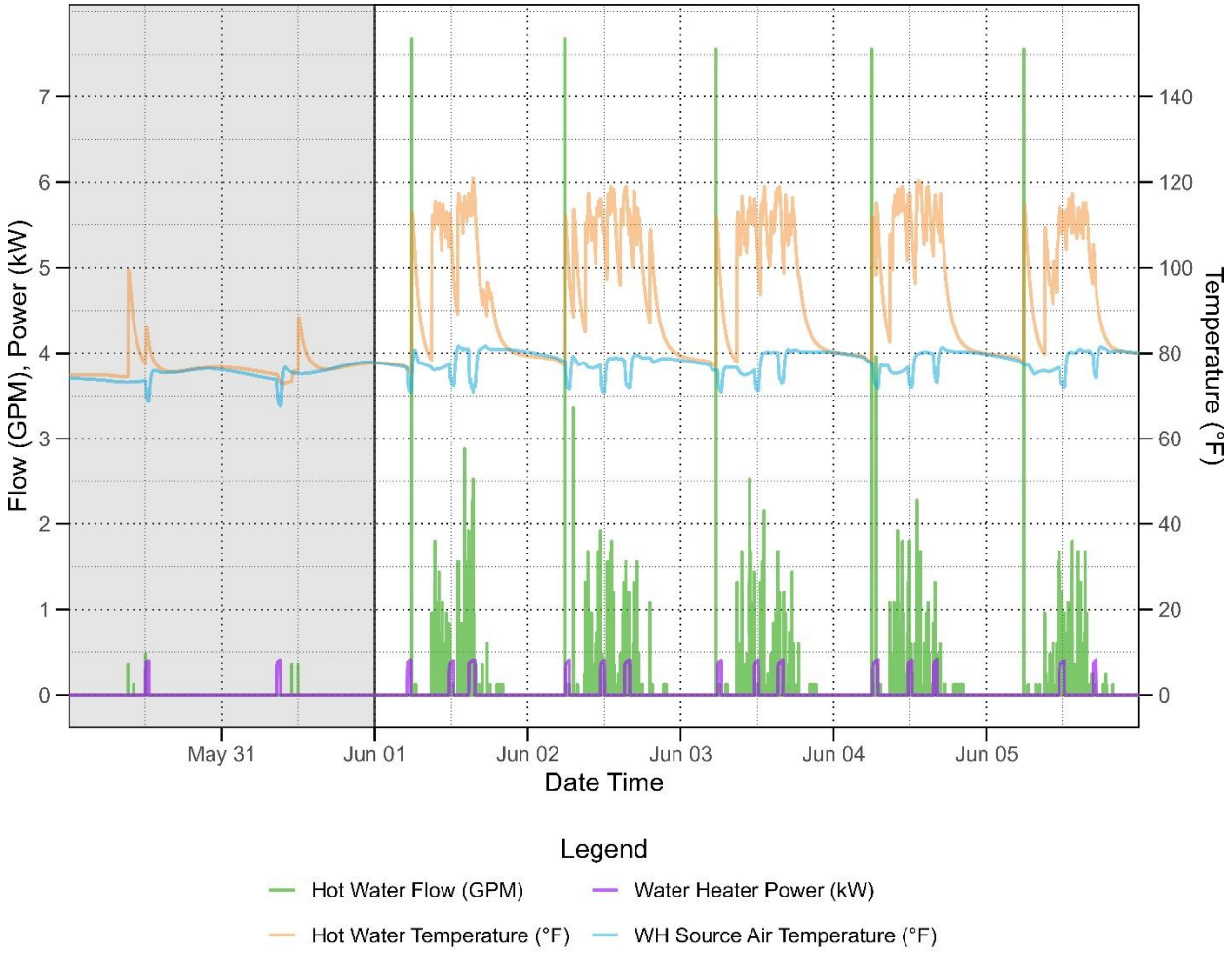


Figure 35: Site 5 representative week plot.

From the representative week plot shown in Figure 35 for Site 5:

- The plot shows day-to-day variation in flow (GPM) and power (kW) around the median day.
- Across the week, hot water flow and water-heater power vary together, with periods of higher flow corresponding to increased power draw and periods of low or no flow showing reduced power dominated by standby operation.
- Hot water temperature remains within a relatively stable band over the week, indicating that the system maintains setpoint temperature even as demand varies.

This representative week illustrates the relationship between hot water demand and water-heater power use at Site 5 and highlights how the HPWH responds to varying daily loads while maintaining hot water temperature under changing source air temperature conditions.

In Figure 36, the representative day plot for Site 5 zooms in on the median water use day (2026-06-02), showing hot water flow, water heater power, hot water temperature, and source air temperature over a 24-hour period.

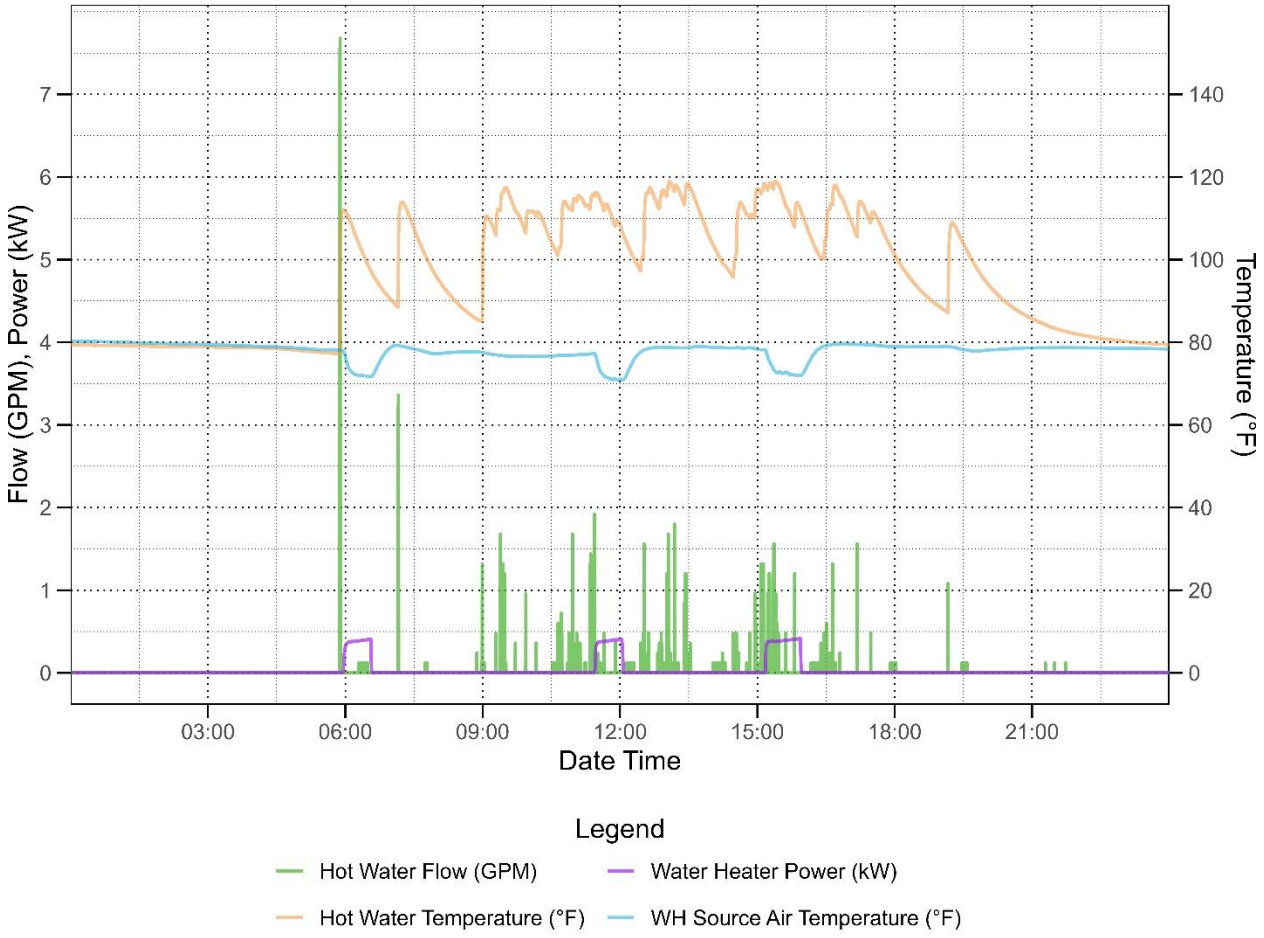


Figure 36: Site 5 representative day (median water use day) 6/2/26.

On the representative day at Site 5 (June 2, 2026), hot water use was concentrated in the early morning, with moderate demand during the rest of the day and almost no use overnight. The largest draw occurs just before 6:00 a.m., reaching slightly above 7.5 GPM, followed by a second, smaller peak just before 7:00 a.m. at just under 3.5 GPM. After these morning events, hot water use is limited to sporadic, low-flow draws between approximately 0.25 and just under 2 GPM during typical working hours (roughly 9:00 a.m. to 6:30 p.m.). From about 6:30 p.m. through 6:00 a.m. the following morning, there is essentially no hot water use, aside from three very small draws of about 0.2 GPM around 9:00 p.m.

Water heater power closely tracks these flow events, ramping up in response to the morning peaks and the scattered daytime draws. Importantly, the unit does not cycle overnight, consistent with the near-zero demand during that period. This behavior suggests that the system is not short-cycling and

is generally operating in a demand-driven manner, with minimal standby operation when there is no hot water use.

Delivered hot water temperature remains within an acceptable range throughout the day. The system appears to recover well between draws, and the outlet temperature never drops below 90°F, even during the largest morning peak. This indicates that the water heater capacity and controls are adequate for the observed demand profile on this representative day, with no evidence of temperature instability or user-perceived comfort issues.

The HPWH source air temperature is nearly constant at around 78°F under non-operating conditions, reflecting a relatively stable room environment. When the HPWH is running, the source air temperature drops modestly to around 70°F, indicating that the unit is drawing heat from the room and providing a small amount of space cooling. This cooling effect appears limited and controlled, suggesting that the HPWH operation is unlikely to cause significant comfort issues in the mechanical or storage space, while still benefiting from a relatively warm and stable source air environment.

Appendix I Attune Hardware

All data on the mesh network is encrypted using the AES-128 standard before being transmitted wirelessly to the Gateway. Gateways serve as the point of contact between the Attune network and the internet. A cellular modem provides an internet connection for the gateway that is completely independent of any site network. The gateway is also equipped with 4GB of memory, providing a measure of data backup in the event of a communication outage. From the Gateway to the cloud, the data is encrypted using Secure Sockets Layer (SSL) and will only communicate with Attune servers. The tool's user interface will monitor incoming data to ensure the quality of the data and to identify potential issues with the metering system. Attune's dashboard will allow the user to set up notifications when measurements cross certain thresholds. Its system status feature provides notification when components of the system go offline or have a low battery, and it allows the user to monitor connection strength between nodes of the mesh network. Access to the different features in the Attune platform can be defined by an administrator. This can allow specific data to be seen or to prevent users from making changes to the system. Figure 37: depicts the connectivity chain for data streams on the Attune platform. Figure 38 provides more detail on essential hardware for mesh network data collection system of the Attune platform.



Figure 37: Connectivity chain for data streams on the Attune platform.

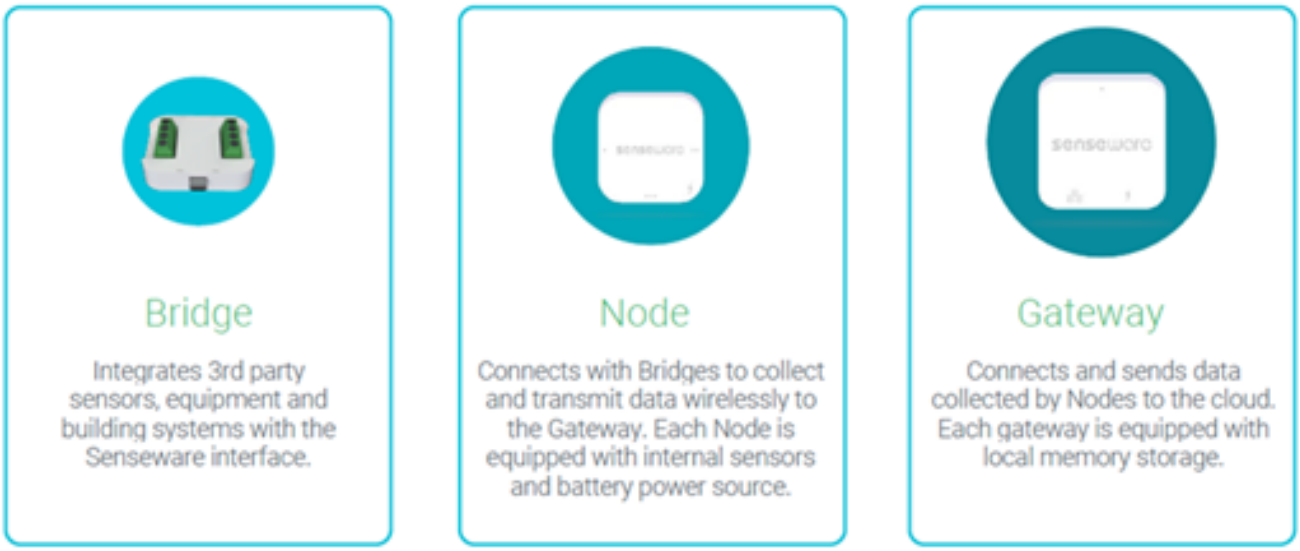


Figure 38. Attune network overview.