Plug-In Heat Pump Water Heater Field Study Findings & Market Commercialization Recommendations

Lessons learned on the performance of 120-volt HPWHs from California-wide installations

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Executive Summary

With buildings accounting for approximately 37% of carbon emissions in the U.S., addressing carbon emissions from the built environment is essential to meet the goals of the Paris Agreement and limit the rise in global average temperature to below 1.5 degrees Celsius.

Water heating and space heating together account for two thirds[1] of residential energy usage in the U.S. and should be the cornerstones of any plan to decarbonize the built environment.

Water heating accounts for around 17 to 32% of energy usage in residential and multifamily buildings. Nationally there are more than 123 million[2] existing residential water heaters and every year more than 7.5 million water heaters are replaced. It is estimated that 90% of water heating replacements occur on an emergency basis.[3] Without an easy, affordable, and fast heat pump water heater (HPWH) replacement solution, homeowners are more likely to opt for a replacement that is similar to the incumbent technology.

Currently, the American water heater market is dominated by two types: natural gas burning water heaters and electric resistance water heaters. While HPWHs are two to four times more efficient than any conventional water heaters, they can be three times more expensive to buy and install. As a result, HPWHs captured only 2.3%[4] of the electric water heater market share nationally as of 2021.

HPWHs face many barriers but these barriers are mostly to do with market and installation practices, not shortcomings of the technology itself. The most significant barriers are:

- Higher upfront and installation costs
- Installation complexity, due to space, ventilation, and condensation requirements
- The lack of a 240-volt electrical supply required for a standard HPWH
- General installer and consumer bias towards conventional models
- Lack of technology confidence and understanding of the long-term cost savings and environmental benefits

The emerging, plug-in 120-volt HPWHs, now entering the market are important new offerings from manufacturers aiming to address some of these key barriers. This report highlights the key findings from the first ever third-party field validation effort on the 120-volt heat pump water heater technology.

New Buildings Institute (NBI) worked closely with 120-volt HPWH manufacturers and utilities in California on a statewide 120-volt HPWH field validation program. As part of that program,

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[1] U.S. Energy Information Administration (EIA). Space and water heating account for nearly two thirds of U.S. home energy use.

[2] U.S. EIA Residential Energy Consumption Survey (RECS). Table HC8.1 Water heating in U.S. homes, by housing unit type, 2020.

[3] Consumer Reports. Tankless Water Heaters vs. Storage Tank Water Heaters.

[4] ENERGY STAR®. Unit Shipment and Market Penetration Report Calendar Year 2021 Summary.

NBI installed 120-volt HPWHs for 32 customers in most climate zones across California (CA). The units were monitored for water and ambient temperature, flow rate, power consumption, and the customers and contractors were surveyed on their usage and satisfaction with the water heaters. Once the fundamental features and the water heater capability to provide hot water were successfully validated, three of the 32 sites were selected to test the water heater demand response readiness and load shifting features to confirm whether they were able to follow schedules, preheat water, and store water. This effort is part of the Advanced Water Heating Initiative (AWHI), a national market transformation effort to decarbonize water heating in buildings.

1.1. A plug-in, 120-volt HPWH technology that can help decarbonize retrofit markets

Overall, the HPWH installations were a success: on a satisfaction scale of 1 (not at all satisfied) to 5 (extremely satisfied), 30 out of 32 participants responded with a 4 or 5 on their final post-installation survey. We expect that households with low-medium daily hot water demand and the correctly sized tanks will have their needs met with the 120-volt plug in products.

The 120-volt HPWHs are designed to reduce cost and complexity that customers may incur from installing a standard 240-volt HPWH in a fuel switching retrofit. Based on the study findings, they saved between $800 and $15,000 per household compared to 240-volt HPWH installation, primarily due to the minimal electrical interventions. From the installer feedback, 120-volt HPWHs were also faster to install, making them ideal for emergency replacements.

These are very low amperage draw heaters, while rated at 15 amps they were only pulling 4-6 amps of current during the monitoring period. We observed a maximum power draw of 400-600 watts (without backup element) and ~1000 watts (with small backup element). As they don’t have the inefficient backup element (or have a small element) we observed an average monthly energy consumption savings of approximately 85% in comparison to the pre-existing gas/propane water heater when normalized to kWh. In addition, about 60% of the sites showed operating costs savings[5] as compared to the pre-existing gas or propane water heater.

> *Gas water heaters account for 93% of water heating equipment—and 40% of gas use[6]—in California homes. For California to meet its climate goals, at least 30% of the state’s residential gas water heaters must be electrified by 2030[7] and the 120-volt HPWH technology can play a pivotal role in this transformation.*

[5] As compared to historical average gas rates.

[6] California Energy Commission. Natural Gas Methane Emissions from California Homes.

[7] Southern California Edison. Carbon Neutrality by 2045.

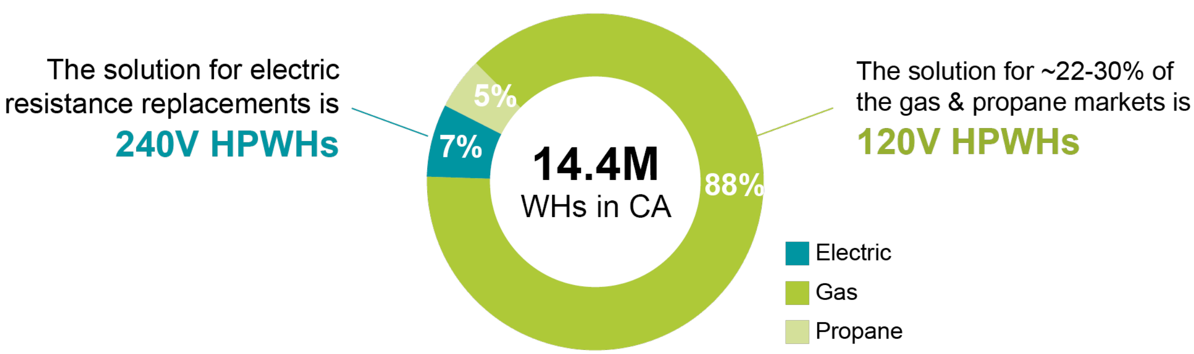
FIGURE 1. EXAMPLE 120-VOLT HPWH INSTALLATIONS

Photo Credit: kW Engineering

1.2. California Water Heater Market Assessment and opportunities to integrate 120-volt technology

Field staff conducted virtual and in-person walkthrough surveys of 153 customers throughout California to find sites that would be appropriate for the initial criteria developed for this study. The 120-volt HPWHs are specified[8] for the space and power constrained applications for the retrofit market sector. Our market assessment determined that about 22 to 30% of the existing California homes can be decarbonized with 120-volt HPWHs without any substantial site upgrades. This percentage suggests that more than 3 million households in California can save on electric upgrade costs, especially in small to mid-size (1-4 people) residential homes with propane or natural gas water heaters.

FIGURE 2. WATER HEATERS FUEL MIX IN CALIFORNIA



Higher upfront costs may discourage the average household, besides climate-motivated early adopters, from electrifying their gas water heaters. However, market sentiment could change if incentives become available for electrification or gas-fired water heaters are no

[8] Northwest Energy Efficiency Alliance (NEEA). Advanced Water Heating Specification Version 8.0.

longer available for purchase.[9] Based on the site evaluations (see section 4.4 for further details), we recommend that only sites needing limited electrical remediation be targeted for this technology.

We observed a favorable relation between house vintage, square feet, and panel size in houses built prior to the year 2000 and smaller than 2000 square feet. These homes typically had 100-150-amp panels. Such households should be targeted with this technology for electrification without incurring expensive electrical service upgrades.

1.3. Key recommendations

This field study determined that the 120-volt HPWH is a compelling technology that can be a contributing solution for meeting decarbonization or electrification goals for a major sector of the residential retrofit market as well as for small commercial applications. Based on the study findings, we recommend the following to policy makers, utilities, and program implementers designing incentive programs for 120-volt HPWHs:

120-volt HPWH products should be absorbed into current HPWH incentive programs.

The 120-volt technology meets water heating needs like the incumbent 240-volt HPWH. While 120-volt HPWHs have a slightly lower uniform energy factor (UEF) compared to the current 240-volt unit, we recommend that these units be absorbed under the existing workpapers/technical resource manuals (TRMs) to be available for incentive programs for accelerated adoption of the technology into the market.

Correct site assessment and sizing are key for technology success.

Medium to small demand households (1-4 people) with a gas fired water heater that needs a replacement are the low hanging markets for 120-volt HPWHs. Sizing and selecting the right water heater for the household needs is the key to successful market adoption of the technology and for positive customer experience.

Installer dual trade service certification helps.

Since there are electrical components to the HPWHs, dual services certification for installers is recommended, i.e. plumbing and electrical. Contractors need to be comfortable installing new outlets and extending circuits as needed. However, since these are plug-in water heaters, the necessary installer experience with electrical

[9] Bay Area Air Quality Management District. [Air District strengthens building appliance rules to reduce harmful NOx emissions, protect air quality and public health](). The Air District adopted amendments to Regulation 9 that require new water heaters in California to be zero-NOx beginning in 2027.

work is very minimal compared to the challenges of major electrical work that sometimes is needed to install 240-volt HPWHs in gas retrofit applications. For 120-volt installation, an approach like Oregon's Flexible Water Heater Installer license,[10] which allows more people to install HPWHs without having to jump through all the plumber journeyman hurdles, would also help with adoption.

Light commercial buildings can benefit.

Commercial buildings currently using natural gas or propane water heaters under 80 gallons may be candidates for 120-volt HPWHs. Residentially sized water heaters are common in small commercial buildings that have low hot water demand. In commercial buildings, the hot water demand often varies by building type. We found that small offices and retail buildings[11] tend to have limited hot water demand and may be served by residential water heater units. Energy efficiency programs should be intentional about including commercial buildings that use residential water heating equipment in their programs.

Equity program opportunities.

We recommend maximizing outreach about 120-volt heat pump water heaters within low-income communities to ensure they benefit from the reduced energy burden provided by the 120-volt HPWH. They are a great solution for Direct Install Programs and are an option for moderate-income homeowners who are looking for the lowest possible cost solution.

Small footprint, small form factor products are needed.

Space is of the essence for retrofit applications. While the specification of the 120-volt HPWHs is developed for space constraint applications, upsizing the unit two sizes above the pre-existing gas fired water heater is adding space limitations on the installations. It is critical that there is further research in this area given that storage capacity is a critical design element of this technology and needed for successful load shifting.

[10] Oregon Home Builders Association. Changes to Oregon Water Heater Installer License add Flexibility and Opportunity.

[11] Based on Northwest market characterization surveys and National Renewable Energy Laboratory's (NREL's) ComStock dataset

Coordinate program design with Inflation Reduction Act funding.

The Inflation Reduction Act (IRA) presents added opportunities for state decarbonization efforts. The federal bill has provisions for limited financial support on electric panel upgrades and HPWHs. If California provides funding for electric panel upgrades, utilities may want to focus on leveraging these funds to support long-term electrification planning. In this scenario, 120-volt HPWHs may be most useful as an emergency replacement technology.

Rate structure reforms.

Based on the increasing gas rates ($/therm) over the past year, PG&E and SMUD customers are estimated to see operating cost savings by switching from gas to electricity for water heating. The cost savings analysis shows that customer financials greatly depend on the gas and electricity rate structures. Rate structure reforms[12] that support heat pump integration for the built environment are going to be critical for heat pump market adoption. Adjustments to rate structures to incentivize electrification will make water heating electrification more palatable to customers. This is especially important when promoting the technology to income eligible populations.

[12] Energy Systems Integration Group (ESIG). Heat Pump-Friendly Cost-Based Rate Designs. Heat pump-friendly rate designs are those that more accurately reflect the marginal cost of power generation and delivery than traditional residential tiered rates, for instance, time-of-use (TOU) rates.

2. Introduction

2.1. Background on 120-volt HPWHs

In 2018, Retrofit Ready Heat Pump Water Heater Summit stakeholders developed a technical specification for an efficient, load shifting-capable heat pump water heater that could be plugged into an outlet on a shared 120-volt, 15-amp circuit. The specification[13] was written to address technology and cost barriers that prevent widespread conversion from gas tank-type water heaters to heat pump water heaters in existing buildings such as multifamily and manufactured housing, and older homes with water heater closets.

To support this new market, New Buildings Institute (NBI) in partnership with California utilities proposed a statewide field validation effort from 2021 to 2023 to validate the emerging technology of 120-volt heat pump water heaters (HPWHs) and expedite the market transformation effort. Five years after the summit, four manufacturers are bringing multiple products (i.e., models and tank sizes) to market.

2.2. Study scope and research objectives

The goal of this field study is to independently field verify 120-volt HPWHs for user satisfaction, installer acceptance, and energy performance to demonstrate the emerging technology. The findings of the study will help with market commercialization of the technology, including but not limited to policy adoption and program promotion. The research findings will also support targeted efforts to decarbonize the existing buildings market.

The study's research questions, and the methodology used to address each question are included in Table 1.

TABLE 1. RESEARCH QUESTIONS AND METHODOLOGY

Research Questions	Research Methodology
1. Does the 120-volt HPWH deliver sufficient hot water for typical user needs and expectations?	Measurement and verification (M&V) and Survey
2. What is the energy and demand performance of the retrofit 120-volt HPWH?	M&V and Energy Analysis

[13] Northwest Energy Efficiency Alliance (NEEA). Advanced Water Heating Specifications 2022. These specifications are also part of the ENERGY STAR Residential Water Heating Specification Version 3.3.

Research Questions	Research Methodology
3. What are the product and installation costs?	Invoice Documentation
4. How much would a user pay to operate the unit in a range of typical homes and utilities?	Operating Cost Analysis
5. What is the user experience, impacts and interaction with the equipment?	Survey
6. What installation issues need to be addressed for commercialization?	Survey
7. What is the load shifting capability?	M&V and Survey

Five objectives of the study are described in more detail below.

2.2.1. Demonstrate equipment applicability in various installation locations and climate zones

Having a variety of installation configurations provides greater data and application assessment and leads to a greater understanding of the field limitations and opportunities of the technology. As such, the study sought to include installations in a variety of residential applications (i.e., single family, multifamily in-unit), installation locations (i.e., garage, closet, basement) and climate zones within California, with a total of 32 sites. The study focused on homes with existing gas- and propane-fired tank-type water heaters, as these are the predominant existing water heater types in California.

2.2.2. Monitor the performance of the 120-volt HPWH

To answer the research questions and support study objectives, the study includes monitoring and analysis of field performance. The primary goals of the monitoring are to track hot water runout events, understand electricity consumption under varying conditions and hot water loads, and determine operating cost scenarios under various utility rates. A secondary goal is to assess the potential to load shift electricity use away from peak price and greenhouse gas (GHG) emission periods.

2.2.3. Understand costs associated with the 120-volt HPWH

One of the major barriers to any new technology is the high upfront cost compared to traditional solutions (whether this cost delta is perceived or real). This study includes tracking of the upfront product, installation, and operating costs to provide the readers with an accurate picture of the cost to implement a 120-volt HPWH in a variety of home types.

2.2.4. Gather information from users and installers

Understanding user experience is an important part of the study. Gathering information about the ability of the equipment to meet user needs and expectations can enable manufacturers to make changes to the equipment if needed and help identify potential roadblocks to widespread adoption of the technology. The study gathered information from installers regarding lessons learned, technology limitations, and training needs, which are also communicated to manufacturers to improve their installation procedures as needed.

2.2.5. Collect information to support 120-volt HPWH eligibility in utility programs

The final objective of the study is to collect information that can be used in utility program work to support 120-volt HPWH eligibility. In addition to understanding installation and code barriers.

2.3. 120-volt HPWH technology description

Heat pump water heater technology has been available on the market since the 1980s, but anecdotal evidence suggests that early models did not have the levels of performance or reliability needed for mass market adoption. That changed in 2015 when GE released the first Geospring model, which was well supported by the manufacturer, had an Energy Factor in the 2.25 range, and a price point around $1,000. The Geospring was adopted by several major utility incentive programs, and other manufacturers offered 240-volt HPWH options in the following few years. The 120-volt HPWHs share many characteristics with their 240-volt counterparts. The section below highlights some of the key distinct features:

2.3.1. Plug in

The most significant differentiating feature of the 120-volt HPWHs is that they can plug into an existing 15-amp outlet and can share the circuit with other appliances. Unlike a standard 240-volt HPWH, 120-volt HPWHs do not need a dedicated 30-amp circuit (see Appendix B for the electrical code requirements). An example of shared circuit use would be when a home cook plugs both a blender and a toaster into a standard wall outlet and uses both appliances at the same time. The 120-volt HPWH can plug into similar wall outlets for easy installation and minimal impact on the existing home electric infrastructure.

2.3.2. Absence of backup heating or reduced element

The reason the 120-volt HPWHs can be installed on a shared circuit is that this new technology does not have an electric resistance back-up element or has a significantly reduced electric resistance element size. A large back up element enables quicker hot water delivery at reduced efficiency. Absence of the element means that the hot water recovery in the case of a depleted tank would be slower than a standard HPWH.

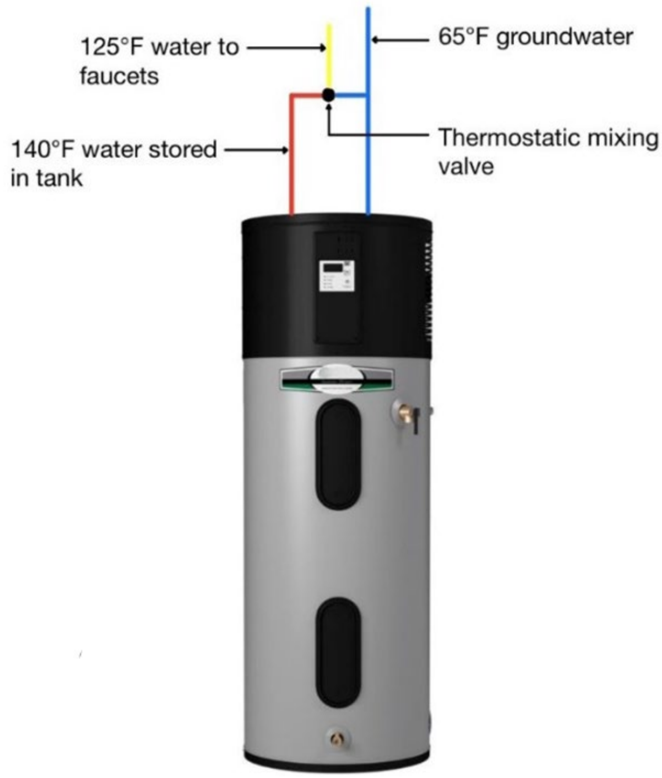
A standard 240-volt HPWH typically has three control settings available for customers, “heat pump only” “hybrid mode” and “electric resistance only.” The 120-volt HPWH operates in a mode equivalent to the “Heat Pump Only” setting on 240-volt HPWHs. It will be highly dependent on the heat pump compressor with little or no assistance from the electric resistance backup heating. Due to increased reliance on the heat pump compressor, the 120-volt HPWH performance will depend on environmental factors that impact compressor performance—such as incoming water temperature and ambient air temperature.

2.3.3. Integrated thermostatic mixing valve

The thermostatic mixing valve decouples tank temperature from hot water delivery temperature, providing additional hot water capacity available from the tank while minimizing the risk of scalding. To reduce the risk of hot water runout events, manufacturers have incorporated an integrated electronic mixing valve. In addition to the thermal capacity boost, the mixing valve also allows for additional controls and flexibility for scheduling to allow the water heaters to participate in load shifting or demand response programs.

Figure 3 illustrates a mixing valve on a water heater. In this example, the resident keeps the storage tank hot at 140°F, effectively increasing the storage capacity of the heater. The mixing valve mixes the stored hot water with cold incoming water and limits the delivery temperature to a safe 125°F. This increases the tank's hot water storage capacity without sacrificing comfort or risking scalding (ASSE 2013).[14]

FIGURE 3. HOT WATER MIXING



2.3.4. Importance of determining the right tank size

Sizing the tank properly is important in the case of storage water heaters and more so for 120-volt HPWHs as they have no back-up or reduced power back-up element. Installers typically determine a water heater's tank size based on its first specified hour rating. The first hour rating is the amount of hot water that can be provided in one hour, starting with a tank filled with hot water. Water heaters with higher first hour ratings can reheat the storage tank quicker after water draws than those with lower first hour rating. Generally, water heaters fueled by gas combustion reheat faster but less efficiently than heat pump systems. In retrofit applications, a plumber will look for a replacement water heater that has a similar first hour rating to the replaced system to ensure the household can expect comparable amounts of hot water after the retrofit. To achieve similar first hour ratings, a plumber may need to install a larger storage tank on the 120-volt HPWH than the replaced gas or propane water heater.

Table 2 summarizes key characteristics of the emerging 120-volt HPWH technology and the longstanding 240-volt HPWH technology. The information provided in

Table 2 is a summary of key metrics and not an exhaustive list. Specific performance metrics such as the number of showers or number of occupants in the home that can be supported vary by the specific tank size and model and thus are excluded from the table.

[14] ASSE International. Guidelines for Temperature Control Devices in Domestic Hot Water Systems.

TABLE 2. SUMMARY OF 120-VOLT AND 240-VOLT HPWH CHARACTERISTICS

Metric	120-Volt HPWH	240-Volt HPWH
Ideal application (retrofit or new construction)	Retrofit gas/propane unit or electric resistance unit replacement	New construction or electric resistance unit replacement
Able to operate on a shared circuit?	Yes	No—requires dedicated 30-amp circuit
Electric panel upgrade(s) required in existing buildings?	No	Sometimes
Estimated first hour rating (50-gallon unit)	45-74 gal	67-94 gal
Electrical requirements	Shared 120-volt / 15-amp circuit	Dedicated 240-volt 30-40-amp circuit
Supplemental reheat	Small element, although some models do have low input (850W upper and lower resistance element) supplemental heat	Yes, higher input, 4500W supplemental resistance element heat
Grid connectivity	EcoPort (CTA-2045 Compatible), Built-in Wi-Fi compatible	EcoPort (CTA-2045 Compatible), Built-in Wi-Fi compatible

Source: NBI calculations and information from manufacturers.

2.3.5. Equipment included in the 120-volt HPWH field study

Four manufacturers are currently bringing 120-volt HPWHs to the market. A.O. Smith, GE, Nyle, and Rheem have been involved in the development and implementation of the 120-volt HPWH field study. Three of the four manufacturers (all but A.O. Smith) offered equipment to be installed as part of the California study. Table 3 summarizes the specifications of the models included in the study.

TABLE 3. 120-VOLT HPWHS UNDER DEVELOPMENT IN THE U.S. MARKET

Characteristic	AO Smith	GE	Nyle	Rheem
				
Type	Unitary	Unitary	Split	Unitary
Model line	TBD	Geospring	e8	ProTerra Plug-in
Tank sizes (Gallons)	40, 50, 66, 80	50, 65, 80	50, 80, 119	40, 50, 65, 80
Backup electric resistance heating	Yes	Yes	For 50- and 80-gallon tanks	No
Thermostatic Mixing Valve	On standard product	On standard product	Available as add-on	**Shared circuit:** Standard **Dedicated circuit:** Add-on
Refrigerant	TBD	R134A	R513A	R134A
Power (W)	900	850	900	900
Breaker Size (A)	15	15	15	15
Max. Amperage	≤7.5A	≤7.5A	≤7.5A	≤7.5A
Heat Pump Output Capacity	4200 Btu/hr	>4000 Btu/hr	?	~4000 Btu/hr
Rated Coefficient of Performance (COP)	TBD	3	2.8	2.8-3.5
Ambient Operating Range (°F)	TBD—expected to be similar to other manufacturers	35 to 120	38 to 120	37 to 145
Anticipated Market Lunch	Mid 2023	Mid 2023	Mid 2023	Launched in July 2022

The first hour rating at a normal mode setting for each manufacturer and tank size is mapped in Table 4 below. The first hour rating is an indicator of the number of gallons of hot water the water heater can supply per hour, starting with a tank full of hot water. This is an important factor for 120-volt HPWHs—due to the lower energy input, 120-volt HPWHs do not have as much quick recovery capability as their 240-volt counterparts.

TABLE 4. MANUFACTURER-PROVIDED FIRST HOUR RATINGS

	Nominal Gallon Capacity	First Hour Rating (Gallons)
GE	50	45
Nyle	80	70
Rheem	50	55
	65	55
	80	72

3. Implementation Results & Findings

This section summarizes the installation, performance, and financial findings from the monitored and surveyed study data from the 120-Volt HPWH field study.

3.1. Early installation lessons learned

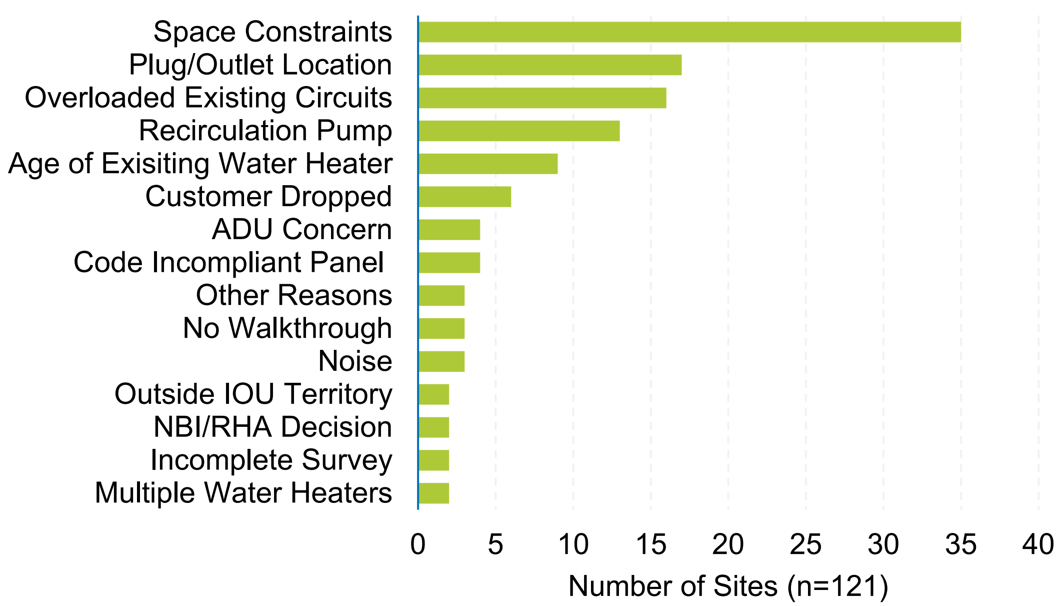
The 32 installations throughout California provided key lessons about this technology and its market adoption barriers.

3.1.1. Space constrained sites

The 120-volt specification[15] is written for the space and power constrained retrofit market sector. However, we found that the manufacturer units are not small enough to fit well for all the sites we came across. Especially for indoor-outdoor closet installations with limited space, we had to reject many sites due to space limitations for not only the physical unit but also additional plumbing, ventilation, and condensation requirements.

Additionally, many sites had outlets that were either too far from the installation location, or the outlets were already constrained by other plug loads. Figure 4 highlights the key reasons that led to site rejections. Note that these reasons should also help manufacturers and national labs with future product development needs.

FIGURE 4. SITE REJECTION REASONS



[15] NEEA. Advanced Water Heating Specification 8.0. This is the latest version and succeeds Version 7.0. Version 8.0 includes important changes to residential water heater specifications.

3.1.2. California Plumbing Code

Based on the study findings, we observed that the California Plumbing Code first hour rating requirements cause an increase in HPWH sizing beyond the manufacturer recommendations. In this case, we followed manufacturer recommendations, based on the assessment by code experts that first hour rating (FHR) is typically enforced for new construction. For retrofits, the plumbing code FHR [501.1 (2)] comes into effect, but the sizing requirement is very rarely enforced compared to the energy compliance requirement. While the plumbing code is outdated and needs its next round of updates to incorporate emerging technologies, manufacturers should consider publishing FHR for range of storage temperatures due to an integrated mixing valve in 120-volt HPWHs. California building codes also require a platform for gas fired water heaters, but we have found that non-removable concrete platforms make it challenging to fit the HPWH into the existing water heater location.

3.1.3. Regulatory and permitting barriers

From the study experience, permitting approvals are one of the key barriers for this technology. Due to HPWH's status of emerging technology, permitting departments frequently ask for extra paperwork. For example, full house electrical load calculations with 100% of HPWH load, requiring a dedicated circuit, floor plans, and single line drawings for a water heater replacement. Additionally, at least one city department required a monetary bond to be submitted. Typically, the permitting process for water heaters is much easier; however, due to the electrical nature of the water heater and lack of awareness around the technology's electrical requirements, we experienced delays. These excessive requirements highlight the need for building official and building department education and awareness.

Based on the feedback received from code officials, there are times when water heaters are installed in existing homes without permitting approvals, especially in cases of emergency replacement. So similar to solar auto permits,[16] streamlining permitting process will help with expediated permits.

3.1.4. Installer education and awareness

During installation of the heat pump water heaters, we encountered several challenges to be addressed by installer training, education, and awareness. Below is a list of areas that need special education and training:

- **General comments:**
  - » Since there are electrical components to the HPWHs, dual services-certified installers are nice to have, i.e., plumbing and electrical. Contractors need to be comfortable installing new outlets and circuits when required. In addition, installers should be made aware of the integrated mixing valve on the 120-volt models. The manufacturer training materials should be clear enough to reduce any market confusion.
  - » Adding water lines will be necessary with some models of the HPWHs because of the location of the inlet and outlet on the tank as compared to a traditional water heater. On the other hand, a water heater platform is a regulation for gas safety and is no longer needed with these units.

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[16] Home Depot. Hybrid Water Heaters. Prices are based on entry-level models without premium features for both HPWHs and gas-fired water heaters to obtain a fair comparison.

    - Split systems have unique installation requirements; hence, it is critical for a contractor to perform a mock-up installation of the unit at their facility before the first in-home installation. Doing so allows many issues to be resolved proactively.
- **When is a condensation pump required?**
    - Installers should be aware that condensate pumps are only required for basements without drain access and for installations in which the condensate drain piping rises above the level of the discharge point, for example to clear a doorway. For sites that do not need a condensate pump, the condensate drain can be directed to the gravity fed drain for the T&P valve. The T&P valve drain line must be open at floor level. It cannot be combined with any other plumbing. However, when a condensate pump is required, it needs to have a dedicated drain line due to potential for backflow.
- **What can a 120-volt HPWH share its circuit with?**
    - It is critical to know what else is on the shared circuit alongside a HPWH to ensure that an overcurrent event that would trip the circuit breaker does not occur. This risk mainly applies to the moment the HPWH compressor turns on, which causes an inrush current that could overwhelm the system if a different appliance is drawing significant current at the same time. Contractors should be knowledgeable of the correct size and voltage HPWH to recommend based on the existing electrical loads on the circuit. Note that we did not have any issues with circuit tripping for the 32 installations as the actual monitored draw of the shared circuit model was close to 5 amps, which only occupies 1/3rd of the 15-amp circuit capacity.

3.1.5. Site selection

Throughout this study, we learned many lessons regarding the retrofit installation due to measurements, electrical systems, and building codes.

- We found that most existing fossil gas-fired water heaters had a plug point available next to the water heater. However, as shown in Figure 4 above, 12% of the rejected sites had existing shared circuits overloaded with other plug-in appliances like freezers, refrigerators, Christmas lighting, or forced air units (FAUs), or the outlet was too far away.
- To avoid other unprecedented setbacks, the contractor should also be aware of the HOA approval process incurred by changes to a house. This potential barrier is especially applicable to multifamily households, where aesthetics and HOA approvals are prioritized and should be a key consideration for emergency replacements.
- Additionally, we recommend detailed clearance measurements for all sites to make sure the site has enough clearance from the bottom of the tank, including room for the expansion tank and other plumbing.

TABLE 5. INSTALLATION CHALLENGES AND LESSONS LEARNED

Challenge	Lessons Learned
Siting, sizing, and installing HPWHs • Size/clearance • Air volume/flow • Condensate drainage • Access to 120-volt receptacle • Noise/vibration	120-volt HPWHs are often too large for many sites or are far from available outlets. Identifying solutions for space constraints, air volume/flow, condensate drainage, and electrical circuit solutions ahead of time is crucial. Requiring homeowners to provide pictures of existing water heater location can help predict installation difficulties.
California Plumbing Code	First hour rating requirements are more applicable to new construction than retrofits. The California Plumbing Code requires an update.
Regulatory and permitting barriers	Because the 120-volt HPWH technology is so new, permitting is one of the biggest challenges. Excess regulation and permitting leads to delays in the installation process.
Installer education and awareness	Because 120-volt HPWHs are electric, it is beneficial to have installers that are dual trade certified (plumbing as well as electric). The installer must also be able to assess whether the HPWH can safely share a circuit with existing plug loads i.e., whether it will trip a circuit breaker.
Site selection	Prior to installation, it is essential to obtain detailed clearance measurements of the space where the HPWH is being installed. Replacing a gas or propane water heater with an HPWH does not always require a new outlet; there may be an outlet within distance accessible for the 10-foot electrical cord provided by the manufacturer. To avoid additional delays, the contractor should be familiar with any HOA process triggered by the retrofit.
Securing & maintaining installation partner	Complete the installation plan and timeline well in advance.
Assembly, configuration, installation, and maintenance of monitoring equipment	Installation of monitoring instruments was specific to the study. We recommend using the field study templates and best practices provided by the AWHI for standardization and consistency.

3.2. Economics of 120-volt heat pump water heaters

In this section, we establish the hard and soft costs associated with a 120-volt HPWH retrofit. 120-volt HPWHs are designed to reduce the costs of installing HPWHs in fuel switching retrofits. The section below includes the cost of the equipment with associated accessories and home electrical upgrade cost savings from opting for the lower power 120-volt HPWH instead of a 240-volt HPWH.

3.2.1. Equipment costs

One feature that adds some costs for 120-volt HPWHs is the integration of the thermostatic mixing valves. These are generally not installed on 240-volt HPWHs but come standard on many 120-volt HPWHs. However, TMVs will be installed on all SGIP/TECH-incented 240-volt HPWHs in CA. And more than half of the 240-volt HPWHs in WatterSaver already had TMVs installed. Manufacturers expect mixing valves to cost $250. This additional feature will slightly increase costs for the 120-volt HPWH compared to their 240-volt counterparts. Table 6 shows equipment cost estimates for 240-volt HPWHs, electric resistance, natural gas, and propane storage tank water heaters. The results show that HPWHs have higher equipment costs than other conventional water heaters.

The 120-volt HPWH may also need a larger tank size. In Table 6, we see that a 65-gallon tank is around $300 more expensive than the 50-gallon tank. Due to the high variability around water heater equipment costs, we chose one retailer for prices. These estimates are based on 2023 prices from Home Depot retailers in California.[17]

TABLE 6. WATER HEATER EQUIPMENT COST ESTIMATES

	Average Equipment Costs*			
	40 Gallon	50 Gallon	65 Gallon	80 Gallon
120-volt HPWH with mixing valve	-	$2,350	$2,630	$3,040
240-volt HPWH	-	$1,700	$2,270	$2,690
Natural gas water heater	$700	$800	-	$1,600
Propane water heater	-	$900	-	$1,400

*Without retailer discounts or utility incentives

3.2.2. Home electrical upgrade cost savings and installation findings

The 120-volt HPWH is designed to reduce cost and complexity that customers may incur from installing a standard 240-volt HPWH in a fuel switching retrofit. Replacing a gas water heater with a HPWH with a proximate shared circuit plug point resulted in time efficient and cost-effective replacements. Without availability of this technology,

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[17] Home Depot. Hybrid Water Heaters. Prices are based on entry-level models without premium features for both HPWHs and gas-fired water heaters to obtain a fair comparison.

replacement would not have been possible over one visit from the installation team (see electrical site selection criteria in section 4.4 below).

Table 7 shows the estimated cost savings from a 120-volt HPWH in a fuel switching retrofit. Due to differing existing electric equipment in homes, certain buildings may be more or less likely to have electric upgrade cost savings by opting for a 120-volt HPWH. We estimated cost data through invoices from other projects in California and from RHA's expertise working on full house electrification projects. We have included a range and typical cost estimate for each intervention because cost estimates have significant variation. These results show that 120-volt HPWHs can provide significant cost savings for power-constrained households (100-150-amp panel capacity).

TABLE 7. HOME ELECTRIC UPGRADE INTERVENTIONS AND COSTS 120-VOLT HPWH

Intervention	Percent of Installations Requiring Intervention	Cost Range	Typical Cost
Permit	100%	$75-200	$200
Extension of shared circuit	40%-60%	$100-500	$100

*Based on the installer invoices, labor costs vary by area.

TABLE 8. HOME ELECTRIC UPGRADE INTERVENTIONS AND COSTS 240-VOLT HPWH

Intervention	Percent of Installations Requiring Intervention	Cost Range	Typical Cost
Permit	100%	$75-200	$200
Dedicated circuit	100%	$400-$1,500	$800
Replacement panel or subpanel without amperage service upgrade**	15-45%	$2,000-$5,000	$3,000
Amperage service upgrade**	10%	$3,000-$28,000	$15,000

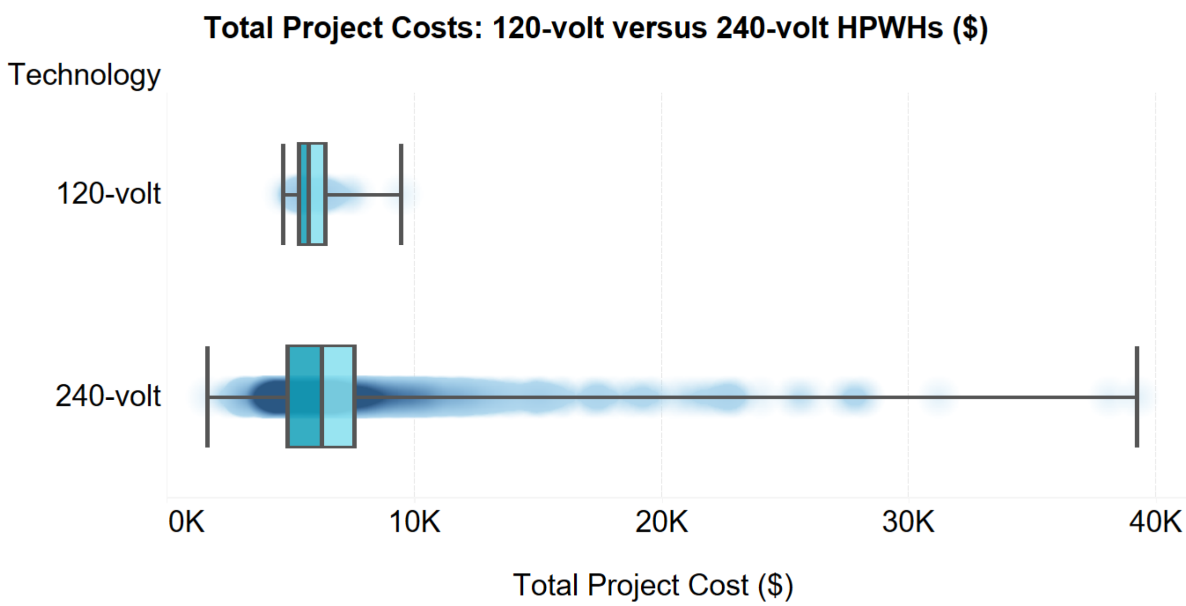
** Based on partner experience on electrification installations. May require additional evaluation. The prices will vary based on conditions and regions.

The 120-volt HPWHs saved between $800 and $15,000 per household compared to 240-volt HPWH installation, primarily due to the minimal electrical interventions. Based on the installer feedback, 120-volt HPWHs were also faster to install, making them ideal for emergency replacements.

Depending on ease of installation, distance driven, and materials required, the invoices ranged from $2,600 - $4,600 for 120-volt HPWHs.[18] The two installers for this study took anywhere from 4 to 7 hours to complete installation. The median total project cost (install and equipment cost) for this study, not including Climate Zones 1 or 16, was $5,758. According to the TECH Working Data set, which tracks equipment installations that received TECH funding, 240-volt HPWH installations with rated storage volume between 50 and 80 gallons often cost well over $10,000, with a median of $6,500.[19]

Figure 5 displays the distribution of total project costs for this study versus that of 240-volt HPWHs using TECH data.

FIGURE 5. TOTAL PROJECT COSTS: 120-VOLT VS. 240-VOLT HPWHS ($)



[18] Installers received a $3,100 incentive per HPWH installation, which may have inflated installation costs.

[19] TECH Clean California. TECH Working Data Set.

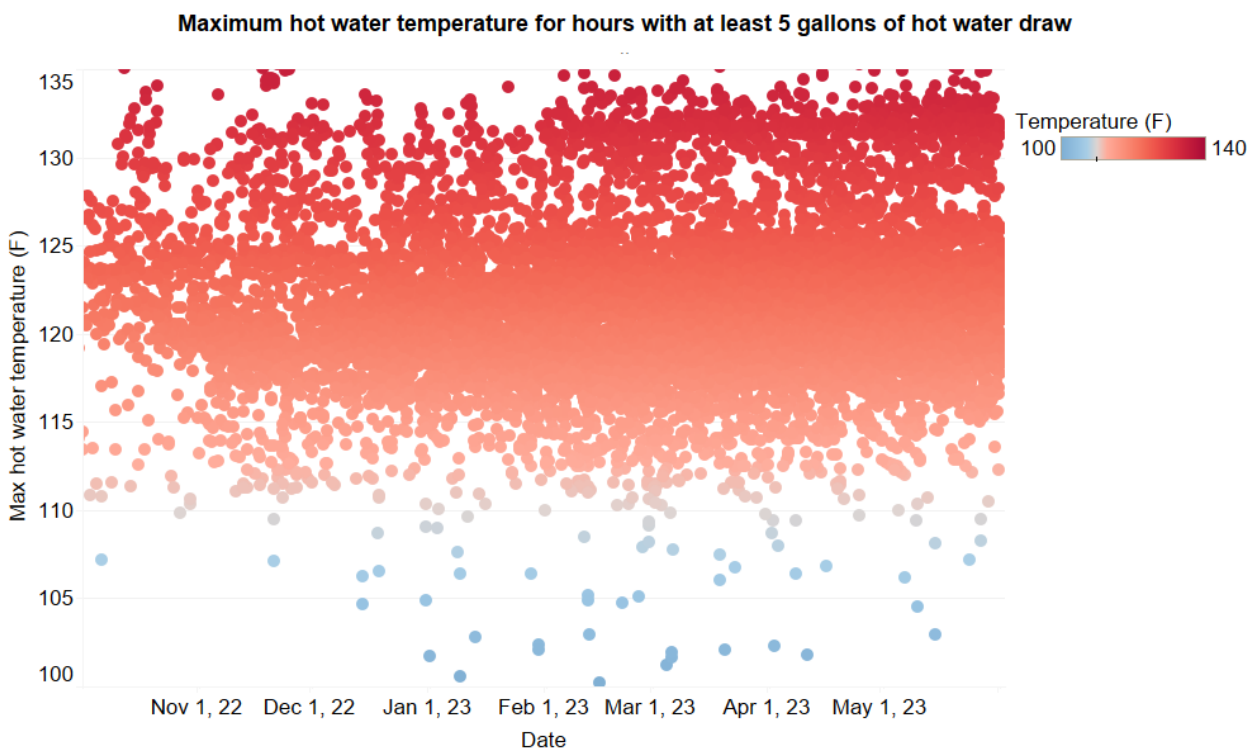
3.3. Performance of the 120-volt HPWHs

The sections below summarize the efficiency of the 120-volt HPWHs based on the monitoring data and how well they were able to meet hot water demands.

3.3.1. Hot water delivery results

We monitored all the sites for the hot water delivery temperatures. Currently, there is no industry standard or metric to evaluate hot water comfort. Based on the qualitative data, we assume that hot water demands are met if the water coming out of the water heater does not go below 110°F (Maguire A. 2018). However, Rheem recommends that showers do not exceed 105°F and that 100°F is a comfortable shower temperature,[20] so the monitored delivery temperature could fall into this range without users complaining of a hot water runout event. Figure 6 shows the hourly hot water outlet temperature for all the sites. The hot water delivery temperature typically does not fall below the setpoint temperature range of 115-125°F. F. F, and overall, even the high demand sites have a delivery temperature of above 100-105°F

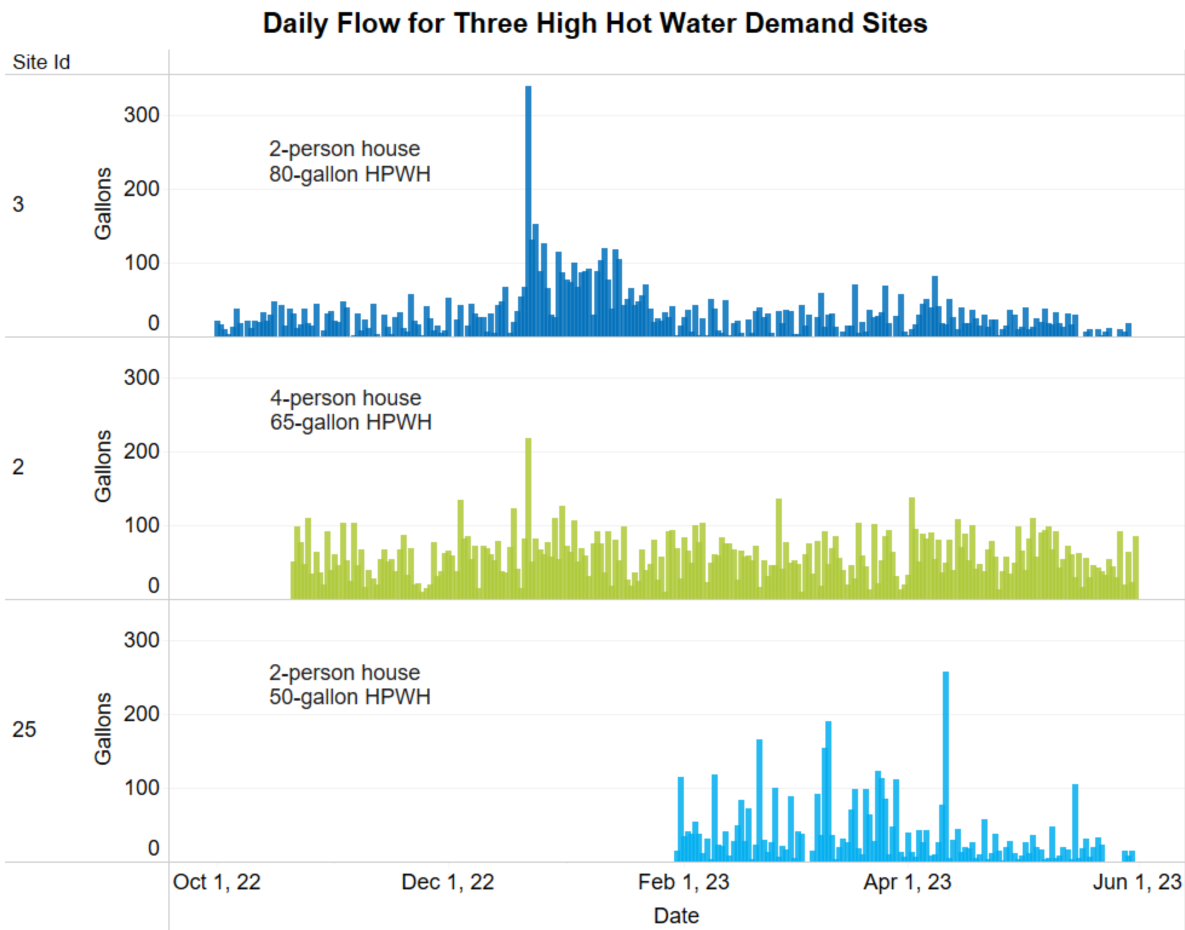
FIGURE 6. HOURLY HOT WATER SUPPLY (DELIVERY TEMPERATURE) FOR ALL THE SITES



[20] Rheem. What is the Ideal Temperature to Shower in? Showering above 105°F may have negative health consequences, such as eczema.

While a deliberate attempt was made to select sites that are low to medium occupancy (2–4 person household), we did have some sites with sporadic daily demand of 100+ gallons per day, and as high as 300 gallons per day during the holiday season. For context, a typical household hot water demand is 45[21] gallons per day (gphd). See Figure 7 below, which shows the typical draw profile and tank sizes of the customers with high hot water demand.

FIGURE 7. DAILY HOT WATER DEMAND AND TANK SIZES

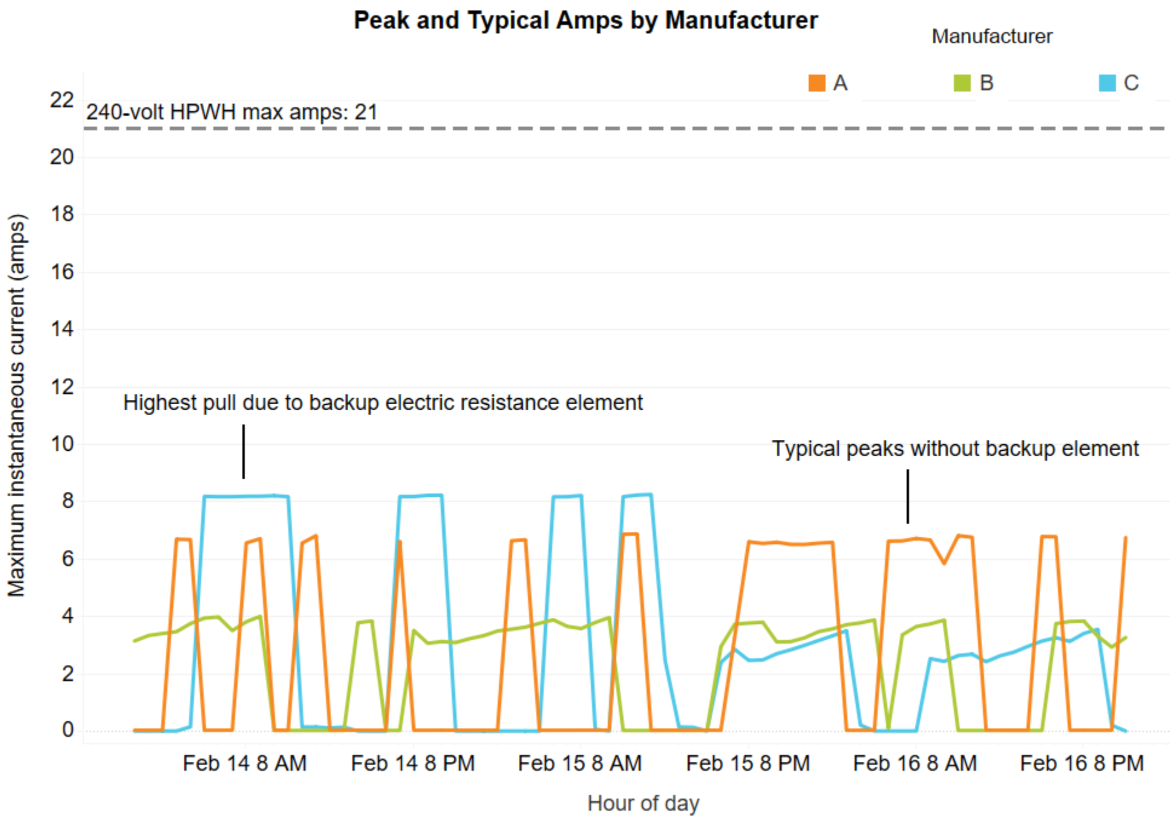


[21] Water Research Foundation. Residential End Uses of Water, Version 2.

3.3.2. Compressor power consumption and run time

These are indeed very low amperage draw heaters, while rated at 15 amps[22] they were only pulling 4-6 amps of current during the monitoring period. shows the maximum instantaneous amperage[23] at the hourly timescale for a two-day period, with each manufacturer model in the study. The 120-volt HPWH with a small backup electric resistance element pulled the highest amps but did not exceed 8 amps. The typical 240-volt amperage is shown for reference.

FIGURE 8. HOURLY MAXIMUM CURRENT DRAW BY MANUFACTURER OVER A THREE-DAY PERIOD

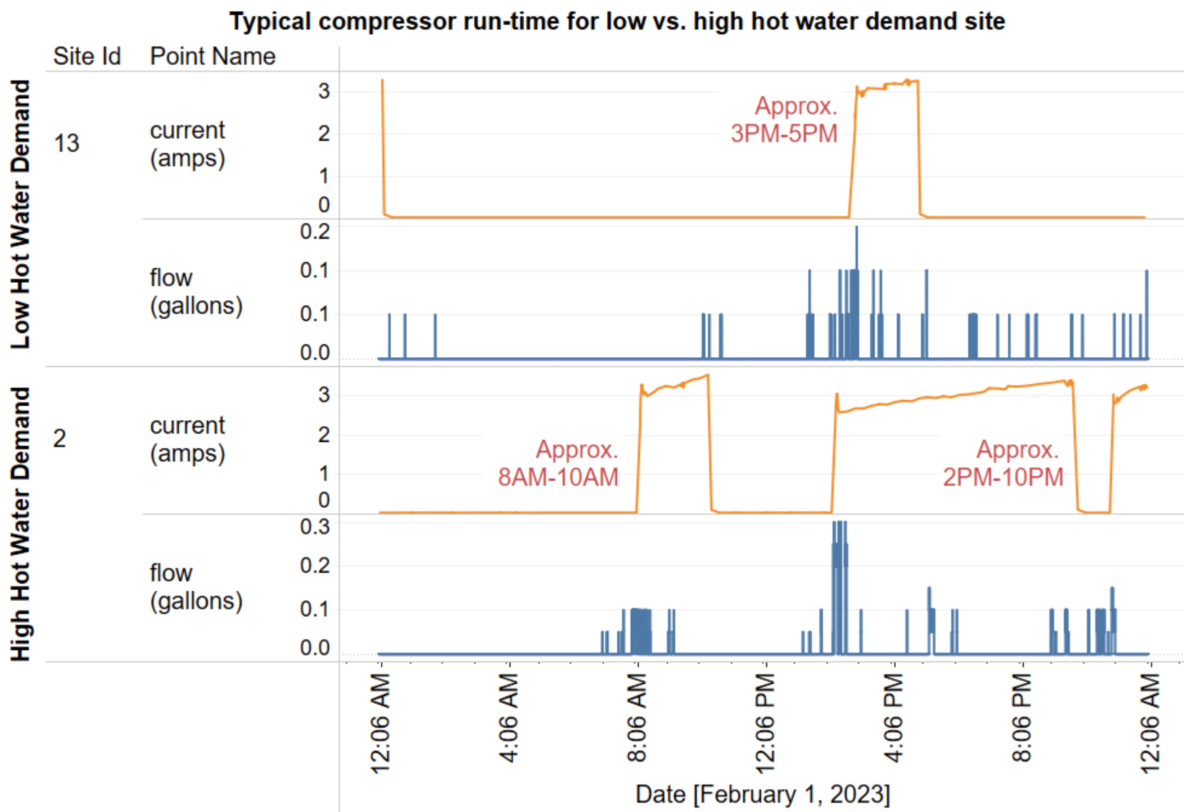


[22] The amperage is for "electrical current," which is measured in amperes (amps). It describes the amount of electrical charge that is flowing through a system.

[23] The wattage is a measure of electric power expressed in watts.

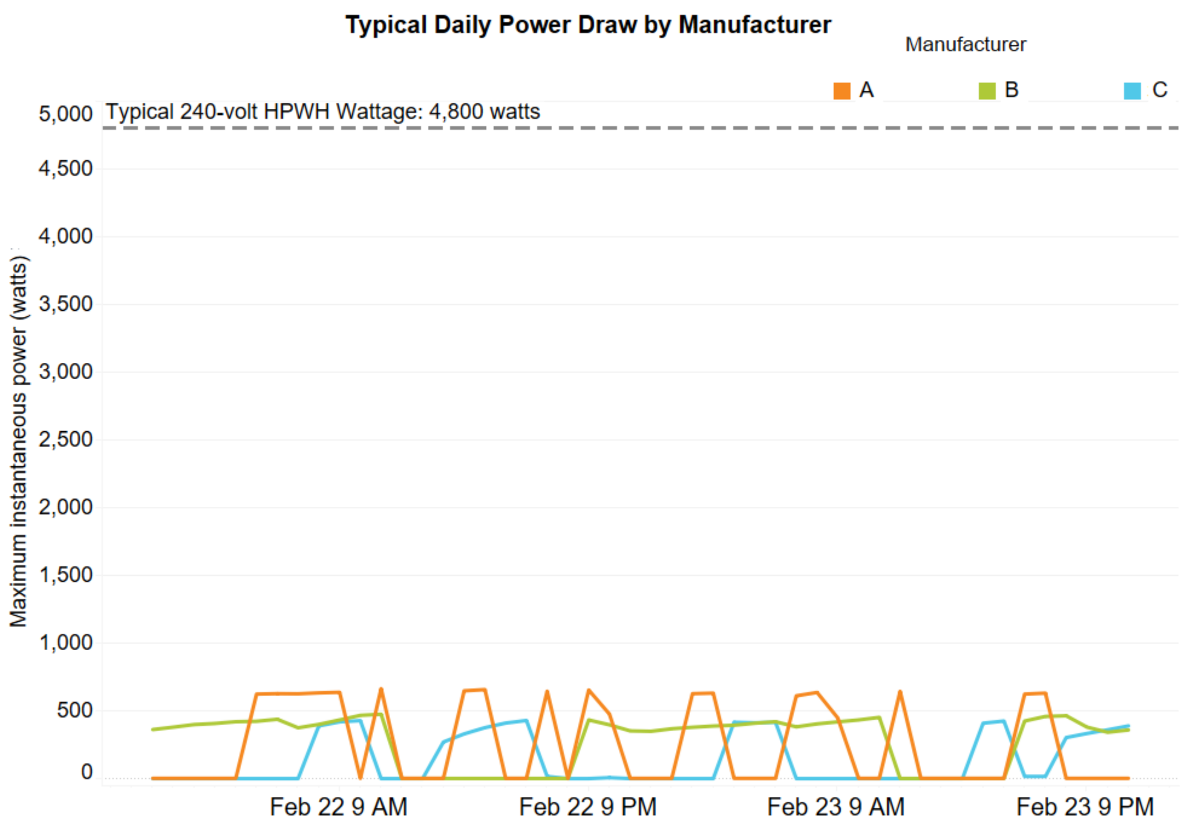
We also observed that the compressor runtime varies by site. An example is shown in Figure 9 below. The top pane shows a site with low hot water demand, and the lower pane represents a high hot water user. Both sites received units from the same HPWH manufacturer. The run time and period depend on hot water usage and draw patterns; for the low use site, the compressor only ran about 2 hours over the day shown here, but for the high use site it ran for 10 hours. As shown, we did see the compressor come on during the 4:00 to 9:00 PM statewide peak at more than only these two sites, highlighting the need for this technology to be grid interactive.

FIGURE 9. A TYPICAL DAILY COMPRESSOR RUN TIME



The maximum power draw varies by 120-volt HPWH model. Figure 10 provides a snapshot of maximum hourly power consumption over the course of three days at a single site, for each manufacturer. The manufacturer with the electric resistance element sees a draw of up to 900-1,000 Watts while in the high-capacity setting (note that this site correlates to one of the highest hot water users in the study). The other manufacturers see a maximum power draw between 450 and 600 Watts. The typical 240-volt HPWH wattage is shown for reference.

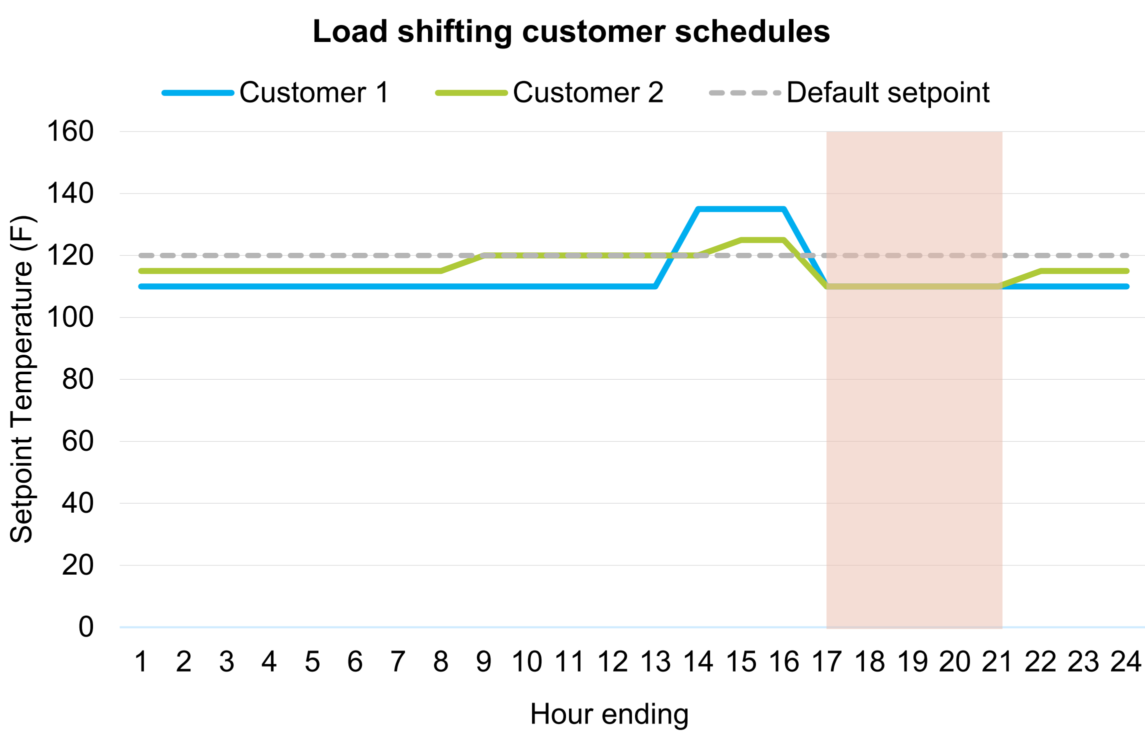
FIGURE 10. TYPICAL DAILY POWER DRAW BY MANUFACTURER VERSUS TYPICAL 240-VOLT HPWH POWER DRAW (WATTS)



3.3.3. Load shifting customers

Three customers opted into load shifting. Two customers utilized a setpoint-based approach, adjusting the setpoint temperature and mixing valve to modulate the amount of hot water in the tank. One of those two customers opted for an aggressive load shift, keeping their HPWH at 110°F for all hours other than 1:00 PM to 4:00 PM, to ensure no energy use during the peak period from 4:00 PM to 9:00 PM (Customer #1, shaded blue in Figure 11 below). The other customer (Customer #2 in Figure 11) elected to take a more nuanced approach, keeping their HPWH at 115°F from the end of the peak period (9:00 PM) to 8:00 AM, then increasing to 120°F until 2PM, increasing further to 125°F until the peak period start at 4:00 PM, and decreasing to 110°F during the peak period.

FIGURE 11. SUMMARY OF LOAD SHIFTING CUSTOMER TEMPERATURE SCHEDULES

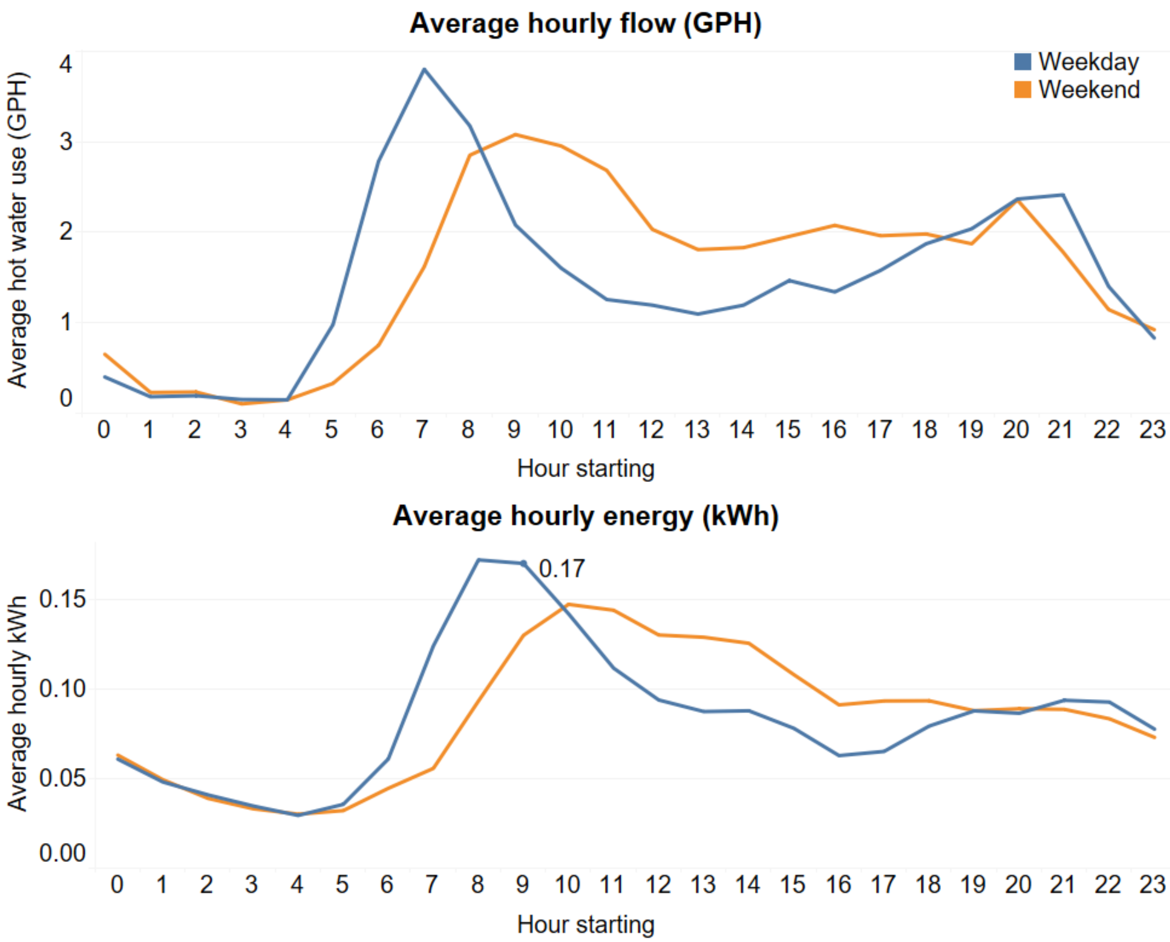


The third customer left the setpoint constant (125°F) and utilized a compressor-based approach through the manufacturer control logic. In this case, the unit was scheduled to start a heating cycle three hours before the peak period, ensuring that the tank would be full of hot water once the peak period began. This customer had a slightly different peak period than the other customers which only lasted three hours, and the heat pump water heater was set to remain completely off unless it becomes fully depleted of hot water. At the end of the peak period, the operating logic returned to normal. This approach may be best suited to lower hot water users.

3.3.4. Energy and flow relation

The hot water use was averaged to develop hourly use shape profiles for weekdays and weekends, shown in Figure 12. Hot water demand peaks between 7:00 AM and 8:00 AM on weekdays, and between 9:00 AM and 10:00 AM on weekends. The instantaneous power readings from the monitoring equipment were also used to calculate the average hourly kWh consumption for each site. The hourly energy usage across all 32 sites was averaged to create the hourly electrical load shape profile for weekdays and weekends shown in Figure 12. The average 120-volt HPWH load peaks between 8:00 AM and 10:00 AM on weekdays. On weekends, the peak is two hours later and slightly lower overall.

FIGURE 12. HOURLY HOT WATER DEMAND PROFILE AND ENERGY LOAD PROFILE ON WEEKDAYS AND WEEKENDS, AVERAGED ACROSS ALL SITES



The average daily energy and hot water use by season and day type (straight average of all sites) is shown in Table 9. Summer months include June through September. Note that many sites were not installed until December or January; the sample size for summer months is limited. In line with previous studies, we found that average hot water use is much less than the 64 gallons per day used in the DOE performance test, and less than the "first hour rating" required by regulations. This lines up with our finding that most users report 120-volt HPWH can keep up with their hot water demands.

TABLE 9. AVERAGE ENERGY AND HOT WATER USE BY SEASON AND DAY TYPE

	Average Daily Energy Use, kWh		Average Daily Hot Water Use, Gallons	
	Weekday	Weekend	Weekday	Weekend
Summer Only	0.97	0.96	23	26
Non-Summer	2.07	2.10	36	38
Overall Average	2.01	2.05	35	37

3.3.5. Energy Factor results

Three metrics quantify the efficiency of a HPWH. They are defined as follows:

- **Energy Factor:** This is the amount of heating provided by the heat pump system to the water in the tank, per unit of electrical power supplied. This metric does include storage (tank) losses, so it must be measured over the course of a cycle during which the tank temperature returns to the same value it had at the beginning of the cycle. One day is a convenient cycle length to use in practice.
- **Department of Energy (DOE) Energy Factor:** This is the energy factor of the HPWH in the context of a specific DOE test that prescribes delivery and supply temperatures, supply volume, and test duration.[24] Due to the high supply volume prescribed by the test method, DOE energy factor values are higher than those achieved in practice.
- **Coefficient of Performance (COP):** The instantaneous heating power supplied to the house by the heat pump, per unit of electrical power supplied, while the compressor is operating. This metric does not include any storage (tank) or distribution losses. Throughout the report, we will use the term Energy Factor (EF) to describe the 120-volt HPWH performance.

Table 10 provides a summary of the DOE rated EF (average of the three manufacturers whose units were installed), and the calculated daily average EF for cold climate sites (CA climate zones 1 and 16), warm climate sites (CA climate zones 10-14), and the combined average for all sites.

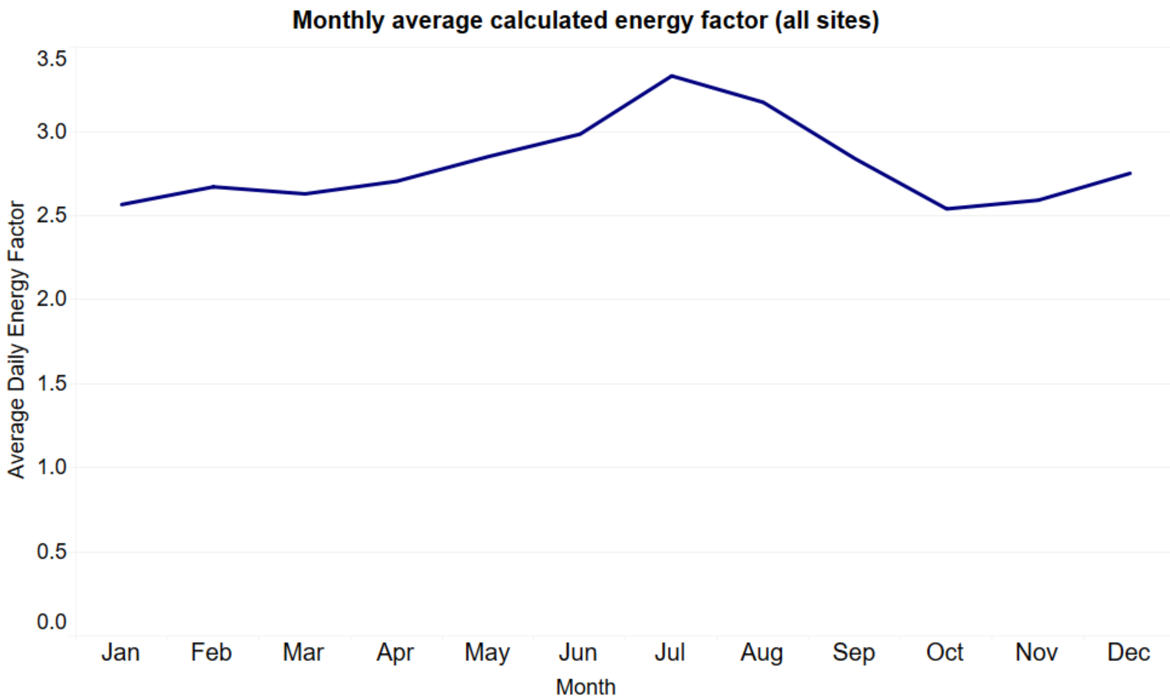
TABLE 10. OVERALL ENERGY FACTOR RESULTS

	DOE Rated EF	Calculated Daily EF		
		All Sites	Cold Climate Sites	Warm Climate Sites
Summer Only	N/A	3.27	*Insufficient data*	3.10
Non-Summer	N/A	2.88	2.60	2.80
Overall Average	2.98	2.90	2.60	2.82

[24] Test conditions include: 64 gallons/day, 135 ºF tank temperature, 58 ºF inlet water temperature, 67.5 ºF ambient air temperature and 50% relative humidity. See 10 CFR Appendix E to Subpart B of Part 430.

The overall straight average daily energy factor for all sites, by month, is shown in Figure 13.

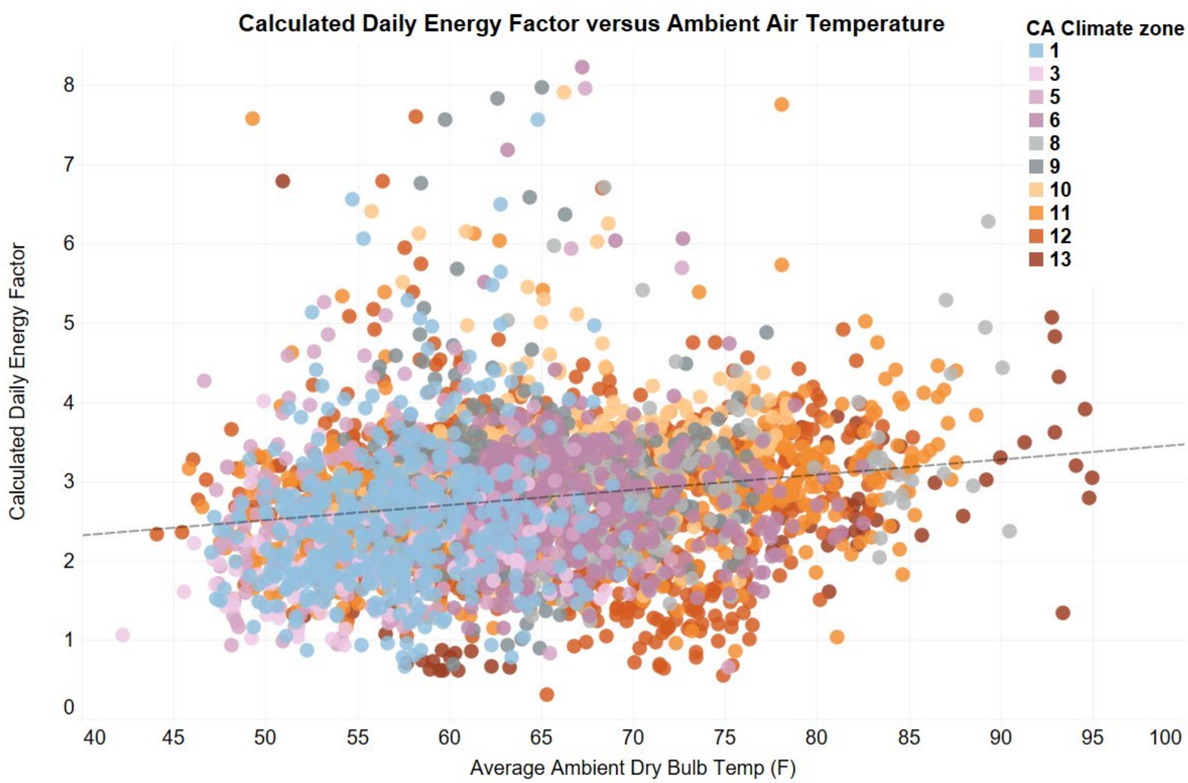
FIGURE 13. AVERAGE DAILY ENERGY FACTOR FOR ALL SITES, BY MONTH OF MONITORING PERIOD



3.3.5.1. HPWH Energy Factor vs. ambient space temperature

As described above, ambient air temperature is one of the key variables that impacts HPWH performance. As Figure 14 shows, energy factor increases at higher ambient air temperatures.

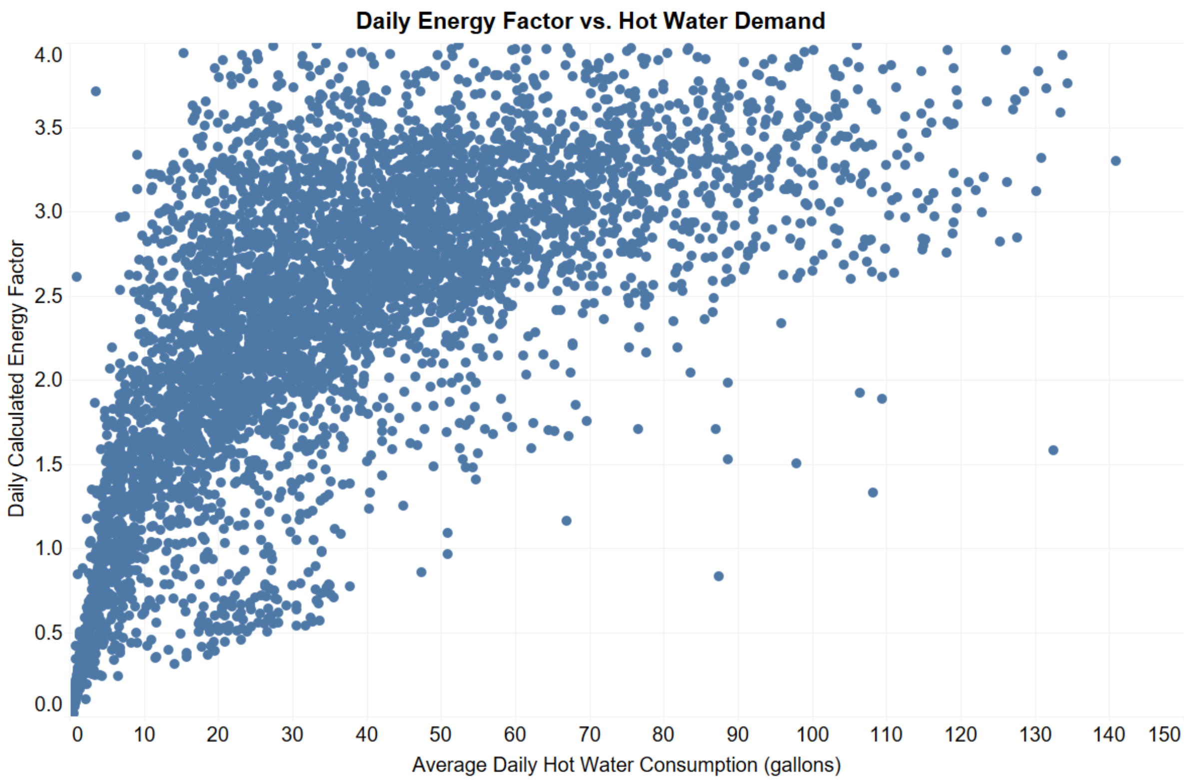
FIGURE 14. DAILY AVERAGE ENERGY FACTOR VS AMBIENT DRY BULB AIR TEMPERATURE



3.3.5.2. HPWH Energy Factor vs. water consumption

Figure 15 below summarizes daily average energy factor compared to hot water consumption of each site (gallons per day). The relationship between the gallons of hot water and performance shows that the energy factor improves as the hot water consumption increases. Days with less than 10 gallons of hot water consumption are excluded; short, low-volume draws provide less accurate energy factor results.

FIGURE 15. DAILY AVERAGE ENERGY FACTOR VS DAILY HOT WATER DEMAND

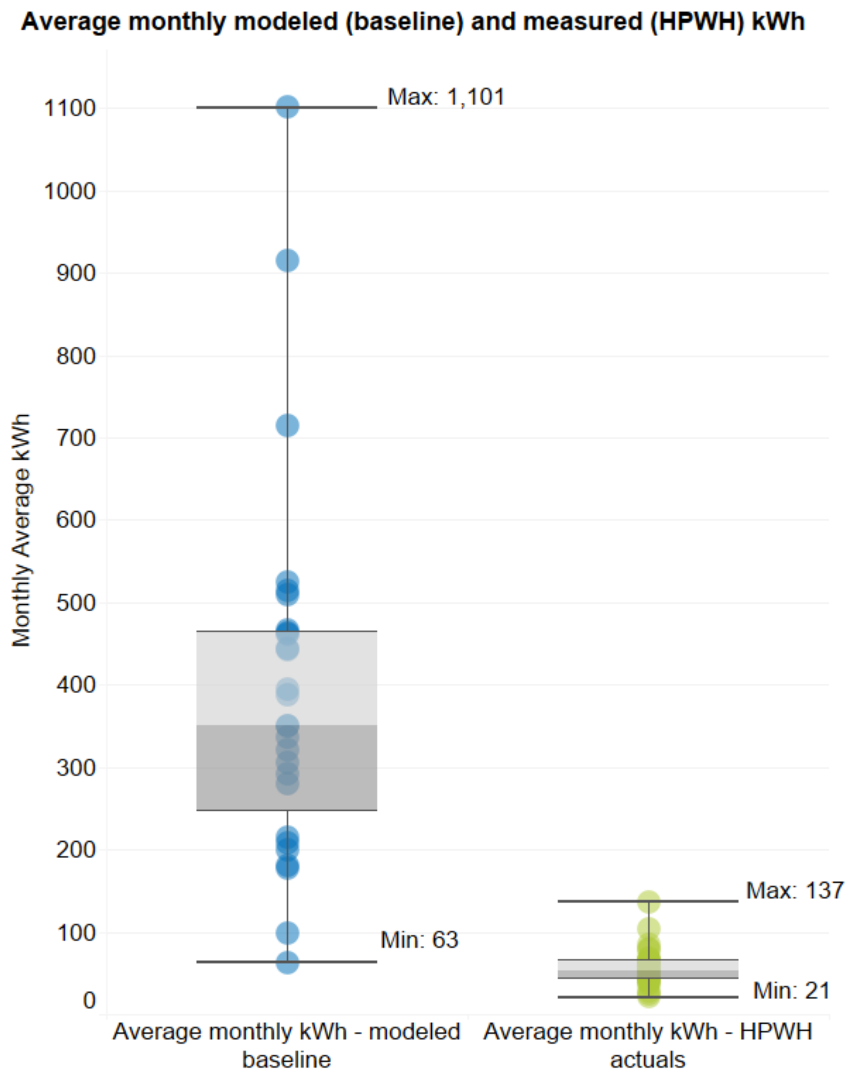


3.4. Site energy savings analysis

The methodology for modeling the energy consumption of the pre-existing water heater is described in Appendix A. The modeled monthly energy use of the pre-existing gas or propane water heater (in kWh)[25] as compared to the average monthly energy use of the 120-volt HPWHs is shown in

Figure 16. Using the 25^{th} to 75^{th} percentile of monitored data, we can estimate that monthly consumption of the 120-volt HPWH would be between 42 kWh and 66 kWh.

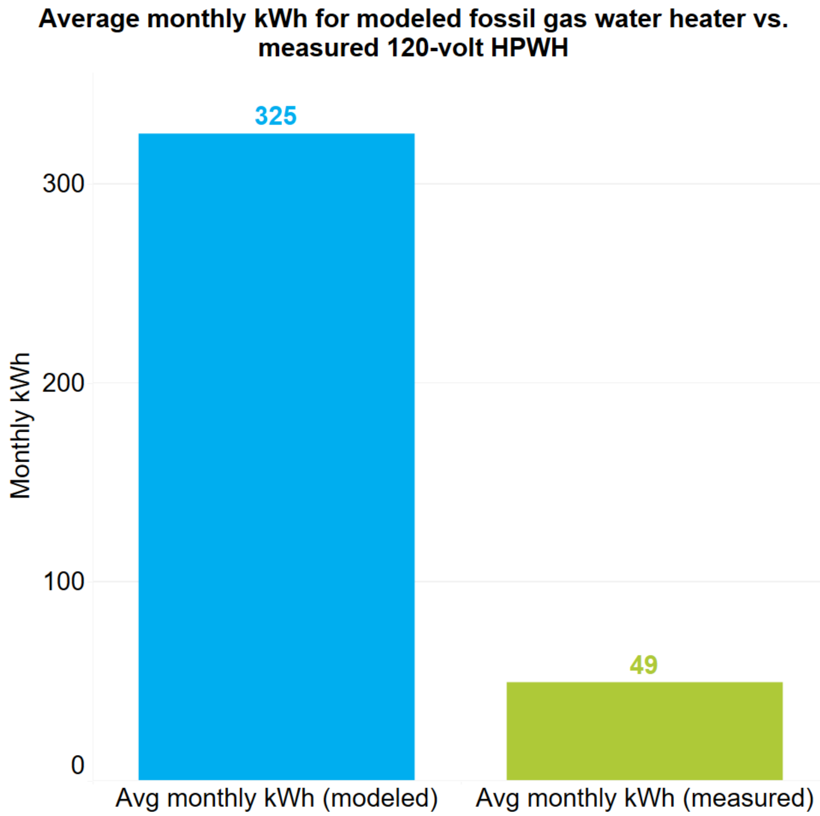
FIGURE 16. MONTHLY AVERAGE ENERGY USE OF PRE-EXISTING GAS OR PROPANE WATER HEATER (MODELED, UNITS CONVERTED TO KWH) AND 120-VOLT HPWH (MEASURED)



[25] Therm consumption for gas water heaters was converted to kWh at a rate of 29.3 kWh per therm.

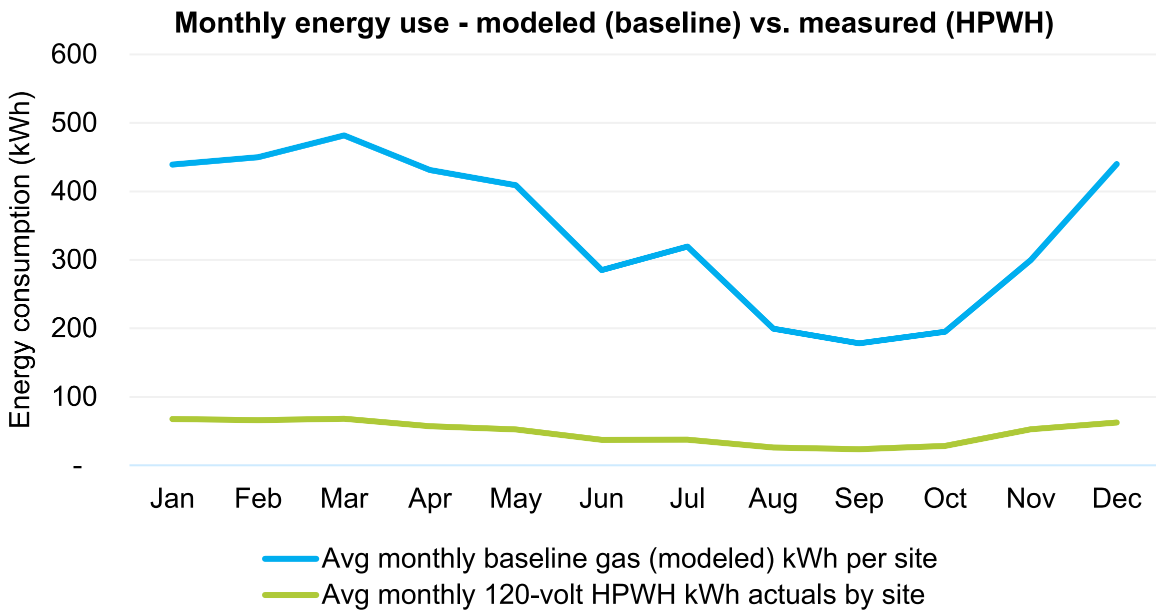
The average energy savings as compared to the gas or propane pre-existing water heater is shown in Figure 17savings between 60 and 700 kWh per month, based on the water use and the characteristics of the pre-existing gas or propane water heater. An average monthly energy consumption savings of 85% was seen in comparison to the pre-existing gas water heater and 82% for a propane water heater replacement when normalized to kWh.

FIGURE 17. AVERAGE MONTHLY ENERGY CONSUMPTION (KWH), GAS OR PROPANE WATER HEATER (MODELED) VS 120-VOLT HPWH (MEASURED)



The comparison of average monthly energy consumption is shown in Figure 18.

FIGURE 18. MONTHLY COMPARISON OF GAS OR PROPANE WATER HEATER ENERGY CONSUMPTION (MODELED) VS. 120-VOLT HPWH CONSUMPTION

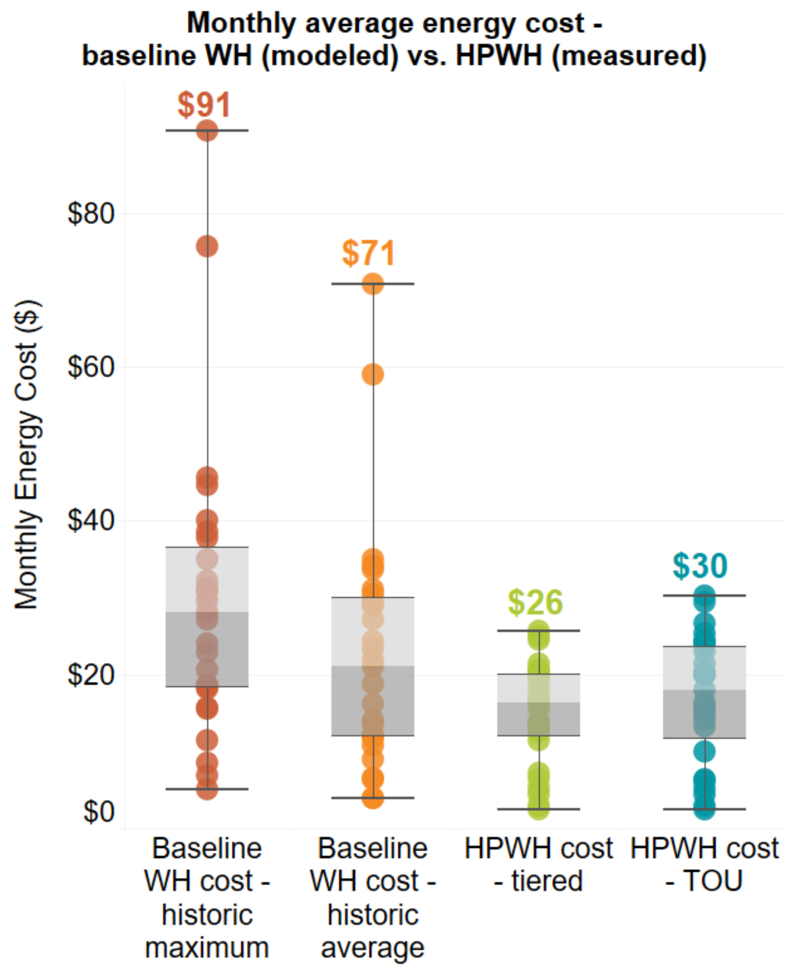


3.5. Operating cost analysis

While average energy savings are consistent across utility regions, the operating cost savings vary based on the utility rate structures and load profiles of the household. The field monitoring found average monthly operating costs for 120-volt HPWHs were reduced by more than 50% compared to modeled gas water heaters for PG&E and SMUD customers. Whereas for SCE customers, the operating costs during summer months were comparable to fossil fuel fired water heaters but during winter months there was a slight increase due to decreased heat pump efficiency from colder air and water temperatures. This was also due to the lower gas prices in Southern California Gas territory. The overall operational cost savings from the field monitoring in California utility territories, with some of the highest electricity costs in the nation, bodes well for savings in other parts of the United States.

The average monthly cost of 120-volt HPWH operation under both a tiered and time-of-use (TOU) rate structure, as compared to the gas cost of the pre-existing water heater under the same use profile, is shown in Figure 19. For the participating customers, the median monthly operating cost of the 120-volt HPWH is similar regardless of the electric rate structure ($14/month for tiered vs $16/month for TOU). Once the water heaters are grid connected and controlled for daily load-shifting optimization (phase 2 of the study), the cost for customers on a TOU rate structure is expected to be lower than a tiered structure.

FIGURE 19. AVERAGE MONTHLY 120-VOLT HPWH TIERED AND TOU ELECTRIC COST VERSUS GAS MODELED MONTHLY COST (MULTIYEAR AVERAGE RATE AND MULTIYEAR MAX RATE)

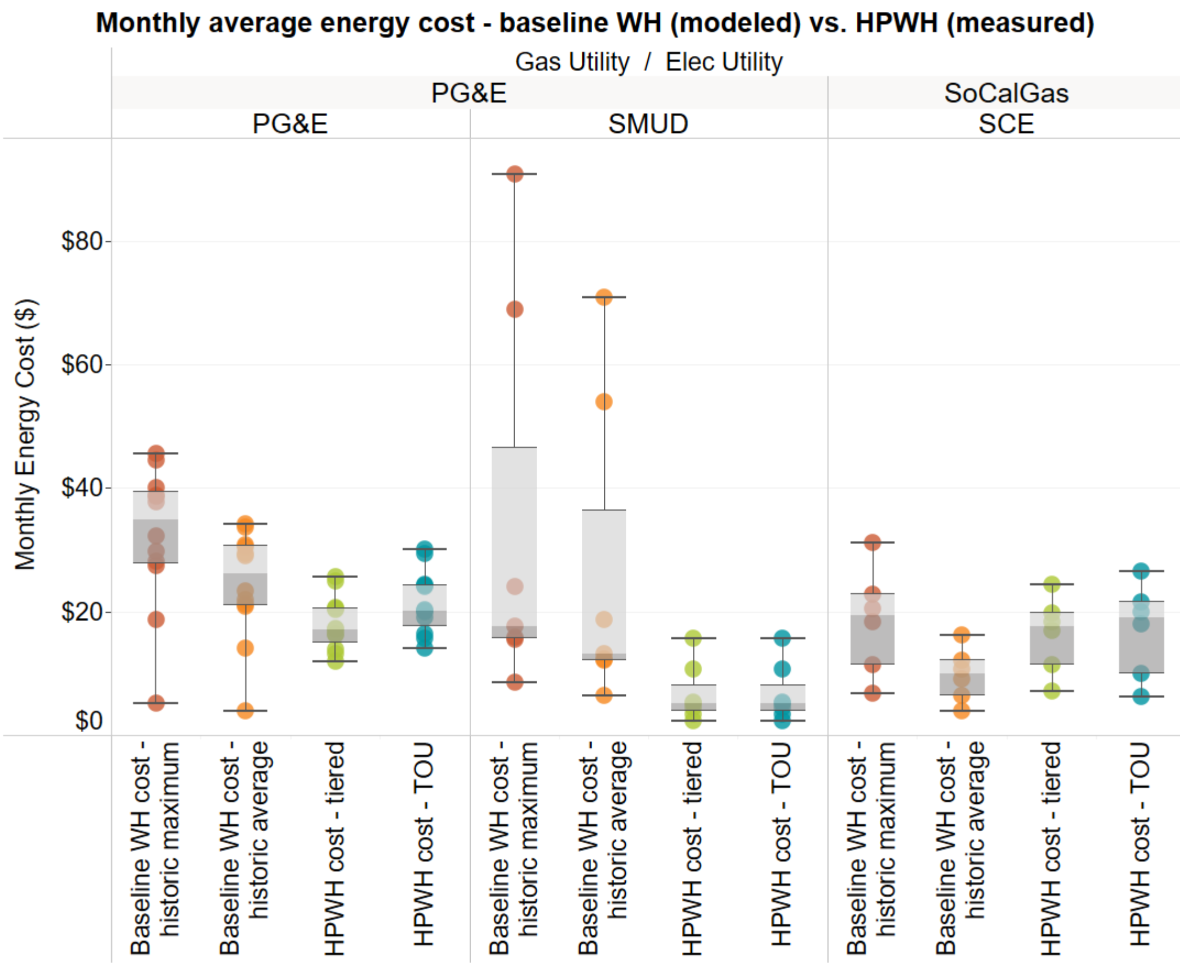


The monthly energy cost savings of the 120-volt HPWH as compared to the pre-existing gas water heater are highly dependent on specific utility rates. Figure 20 summarizes the difference. Under PG&E's and SMUD rate structure, the median monthly HPWH operating cost is consistently lower than the modeled median monthly energy cost of the pre-existing gas water heater. Some positive feedback that confirms the operating cost savings from the customers is quoted below:

> *"Overall, the unit is working very well and our experience is very similar to the gas unit it replaced. I believe our gas bill is much lower than the increase in the electric bill. I anticipate adding a schedule to the unit, so it does not operate during the peak rate time, but with SMUD winter rates the difference is negligible."*

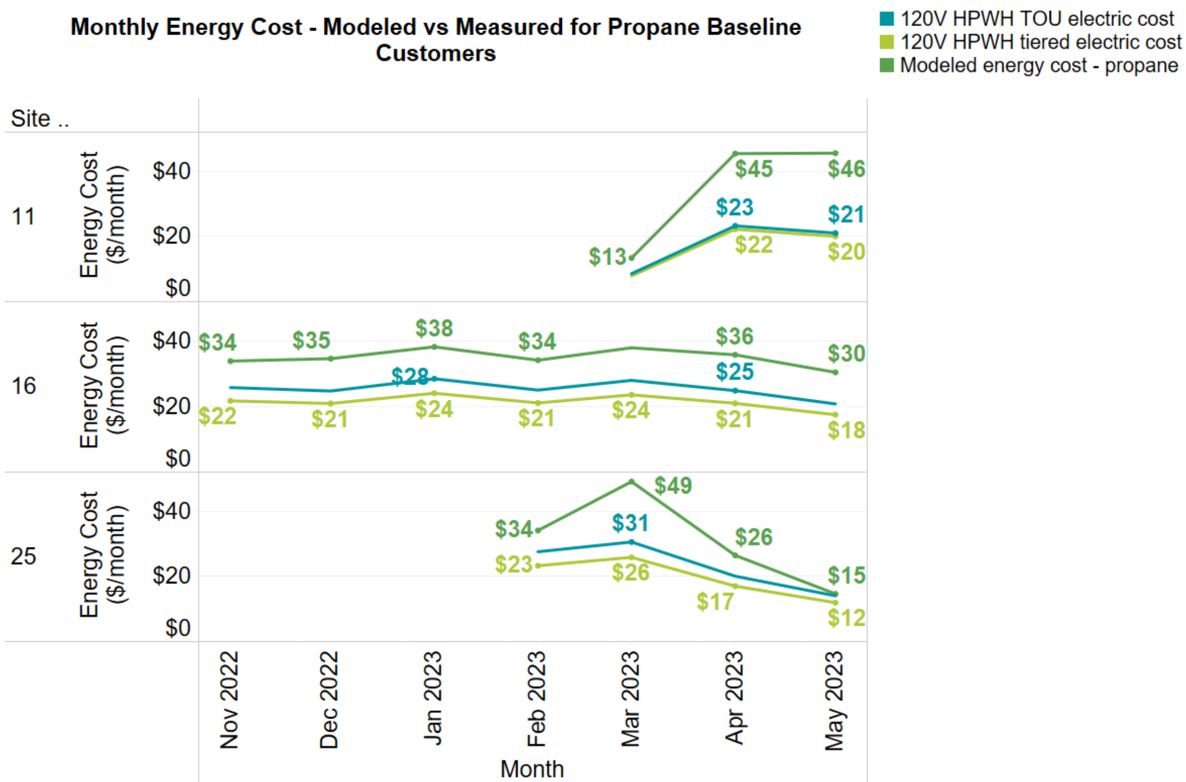
For SCE, where gas rates are lower, the median monthly HPWH energy cost is up to $9 more than the modeled gas water heater when comparing against the historic average gas rates.

FIGURE 20. UTILITY-SPECIFIC AVERAGE MONTHLY 120-VOLT HPWH TIERED AND TOU ELECTRIC COST VERSUS MODELED GAS WATER HEATER MONTHLY COST (MULTIYEAR AVERAGE RATE AND MULTIYEAR MAX RATE)



The pre-existing water heater for three participants was propane, as opposed to utility-delivered gas. The fuel switching yields 26% to 41% savings on monthly operating costs for propane customers. Figure 21 summarizes the monthly energy cost comparison for these customers.

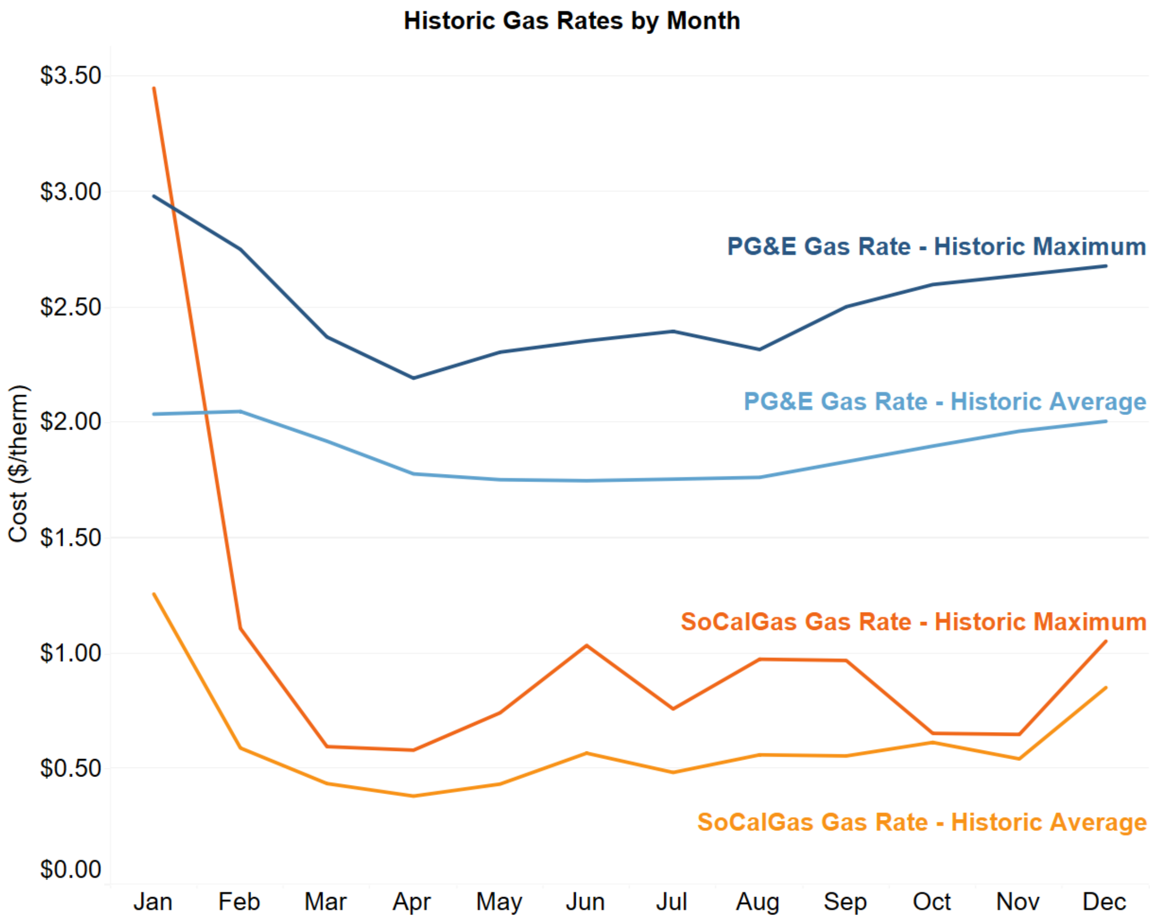
FIGURE 21. MONTHLY ENERGY COST COMPARISON FOR PROPANE CUSTOMERS.



3.5.1. Energy costs

The energy costs for the modeled usage (pre-existing gas or propane water heater) and measured usage (heat pump water heater) are based on hourly data outputs from the model and measured power use at the water heater, respectively. To account for fluctuations in gas and propane prices, six years of provider-specific monthly gas cost data (2017-2022) were aggregated into an average and maximum monthly cost. Propane data was based on calendar year 2022 averages. The results of the historic monthly rate analysis for gas rates in PG&E and SCE territories are shown in Figure 22.

FIGURE 22. PG&E AND SOCALGAS (SCE TERRITORY) MONTHLY HISTORIC GAS RATES.



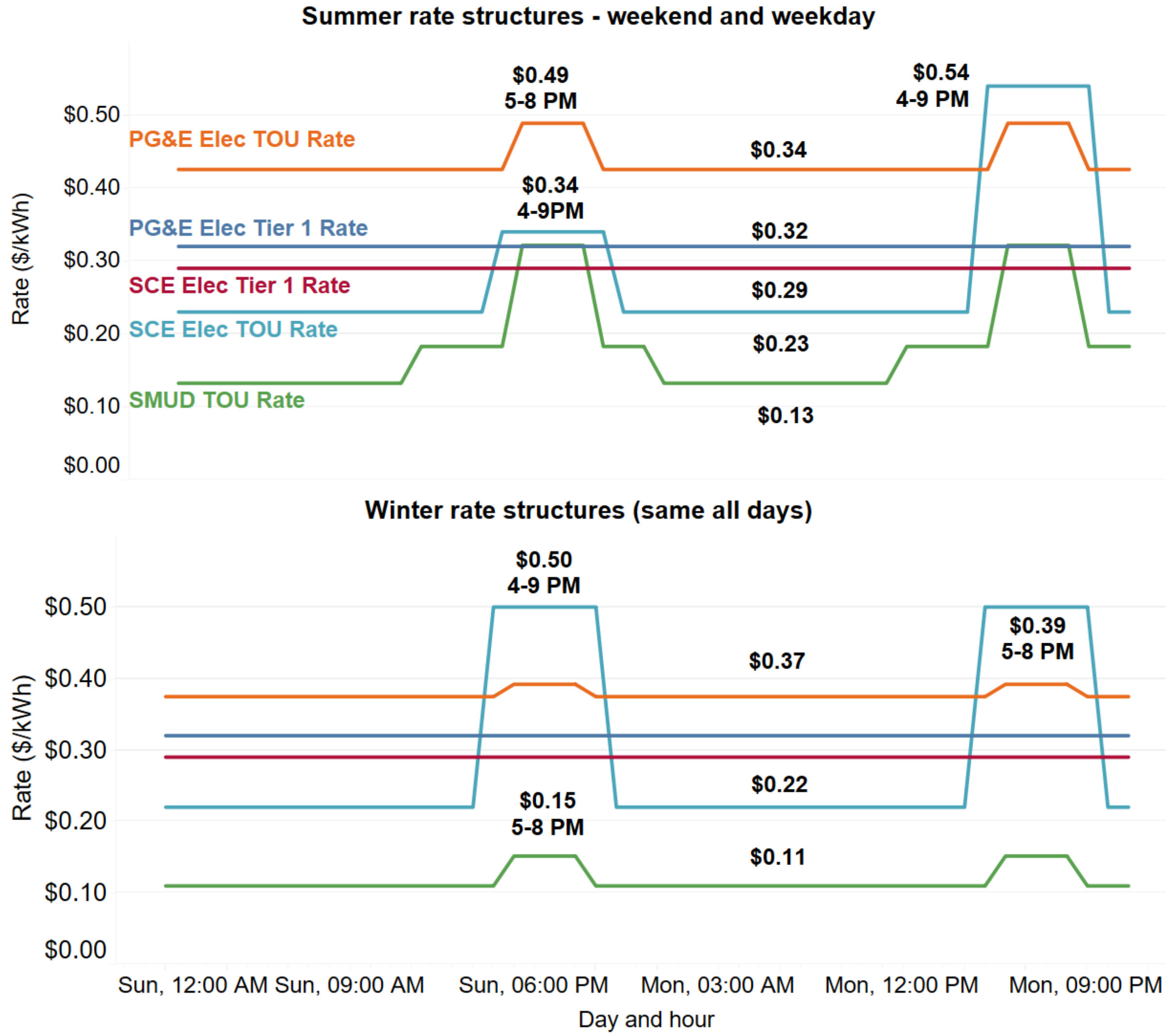
The energy costs for the heat pump water heaters are calculated using an hourly approach. Time-of-use or tiered rates based on the serving utility's current rate structure, factoring in time of day, day of week, and season, are applied to the hourly power draw from each site.

Note that this financial analysis did not look at the impact of the baseline allocation changes with fuel switching (from gas to electric). The tiered rates are not accounting for the use above the baseline allocation. The tired rates will be phased out by all the utilities soon so the costs under TOU rate structures will be most relevant in the near future.

TABLE 11. TIME-OF-USE RATES BY UTILITY

Rate Name	Value	Unit	Rate Category
PG&E & SMUD Gas Rate	See Figure 22	$/therm	Blended 2022 Average Non-CARE + G-PPPS
SoCalGas Gas Rate	See Figure 22	$/therm	Blended Current Rate
SCE Elec TOU-D Rate	$0.22	$/kWh	Winter Off-Peak
	$0.50	$/kWh	Winter On-Peak (4-9PM)
	$0.23	$/kWh	Summer Off-Peak
	$0.54	$/kWh	Summer Weekday On-Peak (4-9PM)
	$0.34	$/kWh	Summer Weekend On-Peak (4-9PM)
PG&E Elec TOU-C Rate	$0.37	$/kWh	Winter Off-Peak
	$0.39	$/kWh	Winter On-Peak (5-8PM Daily)
	$0.43	$/kWh	Summer Off-Peak
	$0.49	$/kWh	Summer On-Peak (5-8PM Daily)
SCE Elec Tier 1 Rate	$0.29	$/kWh	Tier 1 rate
PG&E Elec Tier 1 Rate	$0.32	$/kWh	Tier 1 rate
SMUD TOU 5-8PM	$0.13	$/kWh	Summer Off-Peak
	$0.18	$/kWh	Summer Mid-Peak (12-5PM, 8-12AM)
	$0.32	$/kWh	Summer Peak (5-8PM)
	$0.11	$/kWh	Non-Summer Off-Peak
	$0.15	$/kWh	Non-Summer Peak (5-8PM)
Propane	$2.39	$/gallon	Average 2022 rate for CA

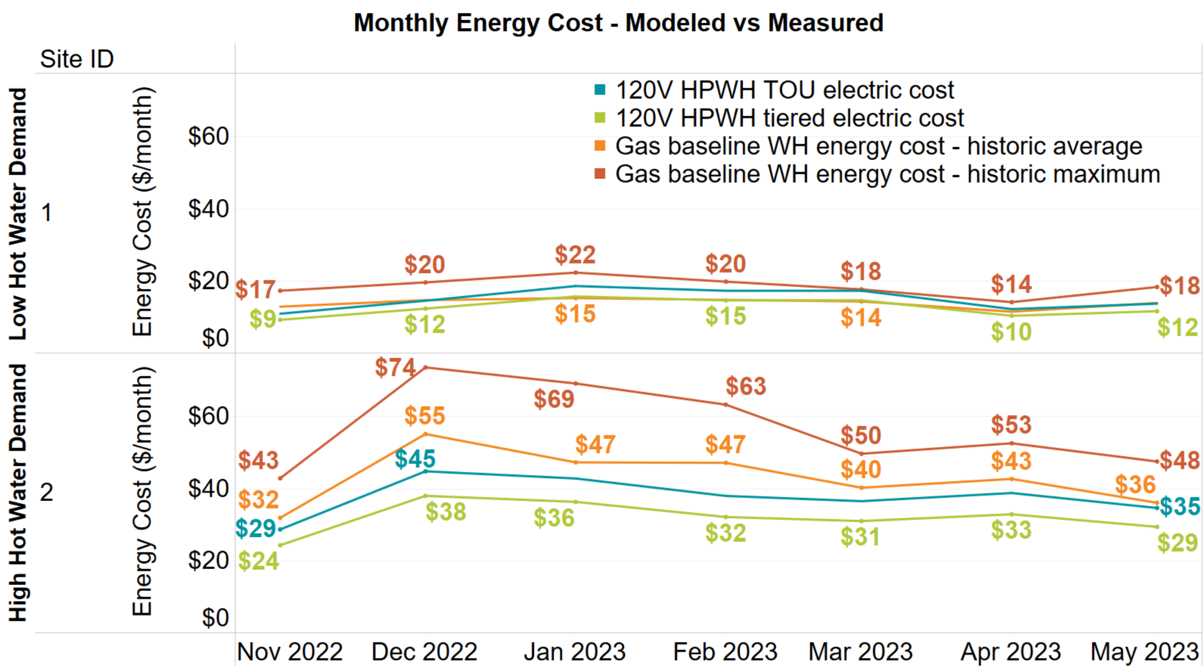
FIGURE 23. SUMMER AND WINTER ELECTRICITY RATE STRUCTURES FOR PG&E, SCE, AND SMUD



3.5.2. PG&E rate structure impacts on operating costs

Figure 24 provides example operating cost ranges for PG&E territory, with a high and low hot water selected to show how costs can vary. For PG&E customers, the HPWH consistently provides cost savings in comparison to the pre-existing gas water heater under both tiered and TOU rate structures for the higher hot water users (site 2 in Figure 24). For the lower hot water user shown (site 1 in Figure 24), the HPWH provides cost savings under the tiered rate structure as compared to the historical gas maximum rate but does not provide cost savings under the TOU rate structure.

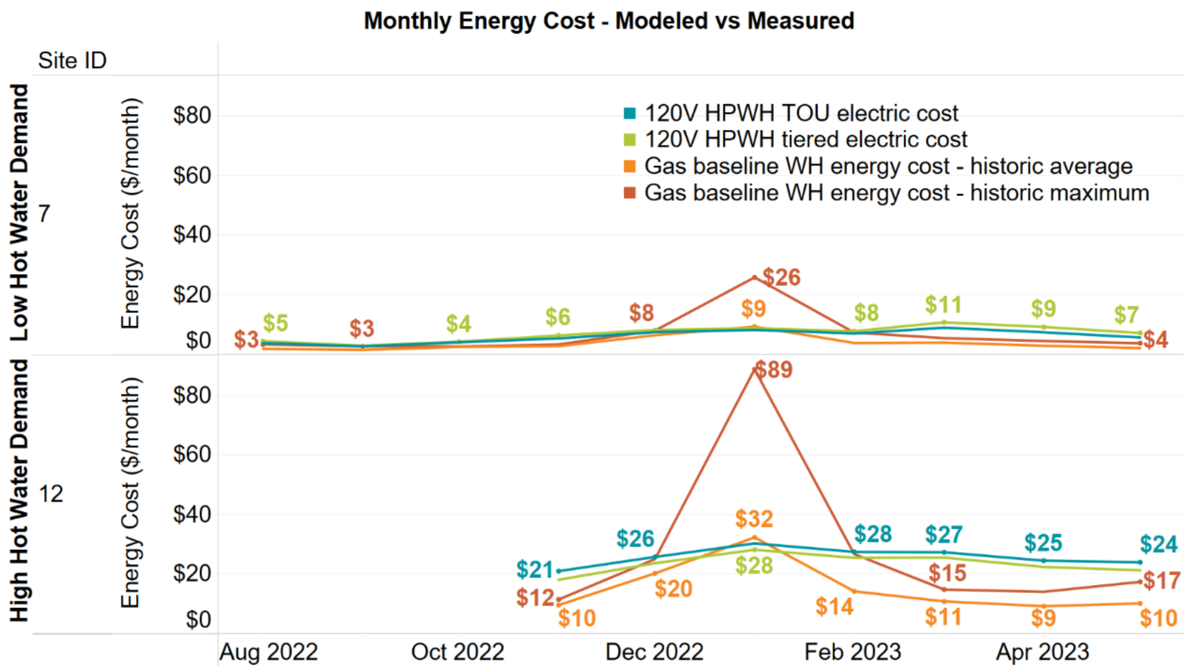
FIGURE 24. COST COMPARISON FOR TWO PG&E SITES—ONE WITH MODERATE TO LOW HOT WATER USE (TOP PANE) AND ONE WITH HIGH USE (LOWER PANE)



3.5.3. SCE rate structure impacts on operating costs

Figure 25. Cost comparison for two SCE sites—one with moderate to low hot water use (top pane) and one with high use (lower pane) provides example operating cost ranges for SCE territory, with a high and low hot water selected to show how costs can vary. For SCE customers, the combination of high electricity rates and low gas rates results in HPWH operation being more costly. As shown in Figure 25, the difference between tiered and TOU rates varies by site.

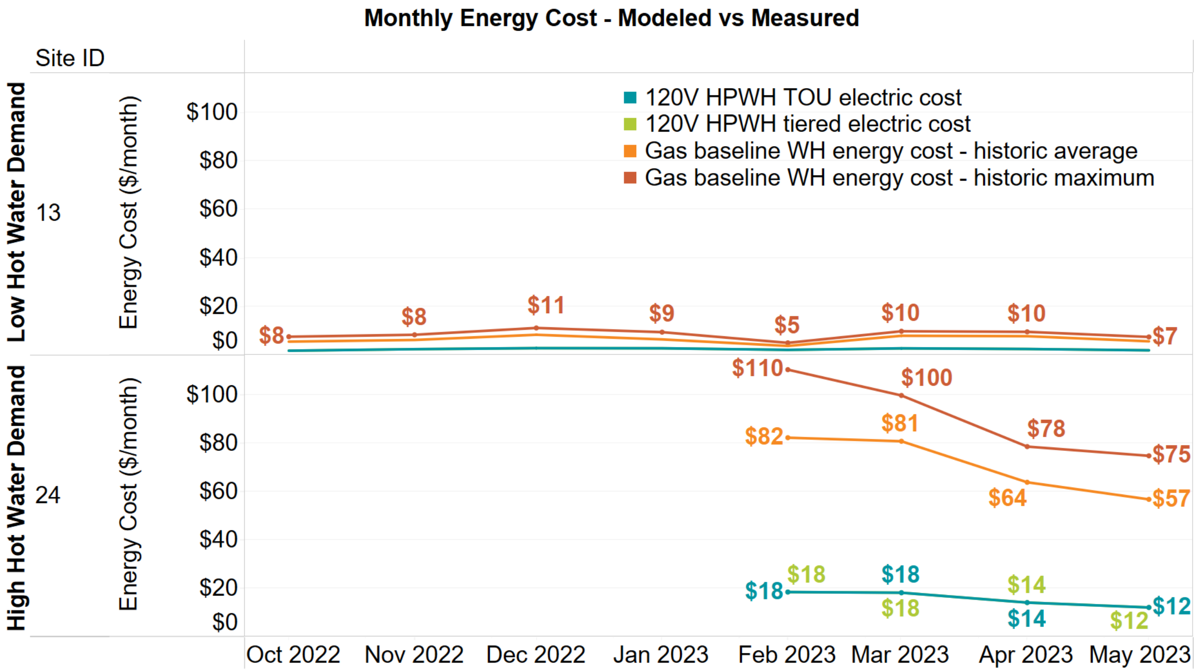
FIGURE 25. COST COMPARISON FOR TWO SCE SITES—ONE WITH MODERATE TO LOW HOT WATER USE (TOP PANE) AND ONE WITH HIGH USE (LOWER PANE)



3.5.4. SMUD rate structure impacts on operating costs

Figure 26 provides example operating cost ranges for SMUD territory, with a high and low hot water selected to show how costs can vary. For SMUD customers, HPWH operation is consistently cheaper than the gas water heater would be, especially for high hot water users. Two examples are shown in Figure 26. Note that SMUD does not offer a tiered rate structure.

FIGURE 26. COST COMPARISON FOR TWO SMUD SITES—ONE WITH MODERATE TO LOW HOT WATER USE (TOP PANE) AND ONE WITH HIGH USE (LOWER PANE)



To summarize the findings above, SoCalGas's low rates paired with SCE's higher electric rates present a stumbling block in the case for building electrification. For SMUD customers who receive their gas service from PG&E, the higher gas rates provide a compelling case for electrification. For PG&E customers, HPWH cost savings varies depending on usage. Anecdotally, one PG&E participant reported that they have observed operating cost savings:

> *"We're VERY happy with our water heater and have seen a decrease in our PG&E bill!"*

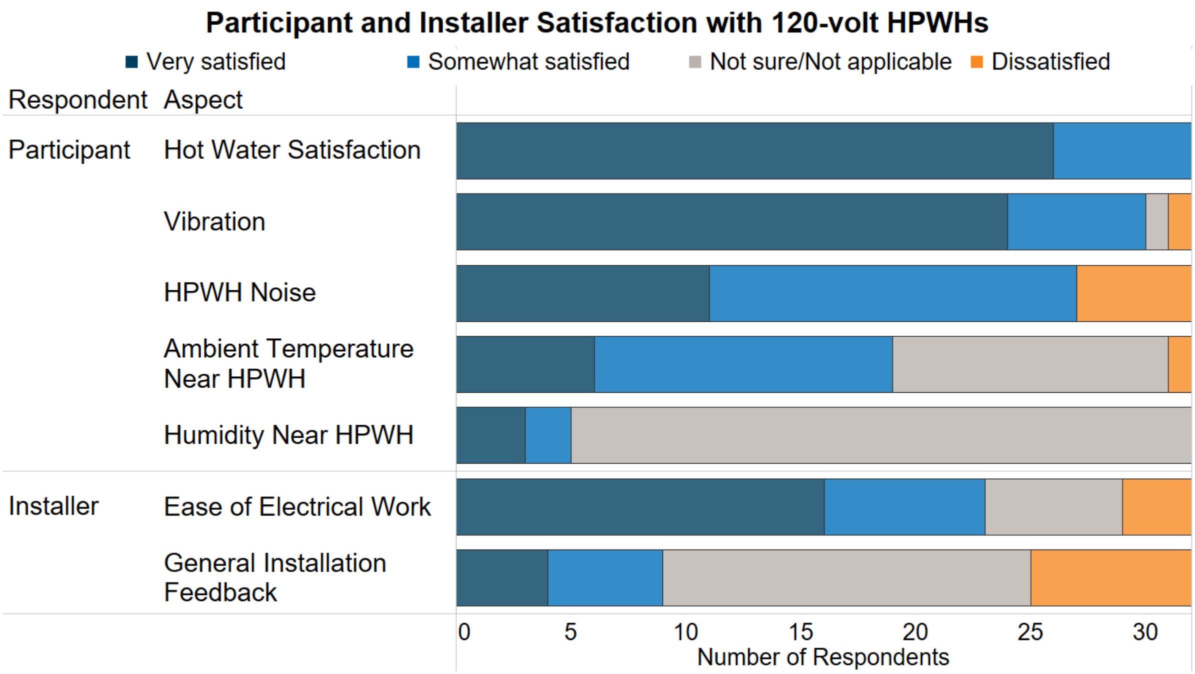
3.6. Survey findings

3.6.1. Survey results

Figure 27 illustrates the aggregated results of the customer and installer surveys. To represent each participant only once here, we used the most recent survey results from respondents (either at six months, or at end of survey period). We found that participants were most satisfied with hot water consistency (i.e., not having runout events), and that they were least satisfied with the HPWH noise.

Additionally, for seven of 32 installs the installers found installation of the 120-volt HPWHs more difficult than replacing a gas water heater with a new gas water heater. However, this feeling will likely shift as installers install more of these units and become more comfortable with this new electric technology.

FIGURE 27. PARTICIPANT AND INSTALLER SATISFACTION SURVEY RESULTS



Several participants shared positive feedback:

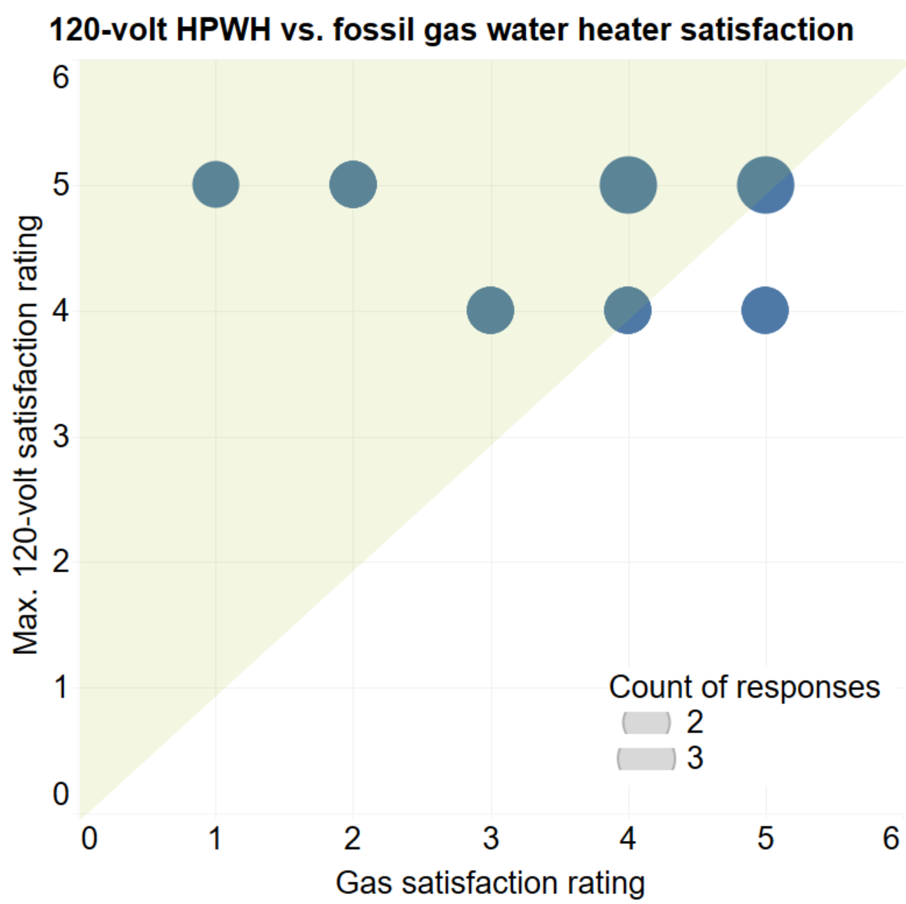
> *"I think the HPWH performs much better than the previous gas water heater. We have had no complaints about hot water supply and the energy usage is way way down."*

> *"Completely love this product, it's great. Have not run out of hot water once, and it's very quiet. Game changer product."*

While some respondents reported decreased satisfaction with the HPWH as compared to their previous water heater, no respondents ranked their satisfaction with the HPWH lower than a three on the one-to-five scale. Conversely, five customers rated their satisfaction with their gas water heater lower than a three on the same 5-point scale. Reasons for dissatisfaction with the gas water heater include low efficiency (i.e., high fuel use), concerns about the flue leaking, and hot water demands not being met.

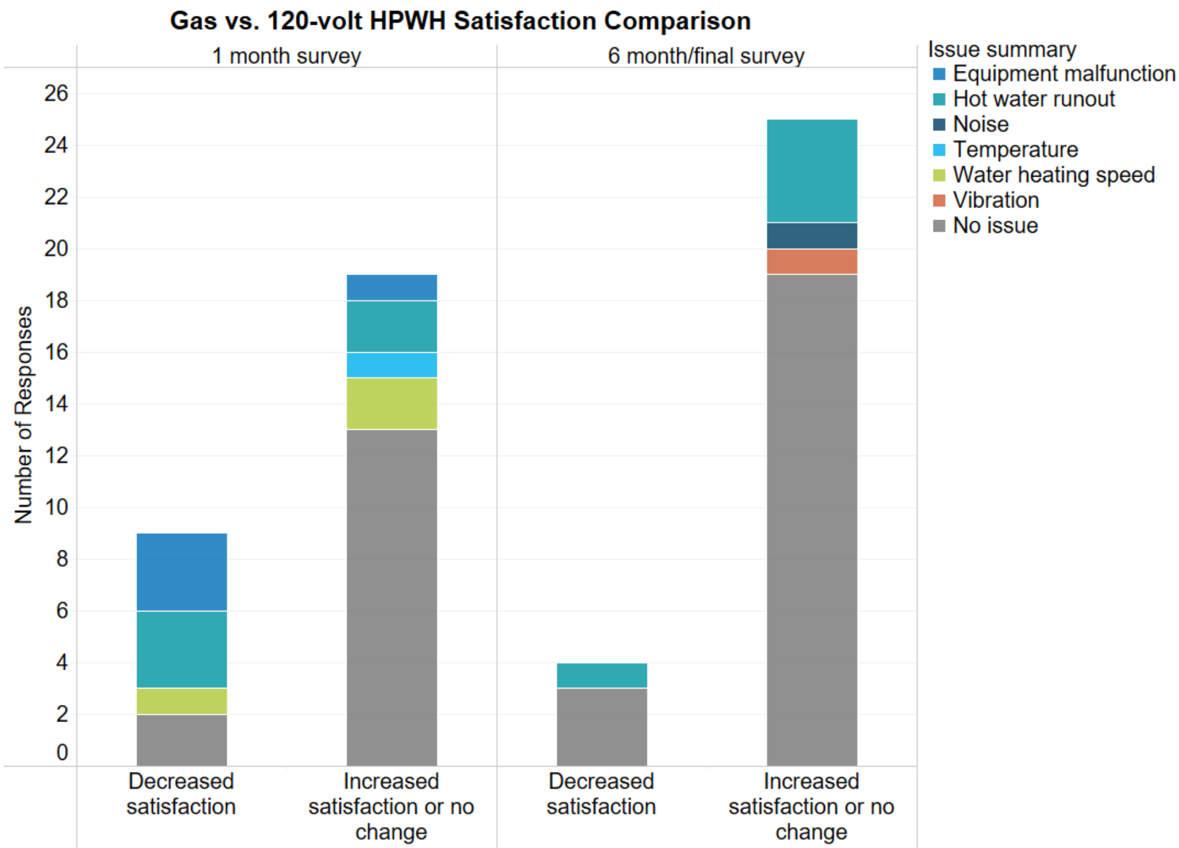
Figure 28 maps the distribution of responses for gas and HPWH satisfaction based on both the first and second satisfaction surveys. Anything in the green shaded area indicates a respondent's equal or higher satisfaction with the HPWH as compared to their previous water heater. Note that in all but three instances, lower satisfaction was correlated to customers that experienced an issue with the HPWH, including equipment malfunctions that were subsequently fixed.

FIGURE 28. OVERALL GAS WATER HEATER SATISFACTION VS. 120-VOLT HPWH SATISFACTION



Most of the participants that reported decreased satisfaction at the one-month survey period had experienced a specific issue with the water heater: either a short-term equipment malfunction, a hot water runout, disruptive noise, and/or a change in temperature of the space where the HPWH was installed. At the time of the final survey, only four customers reported decreased satisfaction compared to their previous gas water heater and 14 reported increased satisfaction. Figure 29 summarizes how participants' satisfaction changed and details issues experienced within each group. Note that not all participants took the pre-installation satisfaction survey, so their satisfaction could not be compared and is thus excluded from the figure.

FIGURE 29. SUMMARY OF CHANGE IN SATISFACTION WITH DETAILS REGARDING ISSUES EXPERIENCED



In five cases participants reported that the HPWH took too long to heat water, or hot water runouts were occurring (5 out of 32 installations). Field study personnel provided customer education including recommendations regarding setpoint and mixing valve temperature adjustment options and best practices for limiting high hot water use in rapid succession. We did not hear any complaints from the customers after they made small changes to their hot water consumption behavior.

Four of the five respondents who reported hot water runouts stated that it was "somewhat disruptive" (as compared to one respondent who stated it was "very disruptive"). Three of the five respondents who experienced a hot water runout are in the top five-highest overall combined hot water users of all study participants. All five participants who experienced a hot water runout used more than 130 gallons of hot water (and in one case, nearly 200 gallons) on their peak hot water use day. One site received a 50-gallon HPWH due to space constraints, but routinely drew more than 60 gallons of hot water in a single hour. See more details in section 3.6.2 below.

3.6.2. Hot water runout sites

A summary of the characteristics of the five sites that reported hot water runout events is shown in Table 12. The first site (site 25) had moderate hot water use on average, but often had days with hot water use above 70 gallons, with two days above 150 gallons. The participants at this site reported that existing piping posed challenges to hot water delivery, even for the previous gas water heater. Additionally, this is a cold climate site where the water heater is located in an unconditioned basement and has lower entering cold water temperatures. Site 2's overall average use is moderate, but this site often used more than 100 gallons of hot water in a day. The installation of the heat pump water heater in a small internal closet (172 cubic feet) without enough ventilation or ducting may contribute to performance issues. This site is also described in Table 12. Summary of sites with hot water runouts. Site 23 was a heavy hot water user, who self-reported that their two children like to take long showers while dishes are being washed. Site 24 is another heavy hot water user, who reported taking four showers a day and had hot water runouts with the existing gas water heater as well. The last site (site 32) was similar to site 25 in that the overall average use was moderate with occasional high use days. This site also tended to have 15-20 gallon draws over several consecutive hours in the mornings, making it difficult for the unit to recover. Especially for sites 23, 24, and 32, a larger HPWH may have been more appropriate, but space constraints prevented upsizing.

TABLE 12. SUMMARY OF SITES WITH HOT WATER RUNOUTS

Sites with Hot Water Runout Events					
Site Number	25	2	23	24	32
Climate Type	Cold	Cold	Mild	Mild	Mild
Number of occupants	2	4	4	4	2
Size of home	1 bed, 2 bath	3 bed, 2.5 bath	4 bed, 2.5 bath	3 bed, 2 bath	3 bed, 2 bath
Installation location	Basement	Internal closet	Garage	Garage	Garage
Size of HPWH installed	50 gallons	65 gallons	65 gallons	65 gallons	50 gallons
Highest gallons/day	189 gallons	138 gallons	137 gallons	141 gallons	136 gallons
Description of runouts and mitigation	Changed hot water use behaviors: avoid taking showers and doing laundry in the same 4 hour block	Sometimes runs out, takes a cold shower	Sometimes runs out, increased setpoint to 125 to mitigate.	Frequent runouts, increased setpoint to 140 degrees to mitigate, along with advice from field study team	Sometimes runs out, has been working with manufacturer

Sites with Hot Water Runout Events					
Possible reasons for runout	Large pipes with long distances between the water heater and points of use—in some cases over 40 ft.	Installed in small internal closet where ventilation may be an issue	Two kids that like to take extra-long showers (and in some cases, one will use up all the hot water on purpose).	Four showers per day; noted hot water runouts with existing gas water heater as well.	Spiky usage with some 100+ gallon days, consecutive draws in the morning hours.

4. Conclusion and Recommendations

For retrofit applications with electrical constraints, the 120-volt HPWH is a compelling technology that can be game changing for meeting decarbonization and electrification goals for residential as well as small commercial market. Below are some key findings and recommendations for supporting wider adoption of this technology.

4.1. Manufacturer recommendations

While 120-volt units are getting market ready—four renowned manufacturers have near market-ready units—there are other manufacturers who are closely watching the development of this technology. Based on the first ever independent field validation study, we have found that 120-volt HPWH successfully met user needs and site challenges and could significantly expand the market for HPWHs in existing homes. The following are recommendations for manufacturers and relate to product development and commercialization:

TABLE 13. 120-VOLT HPWH PRODUCT FINDINGS AND RECOMMENDATIONS FOR MANUFACTURERS

Product findings	Recommendations
Too few 120-volt HPWHs on the market	Scaling production: manufacturing more small form factor 120-volt HPWHs is vital to increase market penetration.
Installation knowledge gap	Cogent instructions: installers need to be able to distinguish 120-volt from 240-volt HPWH installation.
HPWHs are often space-constrained	Smaller footprint models: for retrofits, space is often limited and 120-volt HPWHs are currently too large to replace “low-boys” or tankless WHs—smaller options are needed.
Split systems are for niche markets	Continue development and improvement of split system HPWHs that do not require multi-component installation steps.
Product defects, such as leaks and missing control panels	Quality control and testing: extensive real-world testing of this new technology is necessary to ensure installers and customers are not faced with issues.

- **120-volt HPWH water heaters met user expectations, were preferred to gas water heaters, and were able to be installed in homes where a 240-volt HPWH would have been prohibitively expensive.** The market needs more production of these units and further advancement of technology.
- **Clear instructions in the manual and specifications on the integrated mixing valve are important.** Since these products look similar to the 240-volt HPWHs that come without a mixing valve, it can confuse the installers with the installation requirements. It is critical for manufacturers to distinguish this key product feature in their marketing materials.
- **Smaller footprint, small form factor units are needed in the marketplace.** The 120-volt product is targeted for the retrofit market where space is of the essence. Due to the lower first hour ratings compared to gas units, 120-volt HPWHs require two

sizes up compared to the existing gas tank size. Thus, they are physically larger than the replacement and require adequate air space surrounding the unit. In addition to gas tank-type water heaters, replacements for instantaneous “tankless” gas units will be needed (most of these likely being wall-mounted units). Likewise, there are form factor issues in replacing electric resistance water heaters with HPWHs (“low boys” for example, or units in tightly confined spaces). In summary, multiple new product types will be required to accommodate different housing types and space requirements. Per the lab test results, there is only 3-8%[26] energy penalty for heating the water at a higher setpoint, so we recommend looking at higher setpoints and smaller footprint tank sizes like 30 and 40 gallons.

- **Packaged units are preferable for the residential market.** Split systems have their role in some applications but also have additional installation challenges compared to a fully packaged water heater, as it is a multi-component installation.
- **HPWH improvement opportunities.** We heard a few complaints from installers and customers about manufacturing defects and malfunctioning units. Examples include an oversensitive sensor, a leaky tank, and a missing control panel. While most of these are not 120-volt technology-specific, special attention is required to eradicate manufacturing defects from HPWHs.

4.2. Utility/Incentive program considerations

Based on the study findings, we recommend the following when designing an incentive program for 120-volt HPWHs:

TABLE 14. INCENTIVE PROGRAM DESIGN RECOMMENDATIONS

Technology/Market Opportunities	Recommendations
120-volt technology eligibility	Inclusion within existing programs/workpapers: absorbing 120-volt HPWHs into rebate programs that include other hybrid WHs would accelerate adoption.
Accurate assessment	Improved pre-installation assessment: obtaining a more accurate gauge of hot water use can help ensure proper sizing and technology choice.
Commercial building application	Adoption within small commercial buildings: some small commercial buildings have low enough hot water demand that 120-volt HPWHs more than suffice.
Equitable and affordable adoption	Prioritizing low-income outreach: 120-volt HPWHs offer significant installation savings compared to 240V HPWHs, making them ideal for LMI electrification projects.

[26] NEEA. Plug-In Heat Pump Water Heaters: An Early Look to 120-Volt Products. NEEA conducted a lab test of Rheem’s 120-volt HPWHs – one dedicated-circuit, 12A model and one shared-circuit, 7.5 amp model, each with 50-gallon storage capacity.

- **Absorb the products into current HPWH incentive programs.** The 120-volt technology is similar to the incumbent 240-volt HPWHs. While smaller units have a slightly lower UEF compared to the current 240-volt unit, we recommend that these units be absorbed into existing incentive programs/workpapers for easier and quicker adoption of the technology into the market.
- **Ensure that participants give a realistic assessment of their daily water use.** Even though this study screened for houses with four or fewer occupants, some houses were using significantly more hot water than could be provided by the water heaters. In 24 of the 32 homes, the hot water use only exceeded 80 gallons less than 10% of days. However, five sites had higher use, with one site using more than 80 gallons of hot water 82% of the days that their site was monitored. Program screening procedures for 120-volt water heaters should encourage participants to choose an alternative type of water heater if their demand for water is unusually high. In the few sites that experienced hot water runouts, participants were able to accurately identify that their water use was unusually high for specific reasons. In some cases, water use may be higher in older homes due to single-story layouts increasing pipe run lengths, and the prevalence of large diameter (¾" or 1") trunk pipes in the trunk-and-branch layouts that are typical of twentieth-century homes.
- **Weatherization program integration.** To promote 120-volt HPWHs in fuel-switching retrofits through weatherization programs, the measure's cost-effectiveness will need to be validated. Alternatively, there may be an opportunity for 120-volt HPWHs as a health and safety measure, which are not subjected to the same cost-effectiveness criteria. 120-volt HPWHs may be eligible when replacing atmospherically or power-vented gas or propane water in a weatherized home without adequate combustion air. HPWHs don't require combustion air, so a resident would not need to add mechanical ventilation in this case. If a well-insulated home does not have adequate combustion air, it could create negative pressure in a mechanical closet. This could cause poor draft of flue gases, which could create a health and safety hazard. [27] We have not done sufficient research to thoroughly discuss the implications of 120-volt HPWHs on weatherization programs, but this may be an area for future research.
- **Light Commercial Buildings.** Commercial buildings currently using natural gas or propane water heaters under 80 gallons may be candidates for 120-volt HPWHs. Residentially sized water heaters may be installed in small commercial buildings that have smaller hot water demand. In commercial buildings, the hot water demand often varies by building type. From the northwest market characterization surveys, and NREL's ComStock dataset, we have found that small offices and retail buildings tend to have smaller hot water demand and may be served by residential units. Energy efficiency programs should be intentional about including commercial buildings that use residential water heating equipment in their programs, as these buildings may be ignored in some jurisdictions.
- **Equity aspects of the programs.** Installing 120-volt HPWHs is less labor intensive than 240-volt units (requiring 3-5 hours of labor for condensate and ventilation requirements). In addition to electrical upgrade-related financial savings, we could also see monthly operating cost savings for some sites. The sizing of tanks should vary

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[27] Focus on Energy. 120V HPWH Research (Phase I).

based on factors that include some equity-oriented factors like number of people living in the home. We recommend maximizing outreach within low-income communities to ensure they benefit from the comfort, health benefits (from better air quality in their home and neighborhood), and reduced energy burden provided by the 120-volt HPWH.

4.3. Policy and market recommendations

Below are the findings that are directly applicable to the market and require specifically targeted action by policy makers:

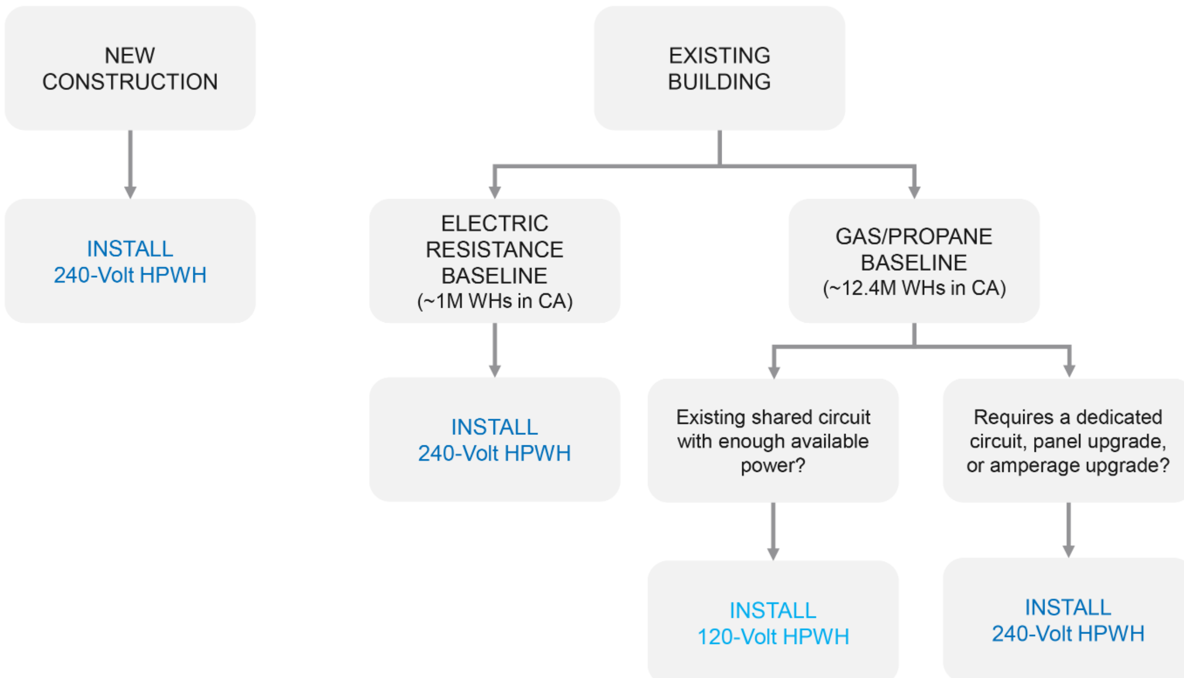
TABLE 15. POLICY AND MARKET BARRIERS AND RECOMMENDATIONS

Policy and market barriers	Recommendations
California Plumbing Code FHR requirements can lead to WH oversizing	Update code: modifying the Plumbing Code to have separate requirements for new technologies would allow for more accurate WH sizing.
Excessive paperwork and permitting lead to delays	Permitting officer training: it's critical to ensure that permitting officers are aware and accepting of 120-volt HPWHs to prevent delays.
Lack of knowledge around 120-volt HPWH installation	Education and workforce development: because this technology is so new, training installers is paramount to ensure best possible performance and lack of installation issues.

- **California plumbing code updates required.** The California Plumbing Code first hour rating requirements cause an increase in HPWH sizing beyond the manufacturer recommendation. For retrofits, the plumbing code FHR [501.1 (2)] comes into effect, but the sizing requirement is very rarely enforced compared to the energy compliance requirement. Based on the code official's suggestion, we recommend that the plumbing code needs to be revisited to focus on the low flow fixture use cases and new emerging water heaters with integrated mixing valves, that allow for higher first hour ratings.
  - » California building code also require a platform for gas water heaters, but we have found that permanently installed platforms make it challenging to fit the HPWH in the site. Since these platforms are not required for HPWHs, the ones that can be easily removed should be removed.
- **Permitting department education and training.** Due to the emerging nature of the HPWH technology, some jurisdictions are requiring extra paperwork which delays the installation. It is critical that collateral materials and training are developed that specifically target education of the permitting officers. In addition, tools and templates should be developed and made available to simplify the permitting process for electrification projects.
- **Installer education and awareness.** Workforce development and training is key for any electrification project success. While 120-volt HPWHs are very similar to 240-volt HPWHs, they have some unique design configurations which should be covered independently in the HPWH training.

4.4. Market sector assessment, best applications, and key considerations

FIGURE 30. MARKET SECTOR ASSESSMENT FLOW CHART



Electrical criteria for the best candidates. Based on the installation financials and ease of install criteria, the low hanging fruit for the 120-volt HPWHs are sites that have an existing shared circuit with sufficient additional available power (i.e., no more than 8-10A of load is expected to be connected to the circuit in addition to the water heater). Out of the 153 site walkthrough surveys performed, 32 installations would be able to make use of an existing 120-volt outlet close to the water heater location. Based on the walkthrough survey findings, in California we estimate that approximately 22-30% of the retrofit single-family homes with gas/propane water heaters can be directly supported by this emerging technology. We recommend that only limited electrical remediation sites are targeted by this technology, for example:

- Installation of an additional 15-amp rated outlet on existing accessible circuit.
- Repair or replacement of existing outlet compliant with current National Electrical Code NEC and CA building code.

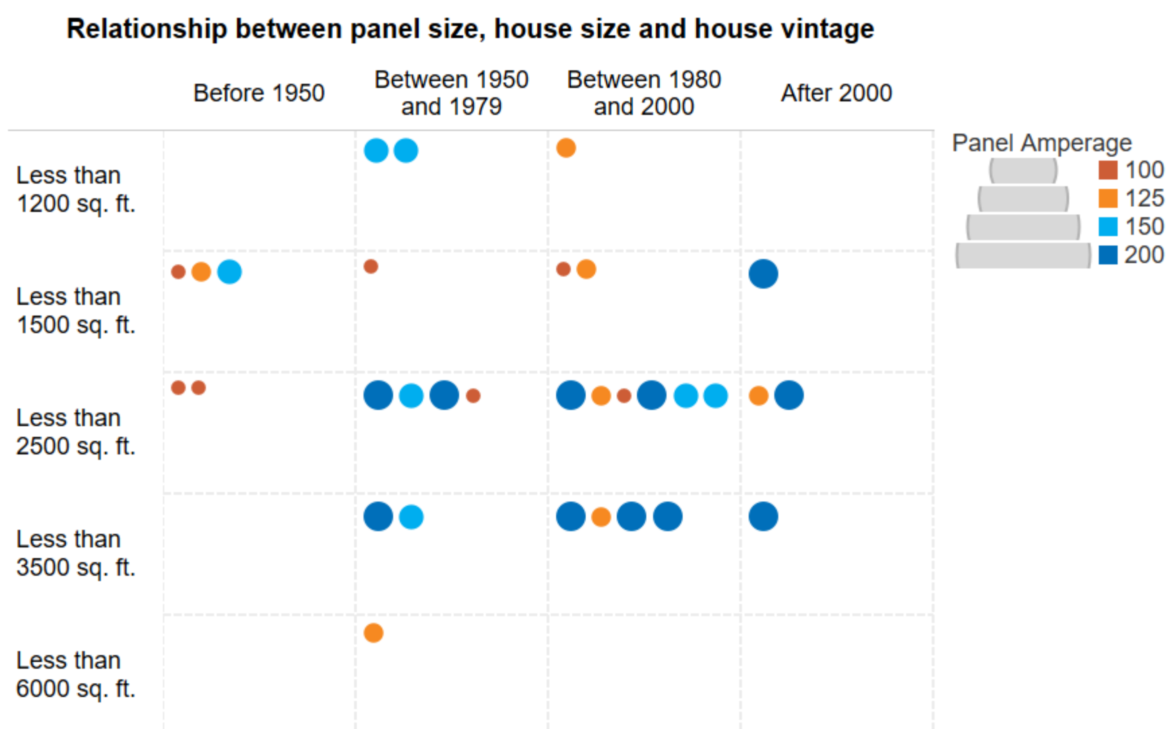
Any time sites require the addition of a dedicated circuit, panel upgrade, or amperage upgrade, 240-volt HPWHs are generally better suited products. This is due to the higher first hour rating and relatively smaller difference in upgrade costs between the products. For the 120-volt installations the non-feasible criteria are:

- Requires an extensive upgrade of the existing circuit (e.g., circuit breaker replacement, upgrading of existing electrical conductor(s), code violations impacting install, or the new outlet required is greater than 25 feet from nearest outlet).

- Requires installation of a new dedicated circuit, or main distribution panel, and/or subpanel upgrade or requires amperage service upgrade.
- Observable code violations that may create hazards or result in failed permit final inspection.

Panel size, house size and house vintage. Though the sample size was small at 32 homes served, the relationships between the house size, vintage, and electrical panel amperage aligned with larger studies. From Figure 31 below, we can clearly see that homes built prior to 2000 have smaller panel amperage on average, and similarly small houses tend to have smaller panels. This technology is well suited for smaller houses, especially those built before the year 2000. Note that the size of the dots in the figure represents the amperage for a particular intersection of vintage and house size.

FIGURE 31. RELATION BETWEEN PANEL SIZE, HOUSE SIZE, AND HOUSE VINTAGE



Site selection recommendations. Based on the runout events that occurred during the study, we recommend that installers and/or homeowners adhere to the key considerations below. Upsizing the HPWH is especially important for households with children or teenagers or for households that anticipate hot water demand spikes, for instance, hosting guests. The project team also stress tested some sites to learn where this product is not appropriate. Based on these tests, key considerations for 120-volt HPWHs site selection are listed here in Table 16:

TABLE 16. KEY CONSIDERATIONS FOR THE RIGHT SITES FOR 120-VOLT HPWHS

Key Considerations
1. This technology is appropriate for smaller demand sites, 1-4 people households. It is critical that the water heaters are sized correctly.
2. Upsize the tank to ensure adequate first hour hot water. For four people households with children, install an 80-gallon tank.
3. Use the mixing valve to maximize available hot water by pre-heating to 140°F.
4. Ensure sufficient air volume (minimum 700 cu.ft) in the room where the HPWH is installed so performance does not degrade due to a drop in intake air temperature. Similarly install in locations where the ambient temperature does not fall below 38F
5. While the manufacturers are working on a solution for noise levels (bringing them below 45 dB(A)),[28] we recommend installing noise dampening pads at the time of installation and installing water heaters in garages or basements, away from the living areas, when possible.
6. Sites that need limited electrical remediation with existing gas or propane water heaters are excellent candidates for 120-volt HPWHs.
7. Since the 120-volt HPWH has an integrated mixing valve, homeowners can choose to store water at higher temperatures, which increases hot water capacity.

[28] PG&E. PG&E Cressey-Gallo 115 kV Power Line Project - Initial Study. Noise levels are considered low when below 45 dB(A).

4.5. Conclusion and Moving Forward

The 120-volt HPWHs are important to decarbonize the retrofit residential and small commercial market sectors. These products should be incentivized by utilities and other programs, such as the Inflation Reduction Act (IRA) tax credits, to support market scaling. In addition, the market requires contractors and permitting department awareness-building efforts.

The market needs more innovative solutions like this emerging technology to support the gaps where a 120-volt HPWH is not feasible. While we estimate 22 to 30% of California homes could be directly supported by these plug-in water heaters, the remaining sites still need unique solutions for replacements. Thus, there is an immediate need for smaller footprint/small form factor products and products with improved compressor capability for cold climates. While European and Asian markets have distinctive products to meet space constraint needs, more of these size-sensible products should be manufactured within the United States.

The overall success of this study highlights one critical aspect of water heating—each household has a unique draw pattern. While one could predict the hot water usage of the household based on the number of bedrooms/bathrooms and number of occupants, it is important to understand their satisfaction with the existing unit and to size the new 120-volt units correctly.

The 120-volt HPWH technology is a key solution for retrofit market decarbonization. With right sizing, they not only deliver hot water, but they also reduce energy consumption by 80-85% compared to the existing gas/propane water heaters. In addition, 18 out of the 32 sites showed operating costs savings[29] as compared to the pre-existing gas or propane water heater. For the sites that saw cost savings, the straight average monthly cost savings was $12 per month. This full report has detailed and layered information on the research, technology, and recommendations.

Moving Forward- accelerating market adoption

If one thing is clear, we can and must act to accelerate the use of technologies, like 120-volt HPWHs, that can move us towards the decarbonization of the built environment. AWHI plans to support efforts happening in California and beyond. The 2023-2025 priority areas for 120-volt technology adoption include:

- Validation of the technology in multifamily and small commercial applications
- Adoption of the performance curves in the modeling software
- Support higher capacity compressor research
- Standardized load shifting (phase 2 of the study just starting)

[29] After switching to a 120-volt HPWH, these participants experienced utility bill savings, based on historical average gas rates. Note that these savings were based on a reduction in gas utility bills with a corresponding (but smaller) increase in electricity bills.

- Permitting and code readiness support
- Market connections and mapping
- Use of low-GWP refrigerants
- More affordable products and install practices in the market

While one state and one region can move a needle in the right direction, no single region can move the water heating market on its own. This research in California has provided an opportunity to templatize a research methodology for adoption by other regions. As part of a nationwide market transformation effort, the methodology has leveraged a similar validation approach, market assessment, and demand building efforts elsewhere.

By implementing this in other parts of the nation, we can further support the emerging technology through market commercialization.

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6. Appendices

6.1. Appendix A: Methodology Design & Implementation

This section describes the methods by which the research team investigated the performance of the 120-volt HPWH in California. It introduces the site selection criteria development and methodology, monitoring approach, and survey methodology. It also describes in detail the framework used to analyze the energy and operating cost performance of the 120-volt HPWHs so that other organizations can conduct their own program to provide incentives and support equity efforts.

6.1.1. Site Selection Criteria

Every site in our study had to meet a set of basic criteria:

- The pre-existing water heater is a tank-type (i.e., storage) gas-fired or propane water heater.
- The pre-existing water heater does not include a recirculation pump.
- The pre-existing water heater only serves one primary dwelling (i.e., does not serve an accessory dwelling unit (ADU).
- The home is in PG&E, SCE, or SMUD service territory.
- The home has no more than 4 occupants.

Having a variety of installation configurations provides greater data on retrofit site characteristics and application assessment. To determine the most important site selection criteria, we identified the primary site-related parameters that could impact the water heater, including climate zone, existing equipment, building type, location of water heater and size of household (as a proxy for hot water demand). These parameters were then mapped to the study's research questions to identify which parameters best aligned with the research goals.

Once the key parameters were identified, NBI worked with funders and manufacturers to determine research priorities and the characteristics of typical homes in their territory where they would expect to install 120-volt HPWH. This resulted in a final set of criteria, shown in Table 17. Sites were selected to try to ensure that the complete sample included all the criteria shown in the table. In addition to focusing on power and space constrained sites, we sought to identify participants that would result in the greatest variation of criteria, while still targeting low-to-medium hot water demand homes with less than four occupants.

TABLE 17. SUMMARY OF SITE PARAMETERS AND CRITERIA

Parameter	Criteria
Climate Zone*	Cold (CA climate zone 1, 16) Mild (CA climate zone 3-5, 6-9) Warm (CA climate zone 10-14)
Building Type	Single family Multifamily
Vintage	Built prior to 1980

Parameter	Criteria
	Built after 1980
Location of water heater	Conditioned (e.g., internal closet) Unconditioned (e.g., garage, external closet)
Demand (in terms of # occupants)	Low (1-2) Medium (3-4)

*Some climate zones were excluded as they are not served by any of the participating funders

6.1.2. Site Selection and Recruitment Process

After completing the site selection criteria, participant recruitment began. We created a pre-screening questionnaire for potential participants to complete. This questionnaire confirmed basic eligibility requirements such as the utility service territory and existing water heater type and collected information related to the key site selection criteria such as number of occupants in the home, climate zone, and the location of the existing water heater. This survey was sent through a variety of outreach channels with support from utility partners. A two-page factsheet and website page were also created to provide additional study details to potential participants.

Potential participants who met the screening criteria were assigned a 5-digit participant ID number to maintain confidentiality and contacted to complete a virtual walkthrough of the home. The Site Coordinator, from RHA, coordinated a video call with the potential participant to conduct a "virtual walkthrough." To maintain confidentiality, videos did not show the customer's face and RHA made sure potential participants knew they could cover their camera when not directly capturing video of the existing water heater and electrical panel. RHA facilitated the call, instructing the potential participant on the key items they needed to capture in the video to determine if the home was a good fit for the study.

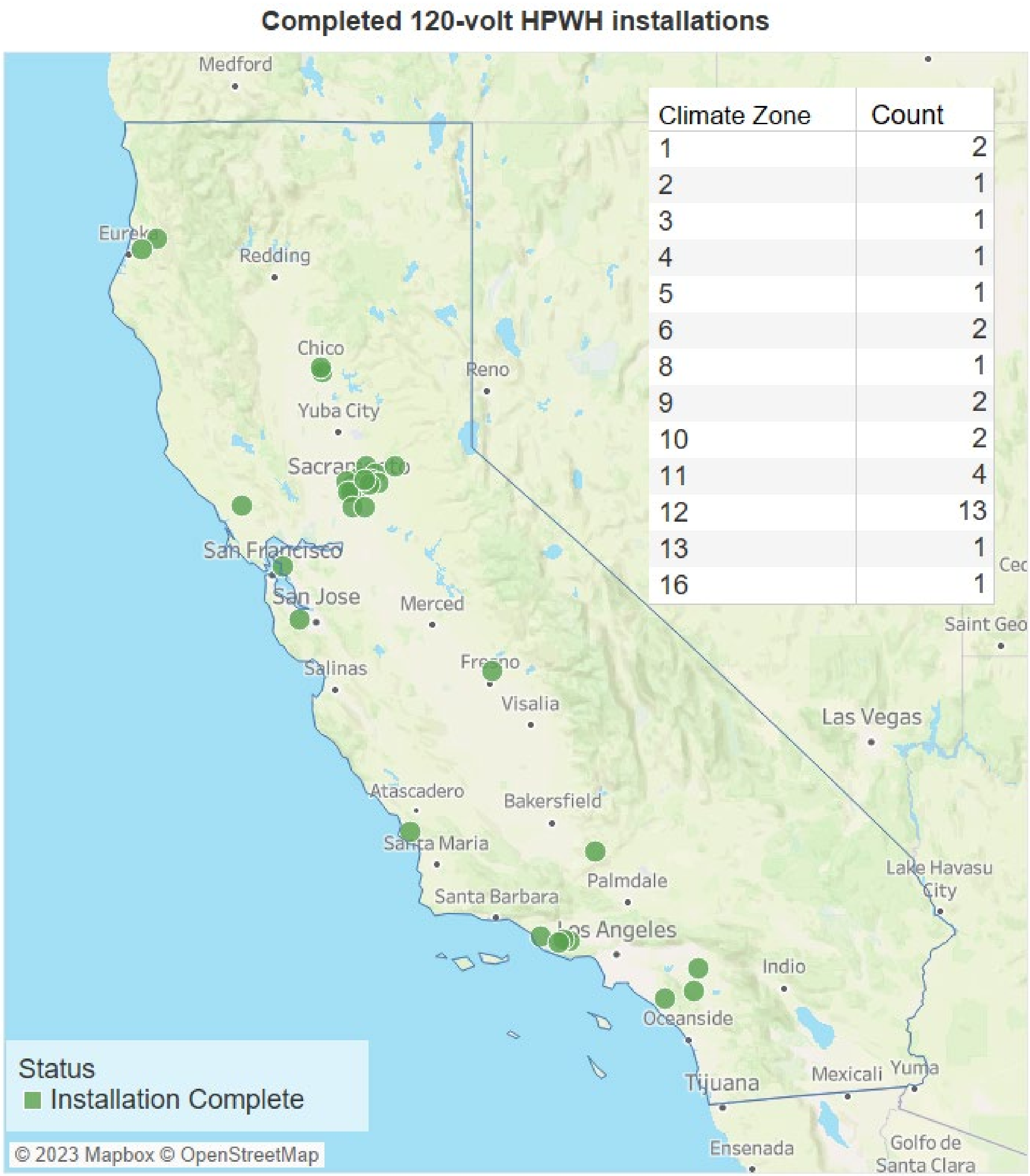
If the virtual walkthrough indicated the home could be a good fit, a tentative 120-volt HPWH model was assigned to the site and shared with the manufacturer for confirmation. RHA collected specific measurements of the space where the water heater would be installed and assessed the load on the outlet that the 120-volt HPWH would be plugged into. If the 120-volt HPWH would fit in the space and would not require substantial electrical work (addition of a dedicated circuit, panel upgrade, or amperage upgrade, see section 6.1.3 for more details), RHA obtained the necessary participation agreement paperwork from the customer and directed the installer to pull the permit for the site.

Selecting the site, appropriate manufacturer, and size of heat pump water heater, while being mindful to include as much site diversity as possible was a challenging process.

6.1.3. Participant characteristics

The study received 332 prescreening applications resulting in 224 potential participants that met the qualification criteria. To identify appropriate sites to fill the 32 slots in the study required 153 virtual walkthroughs. Section 0 provides details on the reasons for rejection of many sites. This section provides an overview of the study sample demographics of the installed sites. Heat pump water heaters were installed in 32 sites across California, capturing 13 climate zones. Climate zones 1 and 16 provide cold climate representation, climate zones 10 through 13 provide hot climate representation, and all other climate zones are considered mild. We had a higher density of sites in climate zone 12 due to receiving a large number of SMUD sites. The installation locations and summary of sites per climate zone is shown in Figure 32.

FIGURE 32. INSTALL LOCATIONS AND CLIMATE ZONE VARIATION



Climate Zone	Count
1	2
2	1
3	1
4	1
5	1
6	2
8	1
9	2
10	2
11	4
12	13
13	1
16	1

Figure 33 provides a summary of the home characteristics for the 32 sites. The study included households with one to four occupants, from 1- to 5-bedroom homes. Most homes in the study were 3-bedroom homes with two occupants. The water heater was located in the garage for most of the homes that successfully met the site criteria. Additionally, four sites were selected where the HPWHs could be installed in a smaller space inside the home. Most homes in the study were older, with only four built after the year 2000.

FIGURE 33. FINAL SAMPLE DISTRIBUTION: NUMBER OF OCCUPANTS AND BEDROOMS PER HOME

Home Characteristics

Bedrooms and Occupants

# In Home	# Beds 1	2	3	4	5
1		1			
2	1	2	11	4	2
3		1	1	2	
4			3	3	1

Installation Location

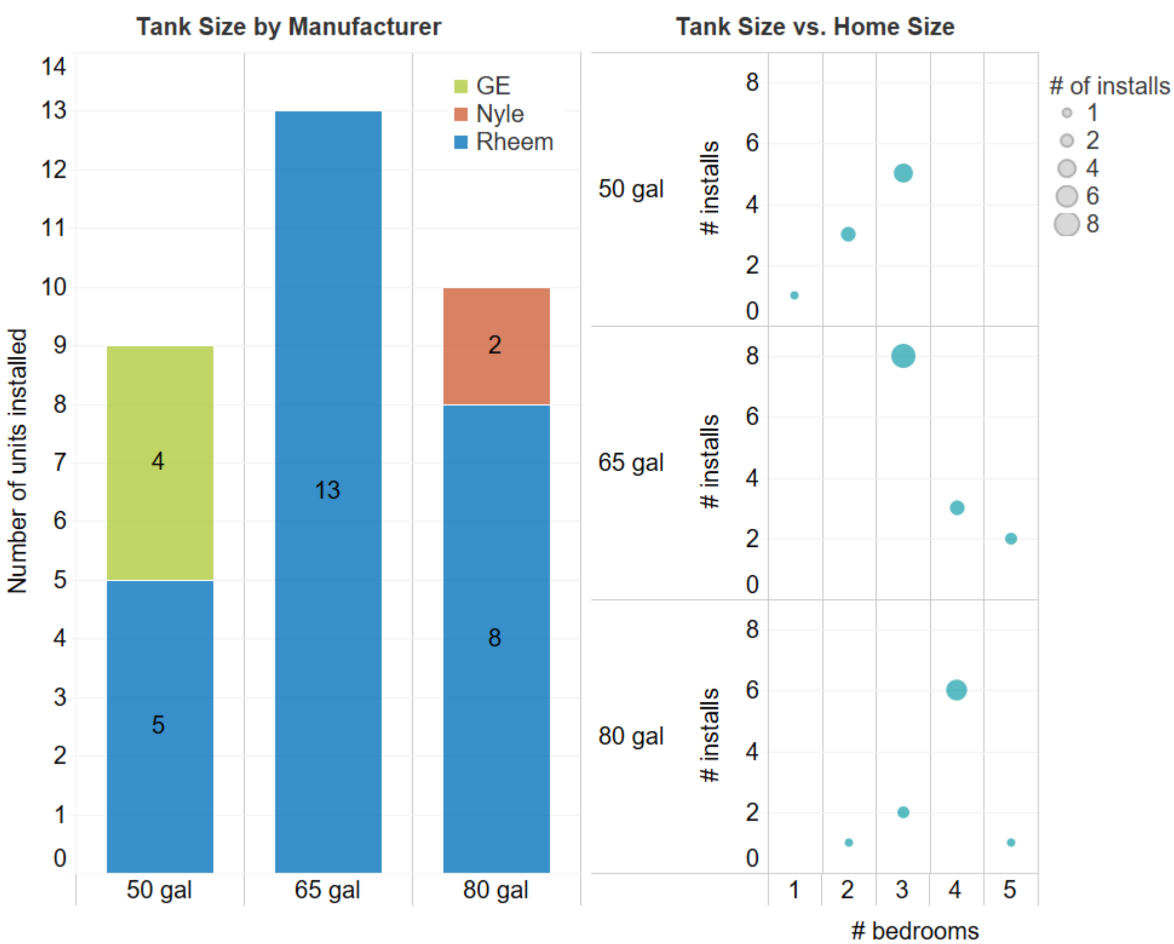
Conditioned	Laundry room	3
	Furnace closet	1
Unconditioned	Garage	23
	Basement	3
	External closet	2

Home Vintage

Before 1950	5
After 1950	10
After 1980	13
After 2000	4

Most of the HPWHs installed were sized at 65-gallons, followed by 80 and 50 gallons. In most cases, upsizing was required from the initial gas or propane water heater tank size. The number of bedrooms was the primary sizing factor, as the number of occupants in a home can change, but the pre-existing water heater size and space constraints were also a factor in the sizing. No 50-gallon HPWHs were installed in homes larger than 3-bedrooms. The most common HPWH size for a 3-bedroom home was 65 gallons. Figure 34 shows the relation between the number of bedrooms and tank selection. The tank size selection is also impacted by the California plumbing code, which specifies first hour rating requirements as determined by the number of bedrooms and bathrooms in the home.

FIGURE 34. NUMBER OF HPWHS INSTALLED BY SIZE AND MANUFACTURER



6.1.4. Monitoring approach

The study monitoring plan is designed to meet the project objectives and answer the research questions. The objectives met through water heating monitoring include:

- Demonstrate that the plug-in water heater provides adequate hot water to the residence: measure both hot water flow and temperature leaving the water heater to verify that the water is delivered at an acceptable temperature.
- Analyze performance: measure electricity consumption, water flow rate, and entry and exit water temperatures to provide a definitive measure of energy use and insight into performance under varying ambient air, inlet water, and hot water draw conditions.
- Test the load shifting capabilities: once the fundamental features of the water heater were tested, load shifting capabilities of the water heater are tested on a few selected sites.

The areas metered and their monitored locations include the following:

- Inlet (entering the water heater) and outlet (exiting the water heater, after the mixing valve) water temperatures
- Water flow (measured at the water heater inlet)
- Air temperature and relative humidity at the water heater (near the evaporator intake)
- Water heater power (plug meter at electric outlet)

The inlet and outlet water temperatures combined with the water flow rate provided insights into hot water runout events. The water heater power measurement provided a means to measure total input energy. Measuring the air temperature and humidity allowed the findings to be normalized to other climates and installation locations.

The monitoring period was designed to last at least 6-10 months to cover a full range of ambient conditions. Capturing the winter months for all sites was most critical as HPWHs must work harder when ambient air and entering water temperatures are lower. As such, the monitoring period covered the months with the coldest air and entering water temperatures (January-March) for all the sites. Several sites were installed in the hottest months (July-September) to understand the seasonal variation in performance and capture warmer conditions. Ambient air temperature and relative humidity measurements were collected onsite by a data logger at 15-minute intervals The power meter was also set to take measurements every 15 minutes, unless there was a power pull, in which case the interval increased to once every two seconds. The in-line temperature sensors and flow meter were installed by a plumber. The monitoring team installed the power meters and data loggers.

The data logger collected the measurements onsite and then transmitted them, via cellular modem, to a remote server for storage and analysis. The cell modem connection was critical to project success because it is a stand-alone connection and does not rely on the residence’s internet connection, Wi-Fi, etc. which can be unstable and unreliable. Another significant advantage of the cell modem data transfer is that it enables continuous monitoring of the data streams. The analysis team can view the status of the sensors to ensure uptime and can set up automatic range checks on the values received to check for reasonableness and alarm if otherwise. With real-time data viewing, the team can respond to problems and fix them in the field to keep data collection on track.

FIGURE 35. DIAGRAM SHOWING METERING POINTS FOR HPWHS

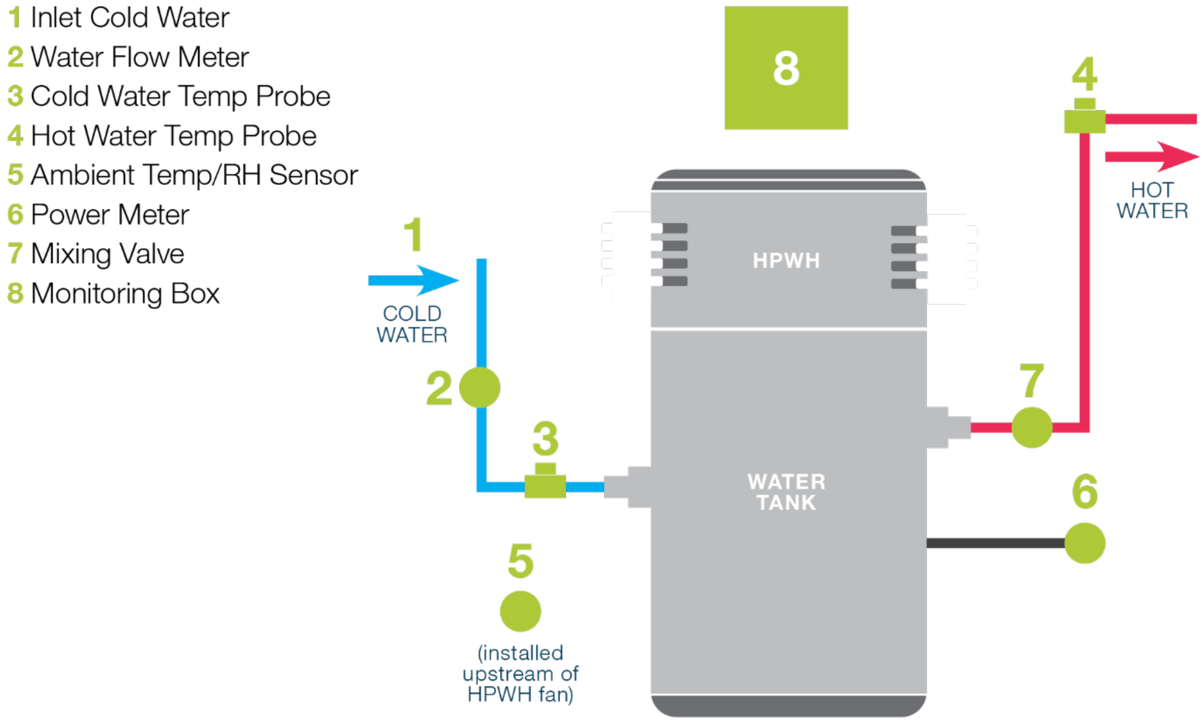


FIGURE 36. PHOTO SHOWING INSTALLED HPWH WITH MONITORING BOX

6.1.5. Load shifting capability verification

Once the fundamental features and the water heater's capability to provide hot water were successfully validated with at least four weeks without hot water runout events under normal operation, a few sites were selected based on customer survey responses to test the water heater demand response readiness and load shifting features. The water heater's capability to follow a schedule, preheat water during nonpeak periods, and rely solely on stored water during peak periods were tested. This process helped verify 120-volt HPWHs load shifting performance and the impact on operating costs and customer satisfaction to help customers as well as utilities plan better during peak events.

The HPWHs were put on a schedule by the occupants, with support from the program and manufacturers, to follow the shed event schedule to align with the statewide 4:00 to 9:00 PM time-of-use (TOU) rate structure. The HPWHs were monitored to see if water heaters were loading and shedding at the right time to align with the TOU period. More focused future study is required to understand the impact of load shifting 120-volt HPWHs on the grid and operating costs.

TABLE 18. LOAD SHIFTING SCHEDULE

Time Period	Phase 1	Phase 2
Objective	Simple energy shifts: load up & shed	Longer energy shift: longer load up & shed
Average length of shed event	Three hours, from 6:00 to 9:00 PM	Five hours, from 4:00 to 9:00 PM
Frequency	Every day	
Schedules	Manufacturers provide the scheduling guidance. Customers schedule through the app.	

6.1.6. Surveys

In addition to information gathered from customers, installers, and manufacturers throughout the study, NBI collected information from customers and installers via periodic online surveys.

6.1.6.1. Customer surveys

As described above, we collected data from potential participants during the prescreening survey. We then asked selected participants to complete a pre-installation satisfaction survey, which requested information about the household's hot water usage (e.g., number of showers per day, average length of shower, clothes washing loads with hot water) and satisfaction with the existing gas or propane water heater.

After the 120-volt HPWH installation, we asked participants to complete a survey indicating their satisfaction with the HPWH approximately one month after the installation, six months after the installation, and at the end of the study monitoring period. We asked the same questions in each of the three surveys.

We distributed all customer surveys via email. If the customer did not complete the survey within one week, NBI conducted a follow-up phone call to either remind the customer to take the survey online or go through the questions over the phone.

6.1.6.2. Installer surveys

Installers were asked to complete an online survey after each 120-volt HPWH installation. The survey requested details related to the equipment needed for the install (e.g., expansion tanks, changes to the condensate drain), electrical needs (e.g., splitting an outlet, adding a circuit) and feedback from the installer on the overall experience (e.g., length of time to complete the installation, issues with permitting, manufacturer support needed). Installers were also asked to provide general feedback via this survey form.

NBI found that it was challenging to get survey responses from the installers as they are rarely at their desk, often driving to or from a site or actively working on a job. To mitigate this issue, NBI began calling installers within a week of each installation to gather the information, asking the survey questions via phone.

6.1.7. Energy simulations

Documentation of the previous water heater included nameplate information, which was used to calculate the hypothetical performance if that water heater had remained in place via an energy simulation back casting exercise. The simulations use the same hot water draws as the newly installed HPWH to neutralize any hot water use changes that occurred during the monitoring period, such as changes in occupancy (e.g., the addition of new children into the home, family members moving out), unusual weather, or periods of extended leave.

6.1.7.1. Water use calibration to calculate pre-existing gas or propane water heater energy use

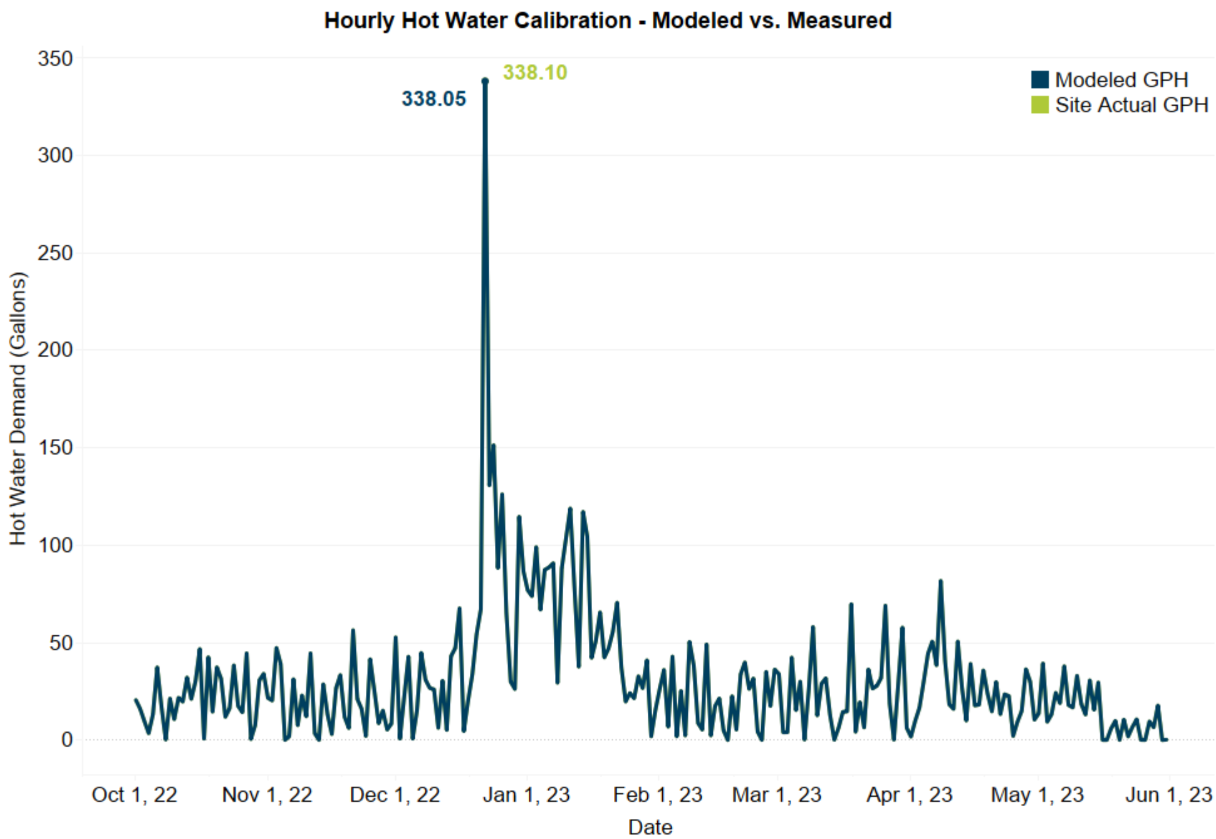
To bypass the impact of change in occupancy, weather related changes between pre and post replacements, and accurately model the hot water draw profiles, we completed a draw profile calibration using OpenStudio. Using monitored hourly total hot water draws from the installed heat pump water heaters, we created custom energy models in OpenStudio for each site based on actual measured hot water usage. Within the energy models, we set the total hot water use to match the hourly draw profile observed in the sites to normalize the use case. At-a-glance, the process is as follows:

1. Aggregate instantaneous measured water draws from the heat pump water heaters to hourly intervals.
2. Normalize the hourly water usage data on a 0-1 scale, with 1 representing the peak hourly draw.
3. Import the 0-1 hourly hot water draw profile, which is a simple .csv file, into OpenStudio using a custom measure.
4. Assign the draw profile to the water heater object in the model, which is a gas or propane tank water heater to match the original water heater for each site. The water heater object includes parameters related to recovery efficiency, standby losses, tank volume, location, and more.
5. Assign the peak measured flow (gallons per hour) from the measured data to the “fixtures” object. This process sets the modeled peak water draw in the load shape. In other words, a value of 1 in the imported draw profile will equate to the peak flow assigned to the fixtures object. Set the peak flow of all other water uses to zero (e.g., dishwasher).

6. As a quality assurance check to ensure all inputs were coded correctly, validate that the hot water use in the model matches the overall hot water use measures at the sites within 0.5%.

FIGURE 37. EXAMPLE CALIBRATION BETWEEN MODELED AND MEASURED HOT WATER DRAWS HOURLY FOR ONE SITE

The difference between the actual consumption and modeled consumption is shown, with the maximum difference (in Gallons per hour) labeled.



6.1.7.2. Baseline energy use analysis

For the modeled energy use, gas (or propane, where applicable) consumption data is generated based on the characteristics of the site's existing water heater nameplate data and the hot water consumption as described above. The calculations included in OpenStudio include standby losses and many other common engineering assumptions. Details about the backend calculations in OpenStudio can be found in the EnergyPlus Engineering Reference.[30] The following characteristics are user-defined:

[30] U.S. Department of Energy. EnergyPlus™ Version 22.1.0 Documentation.

TABLE 19. CHARACTERISTICS OF PRE-EXISTING GAS OR PROPANE WATER HEATER THAT IMPACT ENERGY CONSUMPTION IN OPEN STUDIO MODELING

Characteristic	Impact on energy consumption
Weather file	Impacts temperature of cold water entering the water heater; colder temperature water requires more energy to heat.
Water heater size (gallons)	Volume of the tank (storage capacity). Actual volume is 5% less than rated volume.
Input BTU	Power of the water heater to heat water.
Nameplate efficiency (Energy Factor)	Efficiency of the water heater; amount of hot water produced per unit of fuel input according to a mandated test procedure.
Age of water heater	Efficiency of the water heater degrades slightly over time (largely dependent on water quality). Degradation ratings were taken from the Building America Performance Analysis Procedures.[31]
Location of water heater in the home (e.g., garage)	Ventilation availability impacts heat pump water heater performance. Ambient temperature impacts efficiency of heat pumps, and impacts the standby losses for all tank-type water heaters, including gas or propane-fired water heaters.

Heat pump water heater energy consumption is based on measured power use at the water heater. Instantaneous power readings are rolled up to hourly consumption.

6.1.7.3. Water mains temperatures and supply air temperatures

The water mains temperature (i.e., the cold water coming into the tank) and ambient air temperature both impact HPWH performance. For water heaters in unconditioned spaces such as garages and external closets that are not well insulated, the ambient air temperature is typically similar to the outdoor air temperature and must be taken into account when considering if a heat pump water heater is a good choice for the home. The average outdoor air temperatures and water mains temperatures for the coldest and hottest locations in the study are shown in the table below.

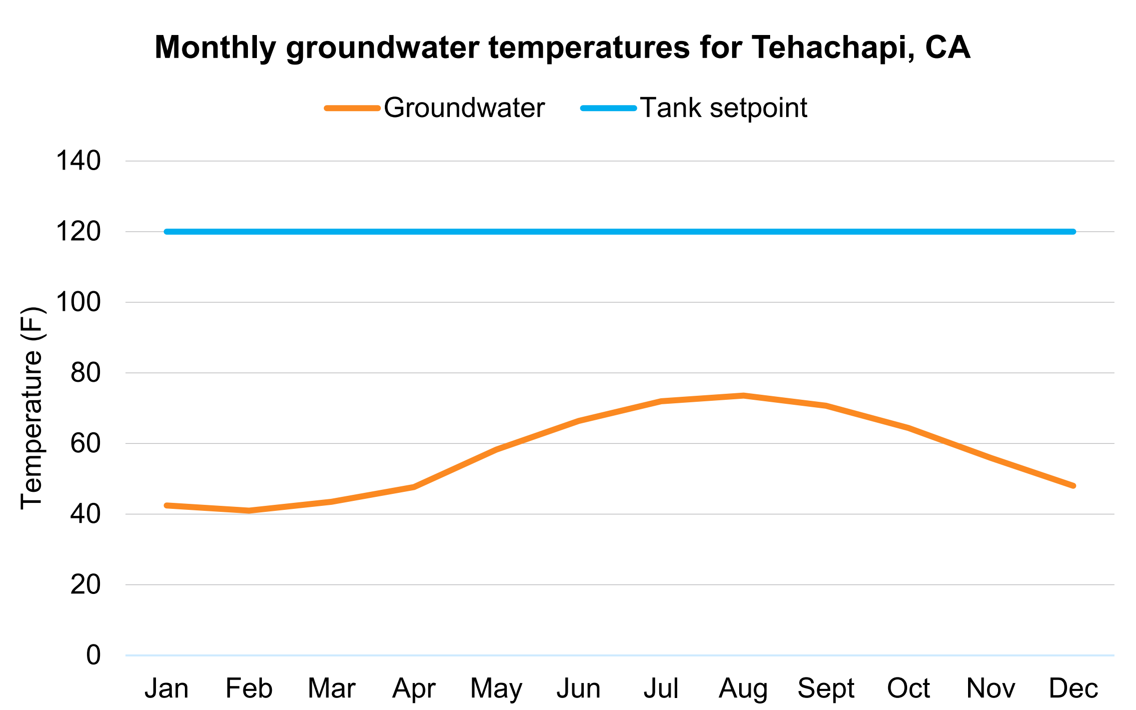
[31] https://www.nrel.gov/docs/fy06osti/38238.pdf

TABLE 20. SUMMARY OF MAX AND MIN WATER MAINS, AMBIENT OUTDOOR AIR, AND HPWH INSTALL LOCATION TEMPERATURES, FOR COLDEST AND WARMEST SITES IN CA FIELD STUDY

	Water Mains Temperature Range	Outdoor Air Temperature Range	HPWH Install Location Temperature Range
Coldest installation location (Tehachapi, CA)	41°F to 73°F	18°F to 100°F	39°F to 87°F
Warmest installation location (Fresno, CA)	49°F to 85°F	33°F to 114°F	43°F to 112°F

The average monthly groundwater temperature for the coldest site (Tehachapi) is shown below. As shown in the figure, incoming water temperatures drop to around 40°F in the winter. This means the HPWH compressor must raise the temperature 80°F to get the water in the tank up to the typical setpoint of 120°F.

FIGURE 38. MONTHLY GROUNDWATER TEMPERATURE VS. TYPICAL 120-VOLT HPWH TANK SETPOINT FOR TEHACHAPI, CA



6.2. Appendix B: California Electrical Code Considerations

For the 120-volt HPWHs in existing buildings the product must be able to be plugged into any existing residential electrical outlet. The outlet size depends on the wire/circuit breaker size and whether anything else is on the circuit. Since plumbers aren't likely to know those details about what's available on the circuit, choosing the closest available electrical outlet is the most conservative choice on watt limits. From the California Electrical Code (see table below), that would be 900W.

Maximum Watts	Circuit Breaker Amps	Circuit Type (dedicated or shared)	Wire Size (gauge)
900W	15A	shared	14
1440W	15A	dedicated	14
1200W	20A	shared	12
1920W	20A	dedicated	12

If an electrical upgrade is included as part of the water heater replacement, then more information would be available about the circuit limitations and the installer might have more options.

When the installer plugs a product into a shared circuit, the circuit breaker (or fuse, in older wiring) will trip if something else is operating on that circuit that causes the combined load to go above 15A. Then everything on that circuit will stop working. The code is written on the assumption that enough products on a shared circuit to draw 15A would rarely be operating at the same time. We did not experience any customer complaints about circuit breaker tripping on the installations.

6.3. Appendix C: Unique Installation Finding

One notable installation-related finding is related to a Concern raised from a participant hearing a persistent clunking noise. We sent a team on-site to diagnose and found:

- The water pressure coming into the house was higher than average, and the expansion tank was not set up properly for the higher water pressure.
- The sound was hammering due to the water pressure. The customer was concerned about the effect on the system. The noise has since gone down after the fix and the customer is assured of no impact on their system.
- City water supply pressures can vary from 40 to 70 psi, adding new equipment like a HPWH and an expansion tank may change the home's existing pressure dynamics.

6.4. Appendix D: Metering Connections Images

FIGURE 39. IMAGE SHOWING MONITORING BOX

FIGURE 40. IMAGE SHOWING FLOW METER ON THE HOT WATER OUTLET

FIGURE 41. IMAGE SHOWING TEMPERATURE SENSOR AT COLD WATER INLET

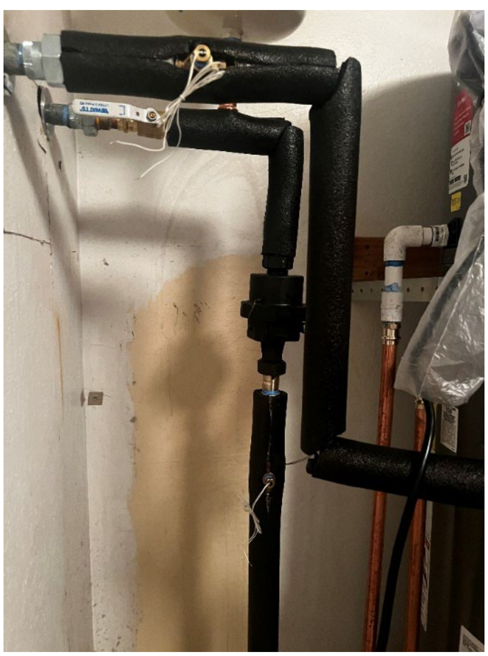
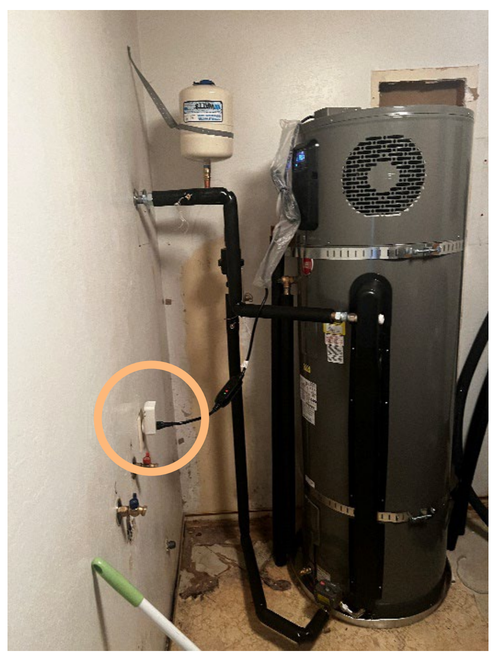


FIGURE 42. IMAGE SHOWING POWER METER PLUGGED INTO 120-VOLT OUTLET



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