NEEA Heat Pump Water Heaters for Demand Response and Energy Storage Cover Note

October 2, 2014

Purpose

Over the past year, Northwest Energy Efficiency Alliance's (NEEA) Emerging Technology group engaged in a field demonstration of residential Heat Pump Water Heaters (HWPH), evaluating the technology's capability to provide demand response and energy storage to the electric grid. The project was conducted in an effort to provide the US Department of Energy with data to inform and support a rulemaking related to the new electric water heater efficiency standards set to take effect in April of 2015. These standards will require electric water heaters larger than 55 gallons to have a minimum Energy Factor greater than 2.0, effectively requiring them to be HPWHs; however, interveners to this standard have proposed an exemption for "grid enabled" water heaters that have the capability to participate in demand response programs.

This project sought to assess whether HPWHs can productively store energy and participate in demand response programs, thereby supporting the broadest application of the new efficiency standards.

Study Findings

The demonstration involved testing the demand response and energy storage capabilities of 20 new and previously installed residential HPWHs located in the Cowlitz County Public Utility District service territory, with monitoring support from General Electric. The project tested the ability to both decrease and increase water heater electric loads in response to a communication signal- all without affecting the quality of water heating service as perceived by the end-user. The report outlines a number of challenges and lessons encountered that may have significance in instructing a successful HPWH control program, including but not limited to, the importance of reliable control and communications systems.

Overall the project demonstrated that HPWHs can participate in demand management programs designed to either reduce peak demand or provide energy storage services to the grid, or both. NEEA sent this report to the US Department of Energy in August 2014 to provide evidence of HPWH demand response and energy storage capabilities.

For more details on the findings and recommendations from this study, please read the full report below.

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Heat Pump Water Heaters for Demand Response and Energy Storage

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Heat Pump Water Heaters for Demand Response and Energy Storage

Pilot Project by Northwest Energy Efficiency Alliance

- Confidential –

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Date: August 2014

Project number: POWUS14072

Reviewed by Charlie Stephens, NEEA

ECOFYS
sustainable energy for everyone

Acknowledgments:

We thank NEEA for their support for this project and for being a true project partner, actively participating in all areas of the project.

We also thank GE for their strong support of the project. Scott Shaffer especially went above and beyond in troubleshooting both demand response problems and equipment issues. His help was invaluable.

Cowlitz Public Utility District was extremely responsive and helpful in finding project sites, assisting with site visits, installation and helping keep the project moving. Ecofys was excited to work with them again and look forward to future partnering opportunities.

Summary

This report documents an in-the-field demonstration of Heat Pump Water Heaters (HPWHs) for providing demand response (DR) to the electric grid. For the purposes of this report, DR includes all intentional modifications to end-use customer consumption patterns of electricity that are intended to alter the timing, level of instantaneous demand, or the total electricity consumption. This includes both increasing and decreasing demand, and making effective use of water heater storage capability.

The project involved 20 residential HPWHs installed in the Cowlitz County Public Utility District (CPUD) service territory. Ten of the units had already been installed as part of CPUD's energy efficiency program and ten were new water heaters installed in homes of low income families. The project was supported by General Electric (GE) which provided the communication signals that were sent via internet to GE's Nucleus communication devices in the homes.

Due to their contribution to peak demand and inherent ability to store and release thermal energy over time, water heaters have long been considered for demand response programs. In April 2015, new US Department of Energy efficiency standards[1] will require electric water heaters larger than 55 gallons to have a minimum Energy Factor greater than 2.0, effectively requiring them to be heat pump water heaters. Interveners have proposed an exemption for "grid enabled" water heaters that have the capability of participating in demand response programs[2]. The greater efficiency of HPWHs implies less electrical energy storage capacity per gallon of water[3]. This project sought to address whether HPWHs can productively participate in demand response programs.

This project targeted active control of 20 HPWHs in residential settings—ten new, and ten that had already been installed as part of the retail utility energy efficiency program. The ten new HPWHs were installed with a tempering valve on the output so that tank temperatures up to 160F could be achieved while maintaining a safe temperature for water delivered to the customer (no greater than 130F). The project tested the ability to both decrease and increase water heater electric loads in response to a communication signal—all without affecting the quality of water heating service as perceived by the end-user. This was effected indirectly by adjusting water heater thermostat setpoint temperatures.

Demand response capabilities were tested over a two-month period by reducing the target tank temperature during peak hours for the host utility, 2 hours in the morning and 3 hours in the evening. The ability to store energy was tested by raising tank temperature during night-time hours to "charge" the tank in anticipation of morning hot water usage. The HPWHs proved to be capable of reducing electricity consumption during morning peak hours by storing additional energy during night-time hours, while maintaining hot water availability at the taps.

It was unclear whether the controlled HPWHs had lower overall energy efficiency as would be expected due to raising the night time temperatures. Although higher temperatures caused heat pumps to operate at lower efficiency, they also reduced the likelihood of the far less efficient electric resistance heating elements turning on. Reducing reliance on electric resistance heating elements increases overall HPWH efficiency, potentially offsetting the lower operating efficiency of the compressor at higher tank temperatures. Alternating high temperature setpoints at night and reducing them in the morning also

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[1] Code of Regulations 10 CFR 430.32(d): http://www.gpo.gov/fdsys/pkg/CFR-2012-title10-vol3/pdf/CFR-2012-title10-vol3-sec430-32.pdf

[2] See for example: https://www.nreca.coop/ect-coop-co-ops-urge-water-heater-rule-change/

[3] Generally the thermal energy going into and out of the tanks are similar for HPWHs and standard electric resistance water heaters, however the amount of electrical energy input is lower in the HPWHs due to their greater efficiency. As a result, the effective *electric* energy storage capability from a power grid perspective is less for HPWHs.

reduced heat pump cycling. This suggests that the addition of control and communication equipment installed for the DR program introduces the potential for tailored optimization of HPWHs to increase efficiency, monitor performance, and reduce cycling of the units.

Participants were fully engaged in the project and provided a wealth of useful feedback about their water usage patterns, their understanding of their water heater settings, modes, and the function of the water heater both in normal operation and during test events. For example, complaints of low water temperature were sourced back to the tempering valve setting. One participant expressed not fully understanding some of the mode settings (they are difficult to understand).

There were a number of challenges and lessons encountered that may have significance in structuring a successful HPWH control program. For example, although the water heater controls and telecommunications equipment were nominally designed to provide the functionality sought by the project, they did not always work as anticipated or designed. This may be attributable to the normal development pains of a new technology, but these issues presented significant challenges to the success of the project. There were also differences among the HPWHs themselves that were not entirely expected. The existing HPWH controls were not identical to the newer ones due to changes in manufacturing that had occurred.

In a few cases, end-use customers experienced difficulties with their water heaters that they naturally attributed to the test project, although they were generally unrelated (e.g., malfunctioning units). Another interesting result was that data from the project was used to identify one water heater that was not energizing the compressor at all. This fact might not have been easily discovered by the homeowner except by noticing a disappointing result on the monthly electric bill. The issue was immediately identifiable through the collected data and ultimately led to repairing the water heater.

The project demonstrated the ability to control heat pump water heaters in a way that accesses the inherent storage capability without adversely affecting household service. There was no evidence that operating water heaters at a higher temperature level reduced the efficiency of the devices. To the contrary, there was some anecdotal evidence that efficiency could be improved. Reliable control and communication systems are a crucial element of a successful water heater control program, and proved to be the weakest link in the demonstration project. Although hot water service was not adversely affected in the operations, customers naturally assumed any perceived degradation of service was attributable to the program.

Despite the challenges, the project demonstrated that HPWHs can participate in demand management programs designed to either reduce peak demand or provide energy storage services to the grid, or both. The greater efficiency of HPWHs over more traditional electric resistance units means that there is effectively less electric energy stored in water heater tanks of equal size. Nevertheless, the functionality in demand response programs is similar.

1.1 Recommendations

1.1.1 Standards Development for "Grid Enabled" Appliances

Standards need to be developed for "grid enabled" appliances that encompass the suite of control and communication capabilities necessary to the effective and reliable participation in demand response programs. Equipment installed at the appliance is not a sufficient condition for successful participation in a demand response program. Additional work around setting more comprehensive standards (e.g., minimum operability and compatibility of components) is warranted.

1.1.2 Two-Way Communication

Two-way communication is a desirable attribute for DR programs, especially those involving HPWHs because of their greater complexity and potential for optimization. Two-way communication enables the device to signal back its response (or lack of response) to control signals and verify proper functioning of the units. The complexity of HPWHs makes verification of intended functionality more difficult to ascertain—both the relatively complex interaction between compressor and resistance elements, and how those components respond to control signals. For example, the unit that ceased operating in the compressor mode was still delivering hot water to the customer, while completely failing to deliver intended energy savings. This project would have greatly benefited from having mode settings confirmed through signals originating from the water heater to verify that signals had been received and acted on.

1.1.3 Explore Better Communication Options

Communication through home Wi-Fi is prone to frequent interruption (router replacements, change of service, changing passwords). Other options need to be explored, such as RF to routers, direct Ethernet connection, and Ethernet over power line technologies.

1.1.4 Establish Full-Suite Testing and Certification

A testing procedure in which a suite of communication and control equipment can be verified and certified would give utilities greater assurance that a particular proposed system will work as intended. There is a proliferation of vendors of individual devices and systems, but wider adoption of this technology would be accelerated by a reliable certification procedure.

1.1.5 Further Investigation of HPWH Optimization

The present generation of HPWH technology does not have the heat recovery period of standard electric resistance water heaters due to the relatively small compressor sizes. Operating the water heaters at higher temperatures can reduce activation of resistance heating elements and merits further consideration as a potential energy efficiency measure. Additional work is merited to identify the potential for achieving greater efficiency levels. This should include identifying optimal setpoint temperatures (with and without tempering valves), and more active "smart" algorithms that can adjust mode and setpoint temperatures based on site-specific observations.

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2 Introduction

Electric water heating represents about one fourth of residential electric energy consumption in the Pacific Northwest[4]. The Northwest's electric water heating load is significantly higher than the 10% national average[5] due to an historically abundant and cheap hydroelectricity resource. The Northwest Energy Efficiency Alliance's 2013 Residential Building Stock Assessment found that 55% of Northwest single family homes relied on electrically heated water.

Water heaters have long been considered for demand response (DR) programs due to their coincidence with peak electric demand, speed of response, and inherent energy storage capability. Programs such as dynamic pricing and incentive-based direct load control have demonstrated the ability to reduce peak electric demand by shifting energy use from high-load to low-load periods.

Increasing levels of generation from variable renewable resources such as wind and solar are in turn increasing interest in using responsive loads to provide ancillary services to the grid (e.g. balancing reserve). Demonstrations of peak reduction and energy storage using electric resistance water heaters have been implemented, providing invaluable experience to all stakeholders involved. For example, recent work performed as part of the Bonneville Power Administration's (BPA) Technology Innovation Program demonstrated that electric water heaters can provide multiple value streams (peak-shifting and balancing reserve)[6].

With the potential phase-out of electric resistance water heater technology in favor of much more efficient HPWHs, the question is: Can a HPWH provide the same range of DR benefits as its predecessor technology? If so, HPWHs provide a pathway to synergizing DR and energy efficiency implementation goals within a single device.

At this time, the U.S. Department of Energy (USDOE) is considering an efficiency standards waiver or exemption from the already-published electric water heater standards that become effective in April 2015 for large water heaters (larger than 55 gallons of storage volume) that are "grid-enabled." If a waiver or exemption is enacted, and if its construction is not narrow enough, such a loophole in the new water heater standards could seriously undermine regional investments in HPWH technology and innovation. This rulemaking is scheduled to conclude sometime in mid-CY 2014. The data from this project is intended to assist USDOE is making appropriate decisions with regard to a waiver or exemption for these large water heaters.

2.1 General Project Description

This project sought to control GE GeoSpring™ heat pump water heaters (HPWH) to demonstrate the ability to participate in demand management programs. The water heaters were in Cowlitz County Public Utility District's (CPUD) service territory. Ten of the water heaters were recruited from CPUD customers who had received an incentive for purchasing an efficient water heater in a previous energy efficiency program run by the utility. Several of the group of ten pre-existing units were in the homes of CPUD employees. The remaining ten water heaters were new units placed in residences recruited by Lower Columbia Community Action Project (LCCAP), a low income non-profit service company.

The first group of ten received $100 for agreeing to participate. The low income participants received new GeoSpring™ water heaters. The incentives for these targeted communities was sufficient to recruit

[4] Pacific Northwest Power and Conservation Council Sixth Power Plan, Appendix C.

[5] US EIA website, 2012 figures.

[6] See: Smart End-Use Energy Storage and Integration of Renewable Energy, BPA, September 2012.

participants relatively rapidly. Some issues surfaced in working with some of the low income residences relating to ability to communicate in a timely manner, and requirements for internet connectivity.

2.2 Research efforts of others

In July 2013 NEEA hosted a HPWH Demand Response Research Coordination meeting. Previous modeling efforts at PNNL and elsewhere have demonstrated the potential of electric resistance water heaters to provide a variety of grid services (peak curtailment, regulation, and voltage/frequency response) in the PNW and nationwide, but the demand response characteristics of HPWHs are not currently well understood. Some utilities are concerned (and their concern is has been acknowledged by DOE) that HPWHs may conflict with DR program goals.

2.2.1 EPRI

EPRI's laboratory and field studies[7] of HPWHs found energy use averaged 50% less than electric resistance units. The average daily load shapes for the mixed-humid climate showed significant reductions in power consumption during the morning and evening peaks, with reductions at the peak hour ranging from 47 to 56%, even in winter. Analysis of the small sample of cold-climate water heaters showed that in winter, those units provided only minimal reduction in peak power (10 to 25%) on average, although full-day energy consumption was 33 to 34% lower.

During large load and low ambient temperature events, the devices can operate similarly to electric-resistance water heaters and may contribute to winter peaks in the same manner.

Customer satisfaction and HPWH reliability were generally high. The majority of the customers of all utility hosts reported being "highly satisfied" or "satisfied" with their HPWHs.

2.2.2 PNNL

PNNL is currently evaluating the performance and demand response (DR) of the Gen II GE GeoSpring™ HPWH under a number of operating configurations in Lab homes. These homes are fully instrumented and have "simulated occupancy". PNNL's DR experiments included events of load shedding (INC) and increased load (DEC) of several durations and at several times throughout the day[8].

[7] See Energy Efficiency Demonstration: Executive Summary, EPRI, March 2013.

[8] See: Demand Response Performance of GE Hybrid Heat Pump Water Heater, PNNL, July 2013, PNNL-22642

PNNL HPWH Experiment Design[9]

Experiment Name	Experiment Description	Time	Duration	Purpose of Experiment
AM Peak Curtailment	Turn off heating elements	7:00 AM	3 hours	Evaluate HPWH load shedding potential (dispatchable kW and thermal capacity) as compared to electric resistance baseline to manage peak load
PM Peak Curtailment	Turn off heating elements	2:00 PM	3 hours	Evaluate HPWH load shedding potential (dispatchable kW and thermal capacity) as compared to electric resistance baseline to manage peak load
EVE Peak Curtailment	Turn off heating elements	6:00 PM	3 hours	Evaluate HPWH load shedding potential (dispatchable kW and thermal capacity) as compared to electric resistance baseline to manage peak load
INC Balancing	Turn off heating elements	2:00 AM 8:00 AM 2:00 PM 8:00 PM	1 hour	Evaluate HPWH potential to provide balancing reserves for dispatchable kW as compared to electric resistance baseline
DEC Balancing	Set tank temp to 135°F	2:00 AM 8:00 AM 2:00 PM 8:00 PM	1 hour	Evaluate thermal capacity of HPWH, as compared to electric resistance water heater, when temp set point is increased to 135 °F
DEC Balancing V2	Turn on electric resistance in Lab Home A; heat pump only in Lab Home B	2:00 PM 6:00PM	1 hour 3 hour	Evaluate thermal capacity of HPWH, as compared to electric resistance water heater, when temp set point is increased to 170 °F

[9] Demand Response Performance of GE Hybrid Heat Pump Water Heater, PNNL, July 2013.

3 Study Objectives

The main goals of this project are to:

1. Determine whether HPWHs are suitable for utility load management programs on a par with standard electric resistance water heaters.
2. Determine whether HPWHs can respond to load management signals.
3. Test whether load management can be implemented without adversely affecting quality of service provided.
4. Determine the effects on HPWH energy efficiency deriving from participation in a DR program.

The results of this project are expected to help inform the debate over whether grid-enabled water heaters should be accorded special consideration under proposed federal regulations.

4 Technology and Installations

4.1 Hardware

4.1.1 GeoSpring Hybrid Water Heaters

The GE GeoSpring™ is a hybrid heat pump and electric resistance 50-gallon water heater with 65 gallons first hour rating. It installs similarly to a standard electric water heater with respect to water and electrical connections. It has earned the ENERGY STAR® rating for exceeding federal energy efficiency guidelines.

When operating in heat pump mode, the water heater draws ambient air from the room to heat the water. GE requires installation be in a room that is at least 10' x 10' x 7' (700 cubic feet) or larger. If the room is smaller, there must be a louvered door. Significant energy savings for these units have been demonstrated, resulting from operation of the heat pump, which is generally far more efficient than relying on electric resistance heating elements.

The units have multiple operating modes that can be selected by the user, or remotely as in this project. The available operating modes are:

- Heat Pump Only

  This is the most energy efficient mode where all the heating is derived from the compressor. However the heat pump is sized such that it cannot provide the recovery available from electric resistance heating, and other modes may be desired during periods of high hot water demand.

- Hybrid

  This mode primarily relies on the compressor for water heating, but allows the electric resistance heating element to come on under certain high demand circumstances. The rated energy efficiency of the GeoSpring™ is derived from operating in the Hybrid mode at a setpoint temperature of 135F.

- High Demand/Boost

  This mode is similar to the Hybrid mode except that the electric resistance heating element is energized sooner.

- Electric Resistance Only

  This mode only allows energizing of the electric heating elements, similar to the operation of standard electric water heaters.

Both water heater modes and temperature setpoints were controllable by both the household residents and remotely through the Nucleus communication device.

4.1.2 Existing HPWHs

Ten customers with existing GE GeoSpring™ HPWHs agreed to participate in the study. A GE Nucleus device was installed at each site to enable communication and control of the HPWH. The Nucleus communicates wirelessly with an Appliance Communication Module (ACM) unit installed in the HPWH. The GE Nucleus can be connected with an Ethernet cable or via Wi-Fi to the router in the home. In our experience connecting via Ethernet cable is much more reliable than Wi-Fi due to outages, changed passwords, etc.

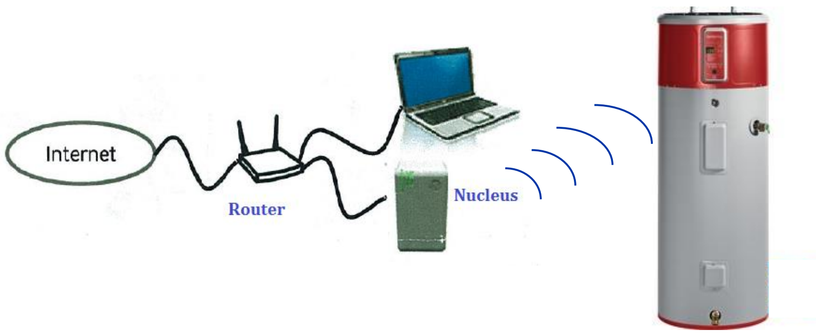


Figure 1: Nucleus installation

Given that the HPWHs were already installed, only data collection and monitoring equipment were installed on these existing units, without adding a temperature mixing valve and flow meter. This reduced the installation complexity and costs as no plumber was needed, only an electrician and data technician. However, lack of a temperature mixing valve meant that these ten units could not be used for high-temperature energy storage testing; and lack of a flow meter meant that the pilot program was dependent on data from other monitoring equipment to infer flow events.

After extensive discussions with GE about the design of the GeoSpring™ HPWH and the Nucleus, it became clear that the Nucleus would not provide monitoring of the tank temperature. This measurement was critical to the research and demonstration, so a thermocouple was retro-fitted on the HPWH near the power terminals for the upper resistance heating element, allowing for temperature monitoring within 2 degrees of actual temperature.

4.1.3 New HPWH Installations

Ten customers were recruited for installation of a new GE GeoSpring™ HPWH. For these customers the new HPWHs were installed with a tempering valve on the output so that tank temperatures up to 160F could be achieved while maintaining a safe temperature for water delivered to the customer (no greater than 130F).

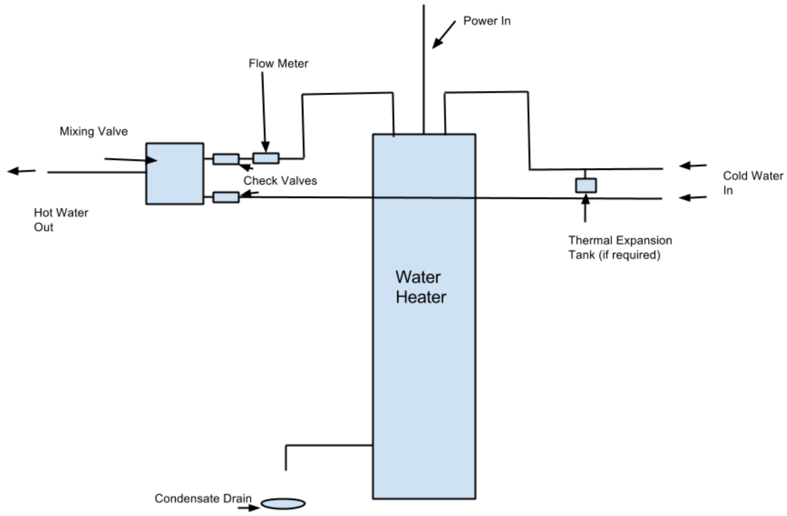


Figure 2: Installation of new HPWH with mixing valve and flow meter

4.2 Software

A firmware upgrade was necessary on the newly installed HPWHs to enable those tanks to increase tank temperature to 160F. The existing HPWHs participated in the program without any software changes.

4.3 Installation Challenges

4.3.1 Unanticipated Issues

Field tests are prone to unexpected issues. Some of the challenges realized in this project are briefly described below.

- Very few tradesmen (plumbers and electricians) responded with a proposal for the work. The contractors selected did acceptable work, but at prices which were high considering the man-hours and cost of materials. The plumber was difficult to contact and took a long time to respond to requests for necessary re-visits to the sites.
- The systems were all to be installed with insulation on the plumbing (as required by the Washington State energy code). However some systems were not insulated, and a flow meter froze and burst during an extreme cold weather event. This site could not be brought back online during the course of the project.
- The setting on the mixing valves was problematic for some residents. In general, the understanding of the mixing valve and how to use it was not good on the part of the contractor or the home occupants. Setting the mixing valve output temperature too low caused some households to change the mode of the HPWH to one which uses the resistance element more often. The result was a loss of efficiency without improving hot water service in the home.

4.3.2 Systemic challenges

Some of the issues faced went beyond individual installations, relating to the specific equipment chosen for this project. These challenges included:

- Many homes had trouble with internet connectivity. The model and age of the router makes a difference in the compatibility with the GE Nucleus and with the data collection system. Incompatibility resulted in either a failure to communicate with the water heater or a failure to collect data, or both.
- Most customers' HPWH thermostats were set to 120F. This temperature setpoint is consistent with the manufacturer setting and most utility leaflet recommendations. However, for a household with more than 2 adults, this setting results in the HPWH energizing electric resistance more often than would otherwise be necessary.
- People who expect a large amount of hot water to be available over a short period of time, e.g. to run a bath or to take several consecutive showers often had high temperature settings and were in "high demand" mode, in which the resistance element comes on more readily. This tends to lead to reduced efficiency. However, as the Nucleus unit had no way of storing the previous setpoint for temperature and mode, some customers had to change their bathing behavior. The inability to store the household's manual settings and return to them after a controlling event was a major source of potential confusion and dissatisfaction with the program.
- Logic inherent in GE's communication system ceased attempting to communicate with the appliances after three unsuccessful attempts. In addition, the system did not have the capability to identify whether water heaters had in fact received a sent signal and acted on it. This severely limited the participation of water heaters in this project. Of the twenty water heaters in the program, several clearly responded to the signals that were sent over the trial period. One of the challenges of the project was that confirmation of thermostat and HPWH mode settings were not included in the recorded data. The actual control of water heaters had to be determined from the resulting water heater behavior. The table in Appendix C summarizes the specifics of each water heater in the demonstration project The aggregated energy use data shows evidence that power consumption during the 8:00 to 10:00 peak energy use periods was in fact reduced as intended. Difficulties in communication and control equipment limited responses and our ability to verify them.

5 Testing Methodology

5.1 HPWH Testing Hardware and Objectives

The project involved controlling 20 heat pump water heaters to demonstrate the feasibility of using them in demand response programs. Ten of them were new units installed specifically for this project and included mixing valves to allow elevated temperatures. The other 10 were existing units that were used to test the capabilities of existing tanks without the additional plumbing involved with installing mixing valves, thus limiting the upper range of temperatures available in those units (to avoid scalding).

The project included:

- 20 water heaters, 10 newly acquired and installed devices with high-temperature capability.
- Testing the ability to reduce power use during peak hours demand hours, specifically 8-10 am.
- Testing the energy storage capability, targeting night-time and very early morning hour pre-heating operations. Thermostat set points were raised at night to store energy, and dropped during the morning peak demand period to reduce the likelihood of needing to energize either the water heater.
- Evaluating the impact of setpoint manipulation on water heater operations, specifically whether the compressor alone could meet the schedule for tank temperature increases.
- Monitoring the units during electric power demand reduction (invoked by lowering thermostat temperature settings) and energy storage (by raising thermostat settings) events to ensure delivery of hot water to the household.

GE GeoSpring™ heat pump water heaters were selected, partly because Cowlitz Public Utility District’s energy efficiency rebate programs had incentivised the earlier installation of 10 units. This expedited the recruitment of site hosts with existing tanks. GE also agreed to support the project by providing control hardware and software and managing the cloud that housed the control plans.

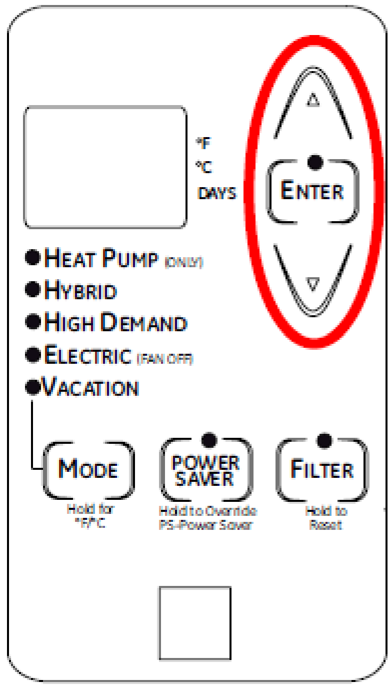


Figure 3: GeoSpring™ control panel

5.2 Control plans

The water heaters were divided into 4 groups of 5 homes each. The first two groups were existing tanks, the other two the new tanks. This allowed 10 tanks to be in control at any given time, with 10 running as they would normally. An unexpected complication was that the Nucleus units did not have any memory to store previous settings, so that the tanks were left in whatever temperature and heating mode setting they had been in at the end of the previous control period. This was generally 130 degrees in hybrid mode, and not always what the users had set the tanks at previously.

Groups 3 and 4 were the newly installed tanks with mixing valves, allowing for safe tank temperature operation up to 160 degrees.

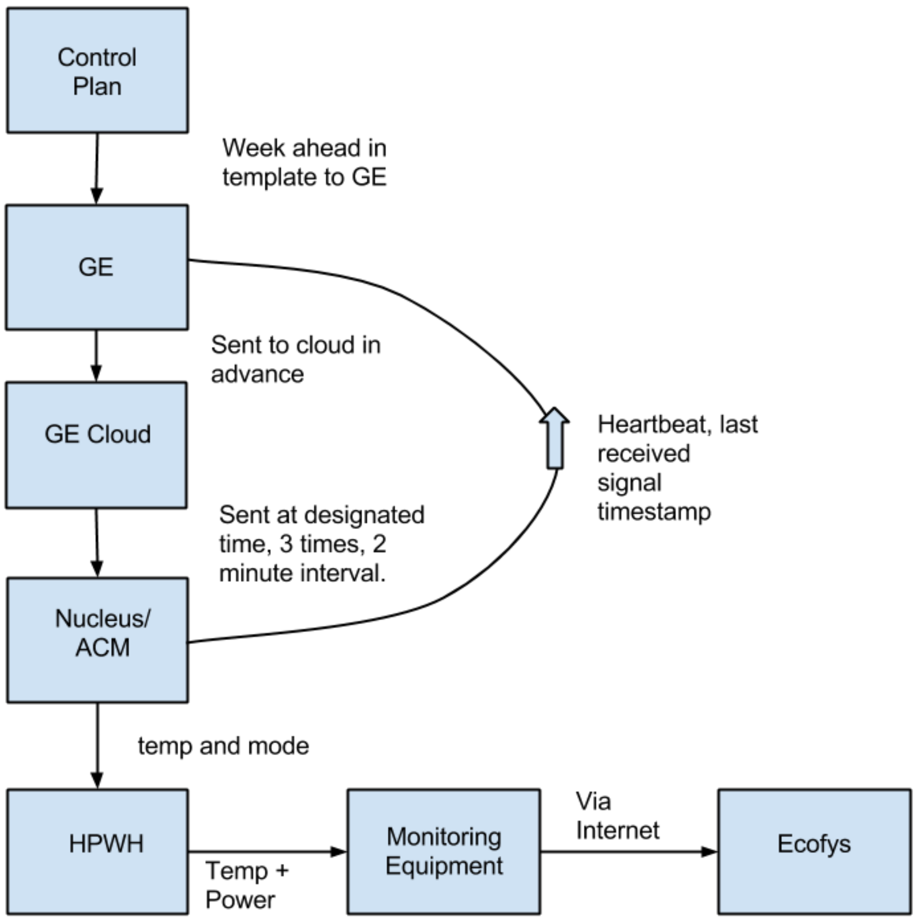


Figure 4: Control Diagram

5.2.1 Peak Shaving (3/1/2014 – 3/7/2014)

This is the first set of control commands that Ecofys planned to send out. Note that there are several modes of operation for the GeoSpring™ (see section 3.1.1 and Figure 3). In Heat Pump Only mode the unit will only use the compressor, not the resistance element (except in one of the units in which the heat pump was not functioning properly). In Hybrid mode the unit uses the compressor to heat the water unless there has been a high water draw or the water temperature has dropped below a certain threshold from the current set point. In High Demand mode the unit uses the compressor, but is quicker to turn on the resistance element. Electric Only mode enables only the resistance element, functioning similarly to a standard water heater.

GE was only able to send 4 commands per day, so the ability to test multiple steps in for a DR event was limited for the purposes of this study.

Group 1:

Command	Date	Time(PST)	Targeted Mode	Setpoint Temp
1	3/1	03:00	Heat Pump Only	130F
2	3/1	05:00	Hybrid	130F
3	3/1	08:00	Hybrid	120F
4	3/1	10:00	Hybrid	130F

Group 2: Control Group (no signals)

Group 3:

Command	Date	Time(PST)	Targeted Mode	Setpoint Temp
1	3/1	03:00	Heat Pump Only	130F
2	3/1	05:00	Hybrid	130F
3	3/1	08:00	Hybrid	120F
4	3/1	10:00	Hybrid	130F

Group 4: Control Group (no signals)

The goal of this test procedure was to reduce electric power consumption over peak hours (8-10 am) by lowering thermostat temperatures 10F.

There were some unexpected power usage spikes in the early morning during the first week of testing. Ecofys and GE determined that instead of heat pump only, the mode commands were going out as resistance element only, instead of the targeted mode. Even so, the overall power use on control days was lower than uncontrolled days from 8-10 am. This problem was fixed on March 7th.

Control groups were sent no signals and were used to gather baseline data for the given time period.

5.2.2 Peak Shaving and Energy Storage (3/8 -3/23)

Group 1: Control Group (no signals).

Group 2:

Command	Date	Time(PST)	Targeted Mode	Setpoint Temp
1	3/8	3:00	Heat Pump Only	130F
2	3/8	5:00	Hybrid	130F
3	3/8	8:00	Hybrid	120F
4	3/8	10:00	Hybrid	130F

Group 3: Control Group (no signals).

Group 4

Command	Date	Time(PST)	Targeted Mode	Setpoint Temp
1	3/8	3:00	Heat Pump Only	160F
2	3/8	5:00	Hybrid	160F
3	3/8	8:00	Hybrid	120F
4	3/8	10:00	Hybrid	130F

This test period combined a reduction in thermostat temperatures in the morning peak hours with elevated thermostat temperatures for the new water heaters beginning at 10 pm. This was intended to test storing energy at night for use during the morning hours. The mode setting was adjusted to "heat pump only" to ensure the higher temperature settings could not cause the electric resistance elements to energize. This test sought to investigate the ability of the water heaters to ride through the 08:00 to 10:00 period while reducing the strong rebound in electricity use at 10:00.

5.2.3 Peak Shaving Morning and Evening, with Energy Storage (3/24 – 3/31)

Group 1:

Command	Date	Time(PST)	Targeted Mode	Temp
1	3/24	4:00	Hybrid	130
2	3/24	8:00	Hybrid	120
3	3/24	10:00	Hybrid	130
4	3/24	19:00	Hybrid	120

Group 2: Control Group (no signals).

Group 3

Command	Date	Time(PST)	Targeted Mode	Temp
1	3/24	22:00	Hybrid	160
2	3/24	8:00	Hybrid	120
3	3/24	10:00	Hybrid	130
4	3/24	19:00	Hybrid	120

Group 4: Control Group (no signals).

This test period explored the ability of the water heaters to ride through the evening Cowlitz peak with a lower temperature. The Cowlitz evening peak is lower than the morning peak, but it was important to demonstrate the HPWHs capability over evening hours as well. Generally these evening hours see less water use, thus giving the potential to delay reheating the water after daily use until the late evening.

6 Test Results

6.1 Data collection

Real-time data was collected into a database and data portal through PowerWise, a commercial vendor of energy monitoring equipment. The portal was very useful in monitoring the operation of the HPWH during the project. For example, Figure 5 shows data for one unit over a two day period in which the resistance element inexplicably came on just after 3:00 am the first day (grey line). This led the project team to discover that in addition to changing the temperature setpoint, the units were inadvertently receiving a signal to change the operating mode to resistance-only. This was resolved during the first week of testing.

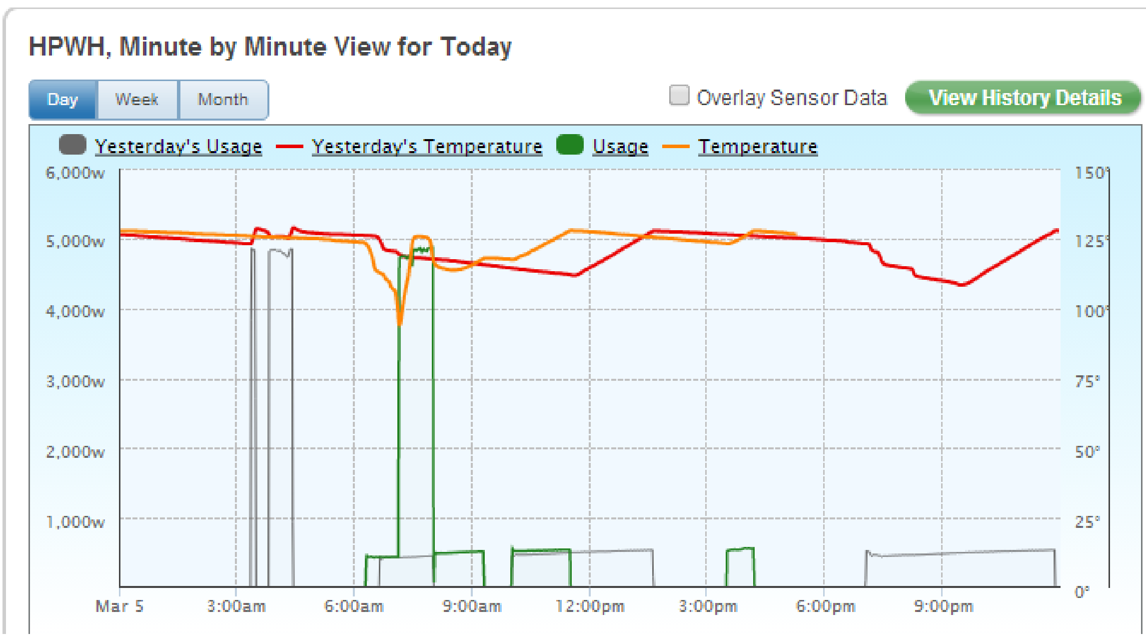


Figure 5: Sample of data from PowerWise portal (March 4-5, Group 1, Site 4)

Figure 5 shows the water heater reducing the power consumption levels at 8:00 am, suggesting that the signal to reduce thermostat temperature was received as intended. At that time, the unit was recovering from a large water draw event (evidenced in the orange line temperature trace) that began around 6:30 am. As the temperature dropped further the unit turned on the resistance element to heat the water more rapidly. At around 7:45 am a new water draw occurs, with the water heater still in resistance mode. At 8:00 am the signal to lower the thermostat temperature puts the unit within a target temperature band in which the unit uses the compressor instead of the resistance element.

This illustrates the ability to reduce power consumption during the target 8-10 am peak demand period. Although the unit continued using electricity during this peak time, power consumption was reduced while maintaining water temperatures within an acceptable range for the household.

6.2 Analysis

The data collected over the course of the project was more limited than originally expected due to delays in installation coupled with difficulties in software and hardware involved in controlling the water heaters. In some cases the control and communication equipment was simply not operating as expected. The delays also limited time and budget for a complete analysis of the collected data. Presented here is primarily a specific example of a water heater being controlled. See Appendix C for a complete listing of the status of water heater participation in the project

6.3 Results

The field tests showed several water heaters responding to the intended mode and temperature set point settings. Several sites were clearly not responding to signals. Because thermostat and HPWH mode settings were not explicitly recorded, water heater response had to be inferred from other available data. Average use patterns showed that energy use was lower during peak periods as planned. Difficulties with communication links and software were referred to previously. The data was not fully analyzed in time for this report, in large part due to the other difficulties encountered.

Figure 6 shows one of the water heaters under a test control week and an uncontrolled week. The water heaters were sent a signal at 11 pm to reach 160F. The longer periods of heat pump compressor operation can be seen in the top chart that span across midnight each day. The setpoint temperature is reduced to 120F at 8:00 each morning to reduce the likelihood of the heat pump operating during that time period.

The chart indicates that the test strategy reduces the overall number of times the HPWH is energized, and reduces the correlation between hot water draws and energizing the HPWH. This illustrates an operation intended to demonstrate energy storage (by heating to 160F at night) and reducing peak demand (by lowering the temperature to 120F during peak hours). Although time and budget limited the ability to more fully analyze the data, this example illustrates the feasibility of fairly sophisticated demand management with HPWHs.

Note that this was part of the test described in section 4.3.3 in which the intended time for starting the pre-heating was 22:00, but the chart shows the devices being energized at 23:00 (possibly related to the change to Daylight Savings Time). This is another example of the difficulties encountered in setting up the system and making it work as intended.

Another feature of the test shown in Figure 6 is that the HPWH was set in hybrid mode which allowed the electric resistance element to come on (the near-vertical blue lines). The electric resistance elements tended to come on at the beginning of the heating period when the setpoint temperature was initially raised to 160F. It would be more optimal from an energy efficiency point of view to set the mode to "heat pump only" for the nighttime heating events. Although the heating element came on more frequently during the test period in Figure 6, none of those events occurred during the 8-10 am high demand period, whereas in the comparison week, on 2/27 an electric resistance heating event fell squarely in that time period.

The HPWHs are designed to deliver heat to the tank at a roughly constant rate. As the tank water temperature rises, efficiency drops and the heat pump power consumption rises to maintain a constant heat delivery rate. This effect is evidenced in Figure 6, where during the long heat pump operations the power consumption rises roughly linearly in time as the tank temperature increases. GE reported the design heat delivery rate is roughly 1,200 watts.

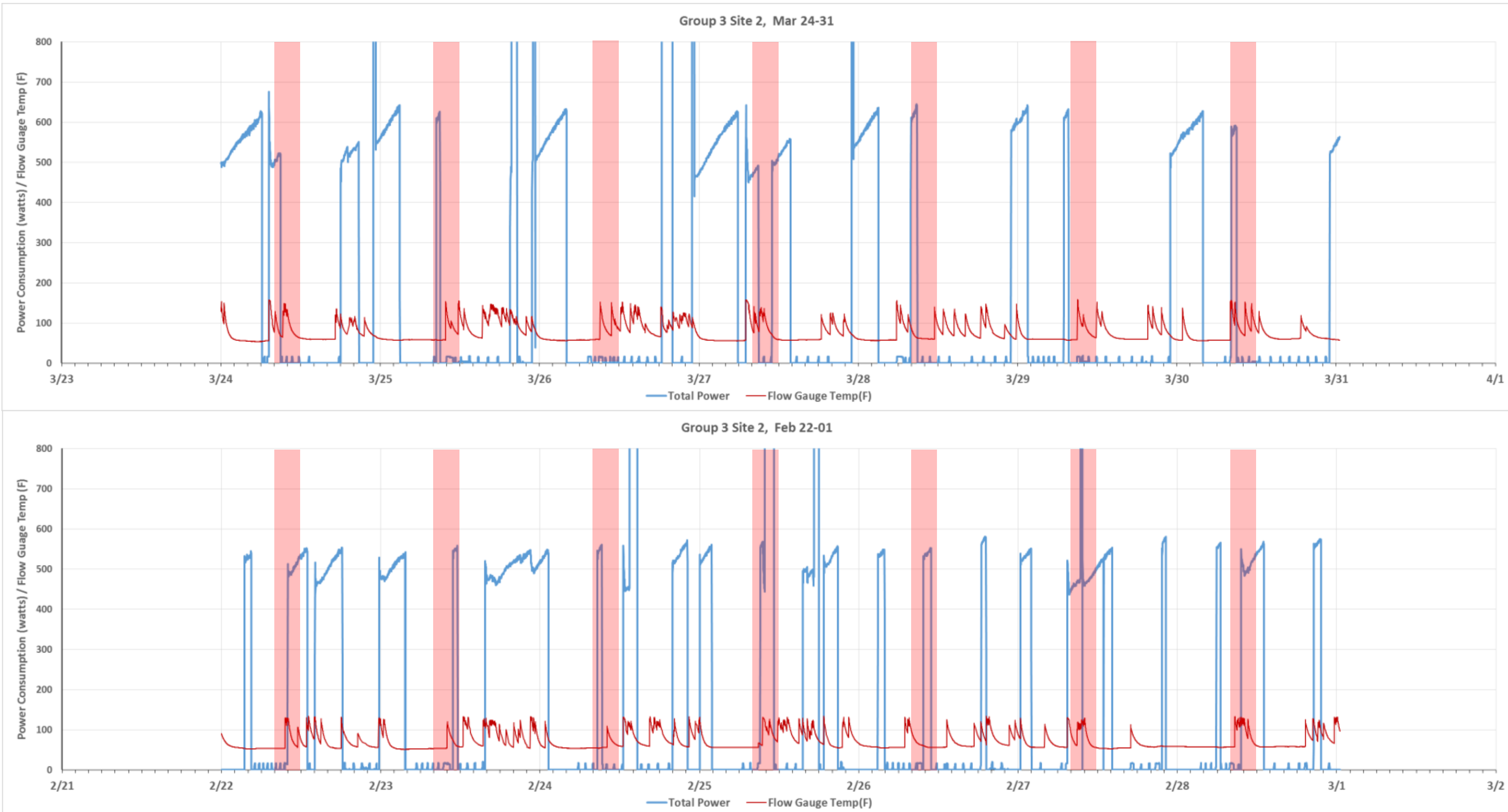


Figure 6: One water heater in Group 3 during a controlled test week (top) and an uncontrolled week (bottom). The red bars indicate the 8-10 am peak load period. The blue lines indicate water heater power consumption, and the red lines indicate temperatures at the flow meter—temperatures rise rapidly when hot water is withdrawn from the tank. Preheating events in the controlled test week began at 11 pm in the top chart and continued for several hours, often beginning with an electric resistance heating element event (the near vertical lines) due to the water heaters being in hybrid mode (these could have been avoided in heat pump only mode). The lower chart shows the water heater coming on every day in the 8-10 am period, whereas two days during the test period (3/26 and 3/29) had no power consumption in that time period.

6.3.1 Energy Efficiency

Overall, the test program participants consumed less electric energy than the uncontrolled group.

Groups 1 and 2: average reduction of 1.48 kWh per month

Groups 3 and 4: average reduction of 0.93 kWh per month

These are relatively small energy savings, and are potentially due to random fluctuations in water usage. However, the reductions run contrary to expectations that higher operating temperatures would increase losses. It is plausible that efficiency in the test periods could have been greater due to the HPWH logic for energizing the electric resistance heating element. With most of the water draws occurring during the day, it is postulated that operating water heaters at higher average temperatures in the test sequences reduced the likelihood of the electric resistance element being energized.

Although the data was not analyzed thoroughly enough to definitively draw a conclusion about energy efficiency when operating to reduce peak hours power consumption or late-hour energy storage, there was no indication of higher power consumption associated with elevated temperatures in these tests. One of the recommendations from this report is to study strategies for optimizing HPWH temperature settings and modes.

The ability to recognize patterns in hot water use and optimize the mode and temperature settings to individual residences suggest that HPWHs participating an a demand management program can both reduce average electrical energy use during peak load hours and store energy without sacrificing overall energy efficiency.

7 Successful Program Design Considerations

Designing a successful water heater demand response program includes careful consideration of each major element of the program:

1) Participant recruitment and incentives
2) Robust and flexible hardware components
3) Reliable two-way communication
4) Adaptation to communication interruptions and restoration of customer settings
5) End use customer education
6) Water heater performance and efficiency optimization
7) Vendor Selection

As a small scale demonstration, the goals of this project mainly revolved around the extent to which emerging heat pump water heater technology can perform in a load control program similarly to the more studied traditional resistance element units. It was nevertheless vital to ensure the most positive possible experience for customers of our allied utility. Successful programs will also ensure that the customer is not adversely impacted. Each of the above elements is examined in more detail below, with recommendations for a robust and successful DR/ES program.

The greater complexity of HPWHs compared to standard water heaters has both advantages and disadvantages. In general, operating HPWHs to provide DR services introduces additional compressor cycling that could result in higher maintenance costs or shorter equipment lifetimes. However operating water heaters at higher temperatures at night and allowing tank temperatures to drop through the day reduced daytime cycling. The combined benefit of fewer cycling events and potentially higher efficiencies from avoiding electric resistance heating suggests a very promising operational strategy for HPWHs.

7.1 Participant recruitment and incentives

Recruiting sufficient and motivated participants is important in designing a successful DR program. The project's incentives were large enough for the relatively specific targeted groups (existing HPWH owners and low income families) to meet the relatively limited number of needed participants. This project did not test the efficacy of different incentive and recruitment techniques to be able to draw useful conclusions for large-scale deployment.

7.2 Robust and flexible hardware components

How data is collected, stored, and transmitted are key choices in any load management program. It is important to verify early on that any technology under consideration will be well supported and have some degree of forward compatibility with new hardware and software. If communications platforms change part way through a program, the added cost of switching outdated equipment can be high, especially with the labor required to implement these changes, both on and off site.

Consideration should be given to whether the selected hardware supports the most recent communications protocols, and whether there is cross-compatibility with devices made by other manufacturers.

Customers expect water heaters to have a much longer life than most consumer electronics. Communication technologies and hardware are changing rapidly, so planning for the future can keep a program running smoothly for multiple years. Selecting and enabling a site is a large part of the costs of any program, so program managers need to choose hardware that can support upcoming technology to the extent possible, incorporates flexibility (e.g., off-site logic programming) or modular enough to update easily on-site (e.g., without using a screwdriver).

Broadband internet is a viable solution for communicating between any central server and the water heater. However, local Wi-Fi was not a robust communication method for reaching the internet. Site hosts often change passwords, switch routers, or simply have strange configurations. Hardwiring the water heater and any control devices to the router is not a necessity, but should be strongly considered in preference to Wi-Fi.

It is also important to consider speed of response. If second-by-second monitoring of the water heater is necessary, choosing a communications technology that provides that bandwidth and reliability is, of course, imperative. If simply sending a one-time signal to lower energy use is the goal, then other communications routes are an option.

Cellular technology tends to be expensive as a communications vehicle, but if it ensures uptime with less maintenance the tradeoff may be worth it. If information technology staff are required to regularly troubleshoot problematic sites, the costs of a program may become prohibitive. The remote location of water heaters (e.g., in basements) tends to be somewhat challenging for many technologies—including cellular. One residential water heater DR vendor reported requiring either a cabled Ethernet connection or Ethernet over power lines in order to maintain a reasonably high level of reliability.

Another secondary consideration is that monitoring and communications equipment use energy. It is important to keep this in mind when choosing technological solutions. Care should be taken to ensure that efficiency gains are not offset by high electrical loads caused by other equipment in the program.

The lack of a robust system of communication was the main reason this project found just one of 20 water heaters definitively responding to the control signals.

7.3 Two-way communication

Two-way communication is important to effective DR programs with HPWHs. Two-way communication provides for monitoring the hardware and energy use and are necessary to verifying water heater response and state (e.g. tank temperature).

Another benefit is the potential for optimizing the operation and maintenance of the units. The complexity of HPWHs makes it especially difficult for end users to know whether their units are functioning properly and two-way communication was vital in diagnosing a malfunctioning unit in the demonstration project. The communication package should minimally be able to:

- Receive signals for controlling both the temperature setpoint and the heat pump mode on at least a ten-minute basis.
- Report back power consumption on at least a ten minute basis, with time stamps.
- Store data on site for at least one week.

More optimally, a robust DR program would:

- Receive and act on signals on a one-minute basis
- Report tank temperatures and/or outflow temperatures.
- Report flow events and rates.

Although it is possible to run a program with one way communication, extreme care must be taken in setting up the program to ensure signals are being sent, received, and acted on at the outset with a high level of reliability. Such a strategy today appears risky as the experience in this and other studies have found communications to be a vulnerable program function. Two-way communication makes it much easier to quickly identify and correct functional issues with the communication system itself, or with other system components.

Appropriate data analysis could both identify problems with water heater performance and optimize controls for energy efficiency. Utility or other third parties running programs in which they own the water heaters would especially benefit from implementing HPWH performance algorithms to manage preventative maintenance costs. This is especially true for heat pump water heaters, which have more complex systems, moving parts, and failure modes.

7.4 Communication interruptions and restoration of customer settings

Dropped communication links need to be managed in a way that does not degrade hot water service. Some form of data storage and logic in the water heater or its controller should be capable of ensuring satisfactory performance while riding through communication lapses. As no communication protocol will be foolproof, it is important to design systems capable of anticipating communication faults, ensuring satisfactory operations through the faults, and recovering when communications are reestablished.

Many water heater demand response projects set the water temperature and heating mode of the water heater remotely for some period of time. After the water heater is no longer controlled remotely, it is very important that water heater returns to normal operations. The site host has a right to expect that the water heater will return to their previous settings. This means that the water heater or its controller must be able to store a default setting that has been set by the household.

Storing one or more pre-defined control algorithms is similarly important. Should internet connectivity drop for any length of time it is important that the water heater can revert to normal operation and not be stuck in a controlled setting. Because weekend water use and grid power needs tend to be different from weekday operations, weekend control operations can be expected to differ from weekdays. Capability to ride through and recover from communication faults might optimally include sufficient storage and logic to accommodate differentiated weekday and weekend operations. In any case, residents should have the option to override the controls at any time.

7.5 End use customer education

Customer satisfaction is closely tied to education. The complexity of the interactions between hot water use levels and patterns, water heater modes and temperature settings, tempering valves, and DR control programs can be confusing to many end use customers. The study found that participants in the program were not necessarily fully aware of the expected outcomes and their roles.

Several participants (or the contractor) unknowingly set tempering valve temperatures too low to provide satisfactory service, and then attempted to compensate by raising the setpoint temperature (which did not help). Other participants were worried about adjusting the temperature or mode at their own water heater.

These are understandable complexities that most people don’t normally concern themselves with. It is imperative that multiple avenues of communication are used, with reasonable repetition, to make it clear to participants the goals of the program, what their roles are, and how to obtain help in addressing their concerns.

7.6 Water heater optimization

Optimizing the combination of temperature and mode settings of the water heater to meet end use needs is important. Setting the water heater below 130F will not result in maximum efficiency for most households. GE representatives noted that they had seen higher efficiency for many households with a higher temperature setting than the 120 degrees that the units ship at. They currently design the water heaters to operate most efficiently in the 130 to 135 degree range. GE reported that it appears the standby losses and lower heat pump efficiency at higher temperatures are offset by the efficiency gains from reducing the use of the resistance element.

Households with more than 2 people are very likely to receive higher overall efficiency with higher setpoint temperatures. This higher temperature may be a bit of an advantage for demand response programs, as it allows for a larger range of useful temperatures, effectively raising the available energy storage capacity. The addition of a tempering valve to allow higher operating temperatures may be an economic energy efficiency measure for HPWHs serving in DR programs.

7.7 Hardware and Communication Vendor selection

Knowing the track record of a vendor is important as well. A start-up vendor may be very easy to work with, responsive, and be able to grow with a program. However they may not have all of the kinks worked out of a system at the beginning of a program. With any vendor it is very useful to make sure there are clear expectations on each side on how the technology will be used, what its strengths and limitations are and how future versions of the technology may change. For example changes in the back end software for a monitoring system may make some equipment not behave in the manner that is expected. Communicating expectations and timelines effectively with vendors may prevent major setbacks.

8 Conclusions and Recommendations

8.1 Conclusions

The project demonstrated both the feasibility of using HPWH technology to participate in demand management programs, and the challenges inherent in implementing such programs. There are a number of critical elements to implementing water heater demand management programs, irrespective of whether the programs are implemented using traditional electric resistance water heaters or HPWH units. The capability of any water heating technology to act on control signals is a necessary, but far from sufficient, condition for a successful program.

Equally important to a successful program is the web of institutional and technological relationships among the end use customer, the utility, program implementer (sender of the signals), HPWH control and communication equipment, and an intensive quality control program capable of assessing whether signals were sent, received, and acted on by the end use device. This project and others have shown that communicating with water heaters from outside the residence is the most vulnerable link today. Home Wi-Fi has proven to be a particularly unreliable element of a communications channel. Other internet options such as cable Ethernet connections to routers, RF communications from the appliance to a receiver at the home router, or Ethernet over power line technologies may be more reliable but were not tested here.

Although orchestrating that network of intercommunication and control is complex, there is value inherent in succeeding at it, especially for HPWH technology. In addition to implementing demand management by storing energy when market prices are low and reducing power inputs during higher value hours, the information available from such a program could be used to increase energy efficiency by anticipating the interaction between water heating use patterns and HPWH on-board logic for switching between heat pump and electric resistance loads. Due to higher standby heating losses operating the heat pump to produce higher temperature water might be expected to lower efficiency, instead it can increase efficiency if it avoids energizing the electric resistance heating elements. An advanced DR program could have additional benefits beyond active demand management and higher overall efficiency, including reducing wear on HPWHs (by reducing compressor cycling) and identifying malfunctioning equipment[10].

8.1.1 Study Objectives

Below is a description of the finding relating to the study objectives identified in section 2. Study results are summarized below.

8.1.1.1 HPWH response to load management signals

The capability of HPWHs to respond to load management signals was demonstrated, however the project underscored the difficulty in achieving that result. Those challenges were not associated specifically with the HPWH technology, but more broadly the complexity of control and communication of end use devices generally. The ability to successfully respond to load management signals requires:

[10] It may be expected that the logic built into HPWHs will become more sophisticated through time for exactly the reasons pointed out in this paragraph. Two important considerations are 1) that the greater sophistication implies an even greater need for communication between the water heater and some monitoring entity to ensure proper functionality; and 2) that the more sophisticated algorithms be designed to be able to work with outside control signals.

1) Ability for the HPWH device to control setpoint temperature and (preferably) operational mode (i.e., hybrid, heat pump only, electric resistance only, etc.).
2) Ability to receive a signal from an outside source (e.g., the internet, RF signal, etc.) and act on it.
3) Ability to signal back to confirm the signal was received and acted on. This may be more important for HPWHs because of their greater complexity, but may also pay greater dividends by allowing for more sophisticated algorithms that have potential to optimize HPWH performance and reduce overall power consumption.

8.1.1.2 HPWH suitability to load management programs

The project showed the comparability of HPWHs to standard electric resistance water heaters with respect to ability participate in load management programs. There are differences between HPWHs and electric resistance water heaters:

1) Because of their higher efficiency and lower overall energy consumption, HPWH effective electrical energy storage capacity is lower than standard electric resistance units for similarly sized units. There are simply fewer electric kilowatt-hours involved in heating a gallon of water in the HPWH.
2) There is an important and somewhat complex interaction between optimal DR operation and HPWH logic that switches between compressor and electric resistance heating modes. To maximize water heating efficiency (and preserve HPWH energy savings), it is important to use heat pump-only modes when preheating the water during off-peak hours in order to avoid energizing the resistance elements unnecessarily. This added control complexity can be an advantage by enabling more advanced logic systems that can optimize the combination of water heating efficiency and trouble-free household hot water service.

8.1.1.3 Ability to maintain quality of service

The project demonstrated that the DR program holds promise to actually improve quality of service by:

1) Retrieving information that revealed defective units (stuck in electric resistance only mode) that would not easily have been discovered by the end use customer.
2) Operating at higher average temperatures than the factory setting, which resulted in more reliable hot water availability to the end user.
3) Gathering information that can be used to optimize the efficiency of reliable hot water service.

An important caveat to these findings is that end users understandably ascribe any adverse experiences to the program—for example, running out of hot water during periods of high hot water use in a residence where the heat pump is set to heat pump-only mode at a relatively low setpoint temperature. Any other plumbing or electrical issues may also be ascribed to the program whether related or not. One end-user in the study complained of hot water shortages before any DR signals were being sent out. The complexity of HPWHs adds to this issue as the end-users may not fully understand the various modes and their interaction with setpoint temperatures and hot water use levels.

8.1.1.4 Determine the effect on energy efficiency

Although the project did not gather enough data to conclusively show the effects on energy efficiency, it became clear that the information retrieved in the process of effectively managing a HPWH DR program can increase the overall efficiency of the units. An algorithm that monitors electric heating element event frequency could be implemented to determine an optimal average tank temperature to reduce the use of electric resistance heating. Raising the temperature to relatively high levels at night in heat pump only mode can be an effective means of riding through what would otherwise cause electric resistance heating events in the morning. This is an important finding.

8.2 Recommendations

8.2.1 Standards Development for "Grid Enabled" Appliances

Standards need to be developed for "grid enabled" appliances that encompass the suite of control and communication capabilities necessary for effective and reliable participation of these units in demand response programs. Control and monitoring equipment installed at the appliance is not a sufficient condition for successful participation in a demand response program. Additional work around setting more comprehensive specifications and standards is warranted.

8.2.2 Two Way Communication

Two-way communication is a desirable attribute for DR programs, especially those involving HPWHs, because of their greater complexity and potential for optimization. It is critical to have confirmation of whether the appliances are receiving and how they are responding to control signals.

8.2.3 Explore Better Communication Options

Communication through home Wi-Fi is prone to frequent interruption. Other options need to be explored, such as RF to routers, direct Ethernet connection, and Ethernet-over-power line technologies.

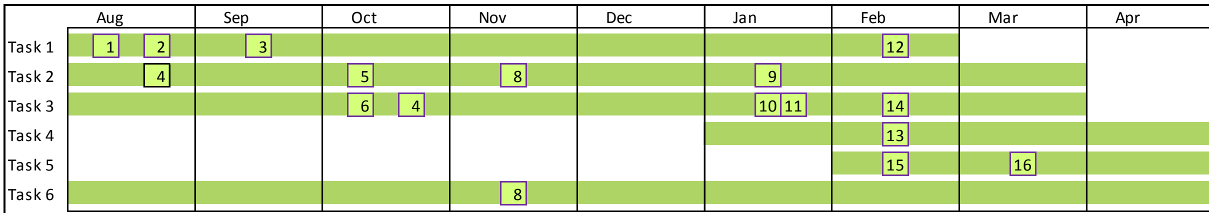
8.2.4 Establish Full-Suite Testing and Certification

A testing procedure in which the performance of a suite of communication and control equipment can be verified and certified would give utilities greater assurance that a particular proposed system will actually work. There is a proliferation of vendors of individual devices and systems, but wider adoption of this technology would be accelerated by a reliable certification procedure.

8.2.5 Further Investigation of HPWH Optimization

The present generation of HPWH technology has a longer setpoint recovery period than standard electric resistance water heaters due to relatively small compressor sizes. Operating the water heaters at higher temperatures can reduce activation of resistance heating elements. This mode of operation merits closer consideration as a potential energy efficiency measure. Additional work is warranted to identify the potential for achieving greater efficiency levels. This may include identifying optimal setpoint temperatures (with and without tempering valves), and more active "smart" algorithms that can adjust mode and setpoint temperatures based on site-specific hot water use patterns.

Appendix A: Project Timeline



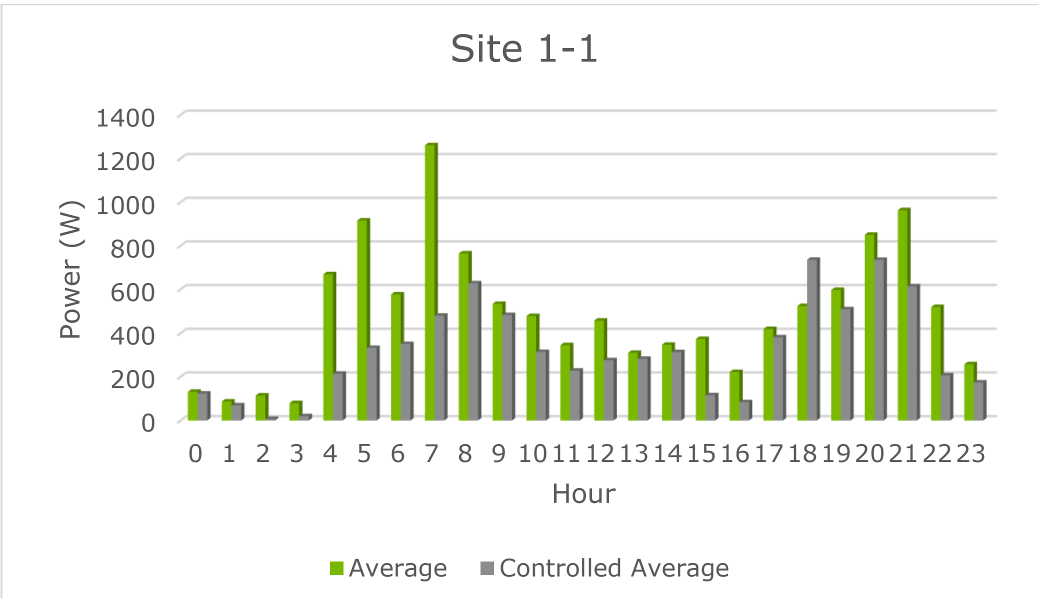
1 Cowlitz PUD Commitment
2 GE Commitment
3 Identification of all participant sites
4 Selection of installation contractors
5 Installation of 10 HPWH's
6 Identified new data collection and control solution (Power Wise)
7 Confirmed limitations of Nucleus units with GE
8 Upgrade to software on 10HPWH's. Ecofys site visits.
9 Data monitoring and communication equipment installed at all sites
10 Control approach for peak shaving agreed with GE
11 First DR event test
12 Finalized all customer agreements
13 Full data acquisition, HPWH performance limitations and control plan definition
14 First units are receiving control signals and modifying usage.
15 Start of collecting baseline data
16 Full testing of demand response and energy storage capabilities

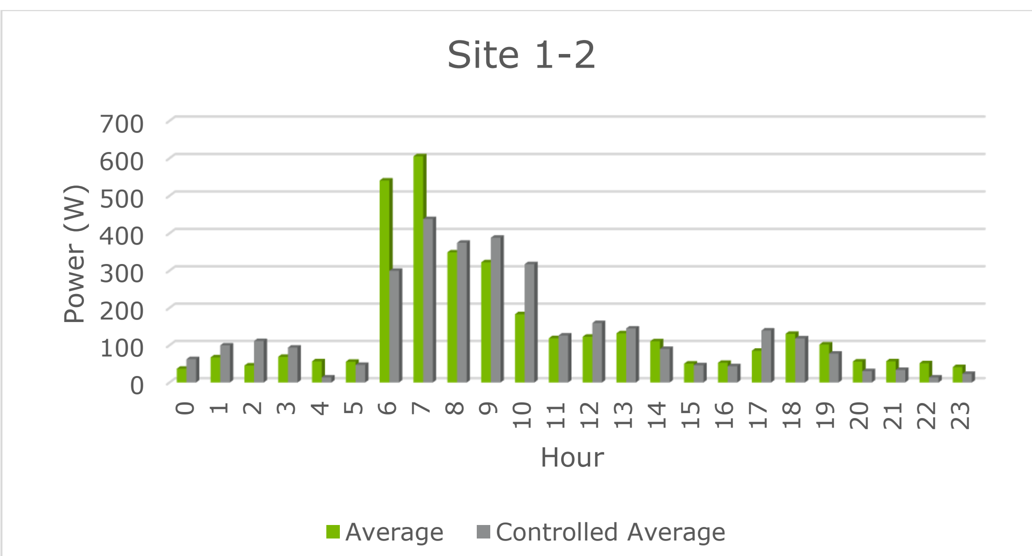
Selection of participants generally went very well. Cowlitz PUD was able to provide a list of people who had received rebates for the installation of GE GeoSpring water heaters. On the whole, all of these homes were quick to agree to participate. However, several sites were less responsive than others in communicating with project staff and contractors. This pushed the installation timeline back significantly.

Installation took far more time than expected. The lack of contractors willing to bid on the installation of the water heaters was not anticipated. For future projects we would advise making certain that the program coordinators communicate effectively to the contractors the project scope and timeline.

Appendix B: HPWH Power Consumption

GROUP 1, controlled for peak shaving as well as peak shaving morning and evening, with energy storage.





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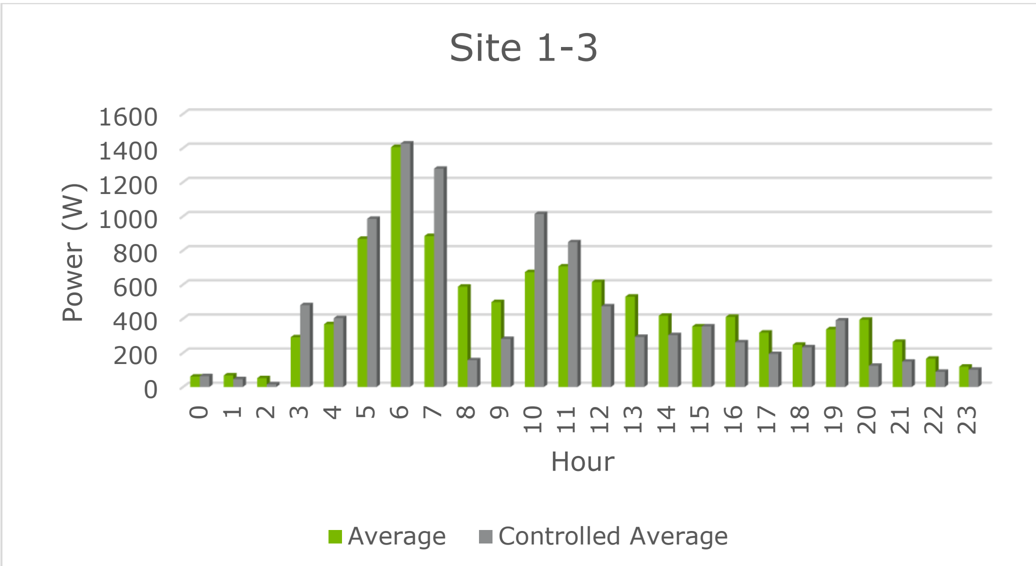

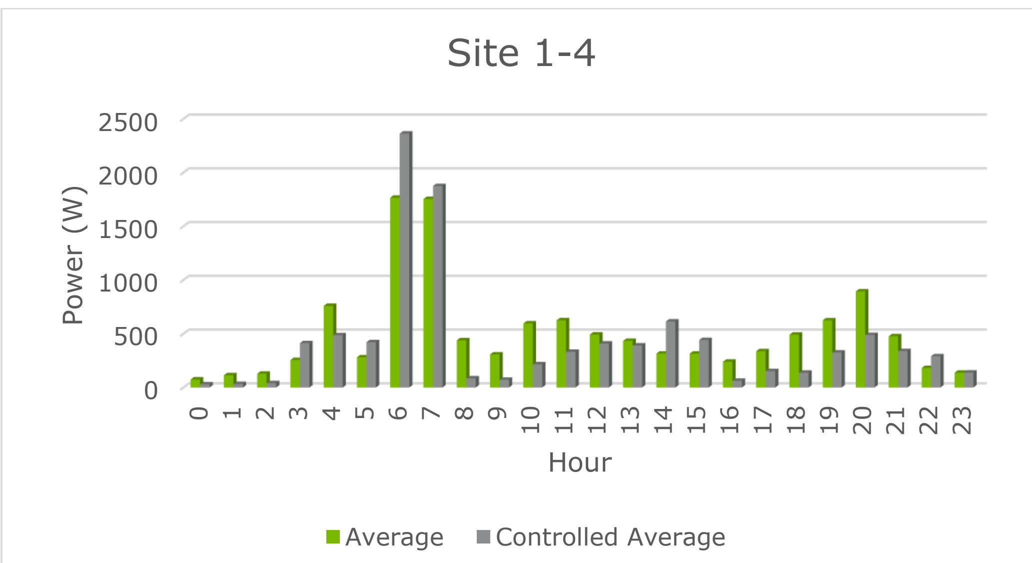

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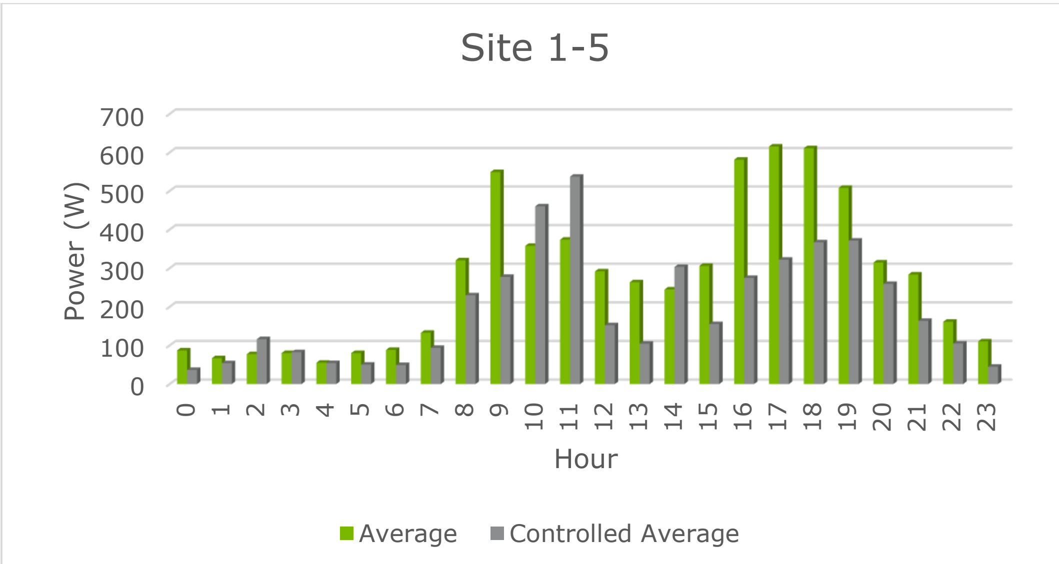
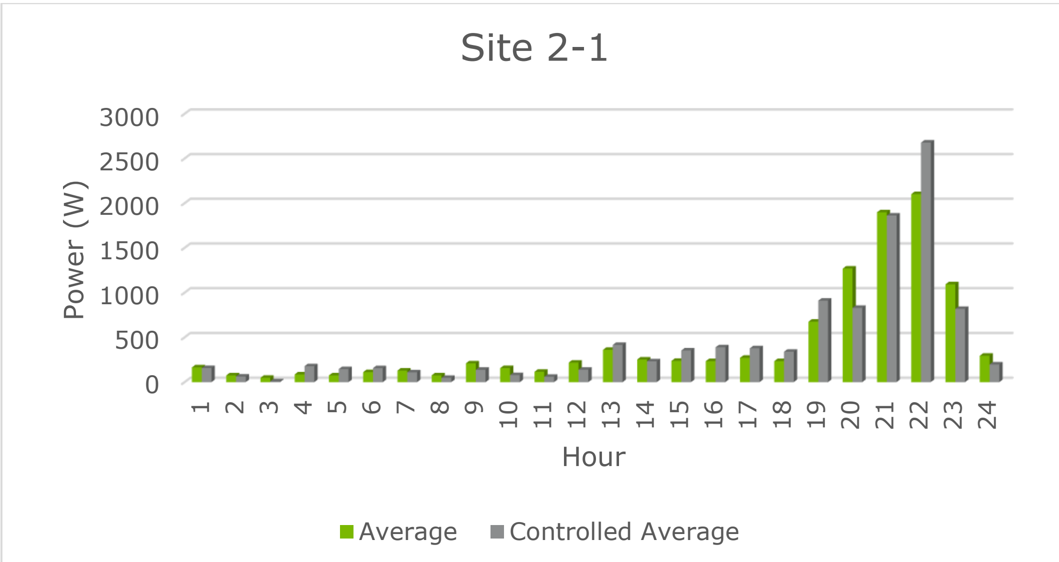
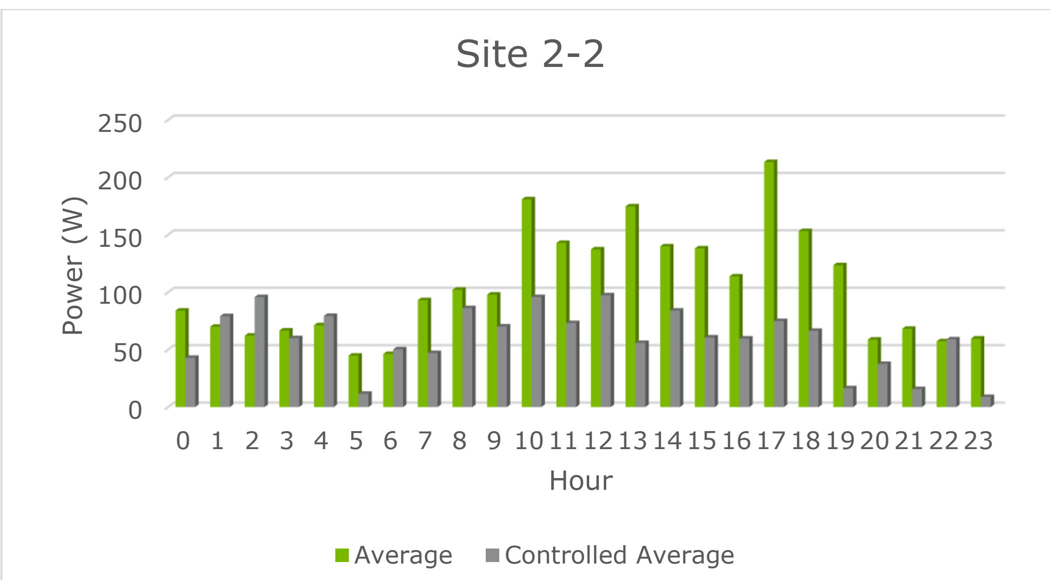


GROUP 2, controlled for peak shaving and energy storage.





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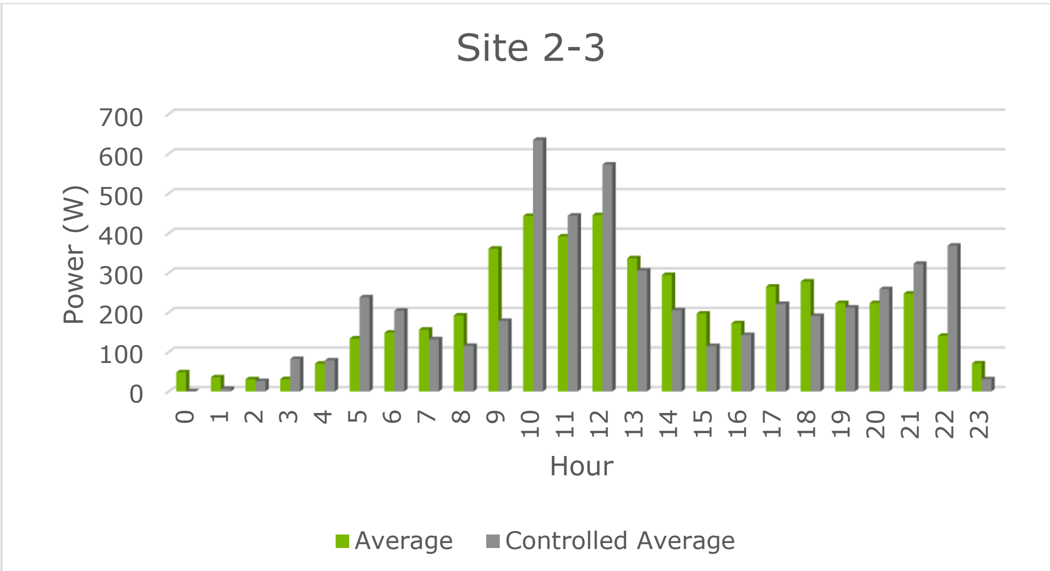
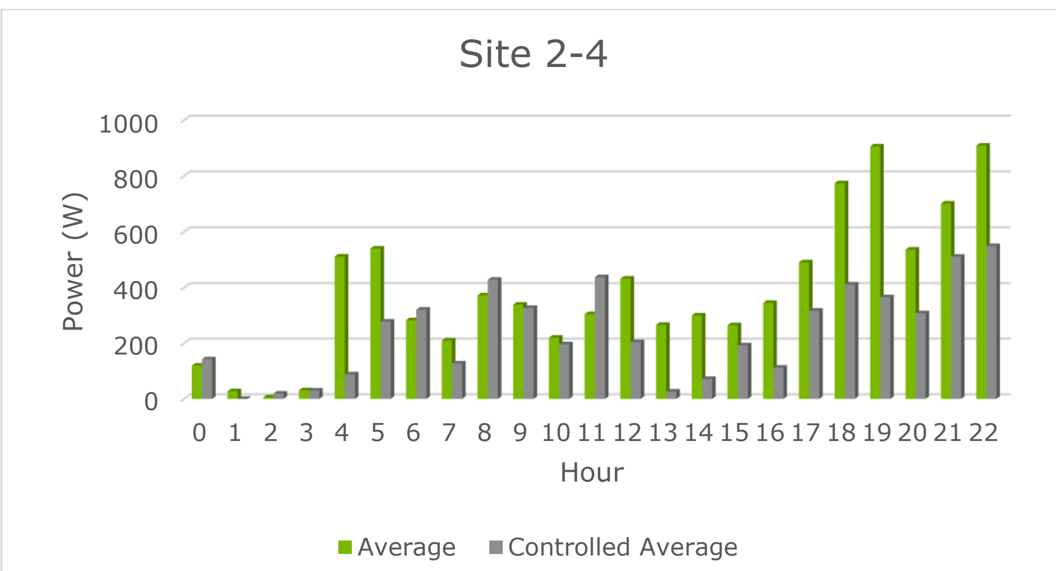
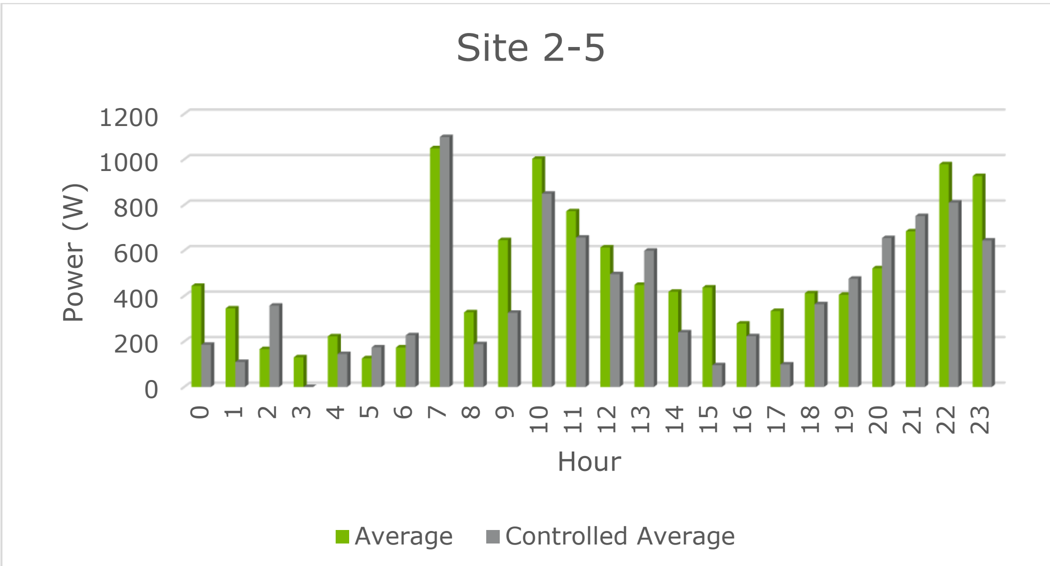
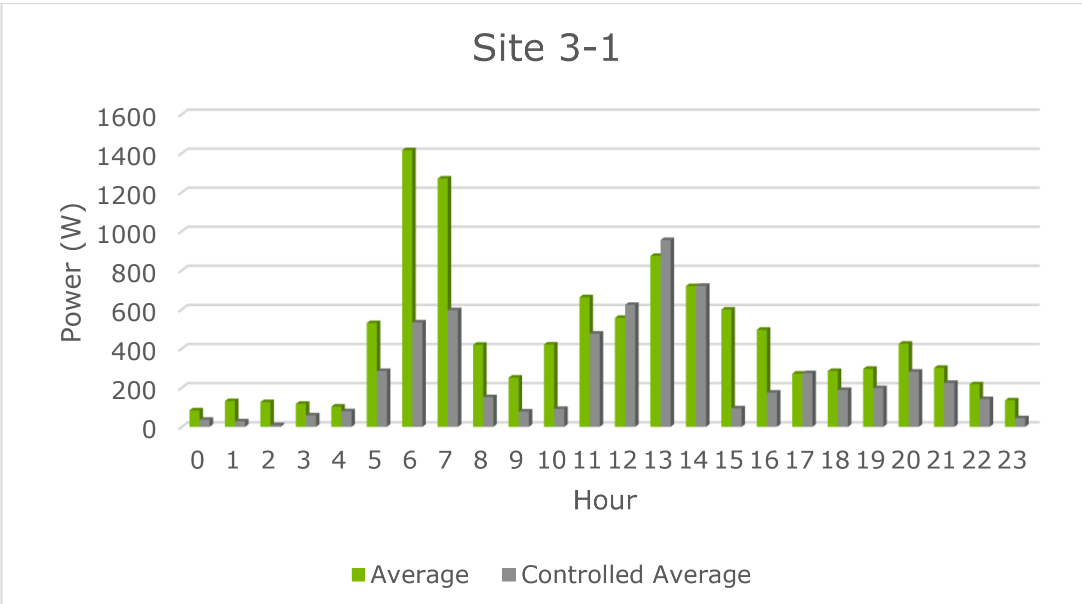


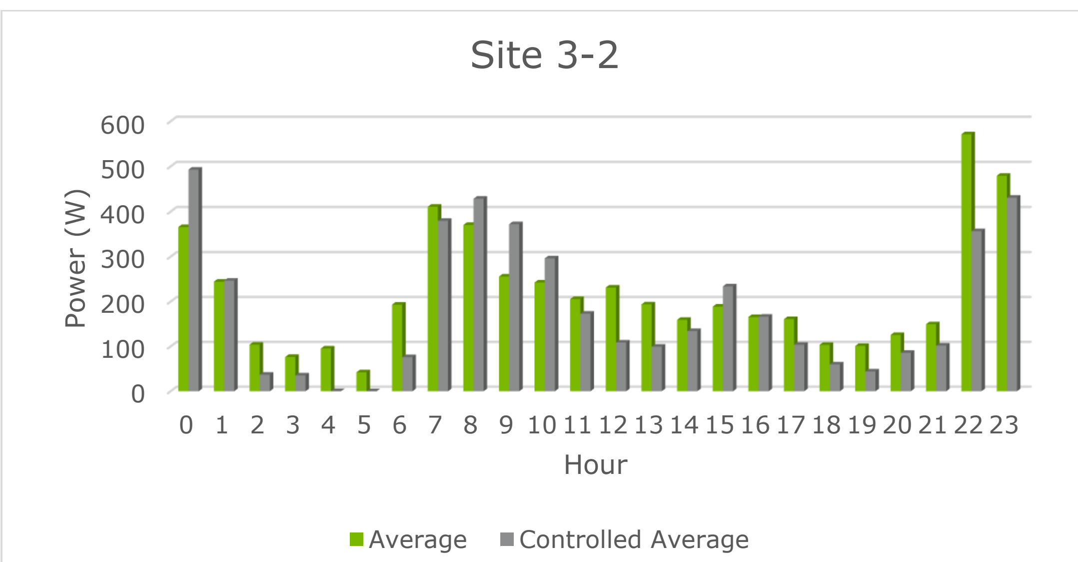


GROUP 2 CONTINUED

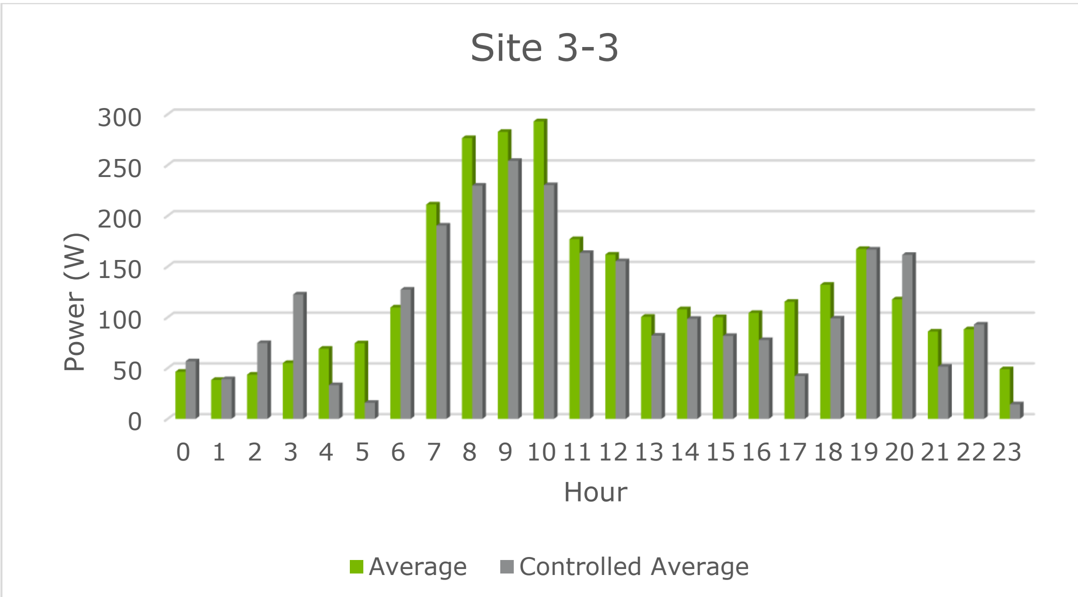


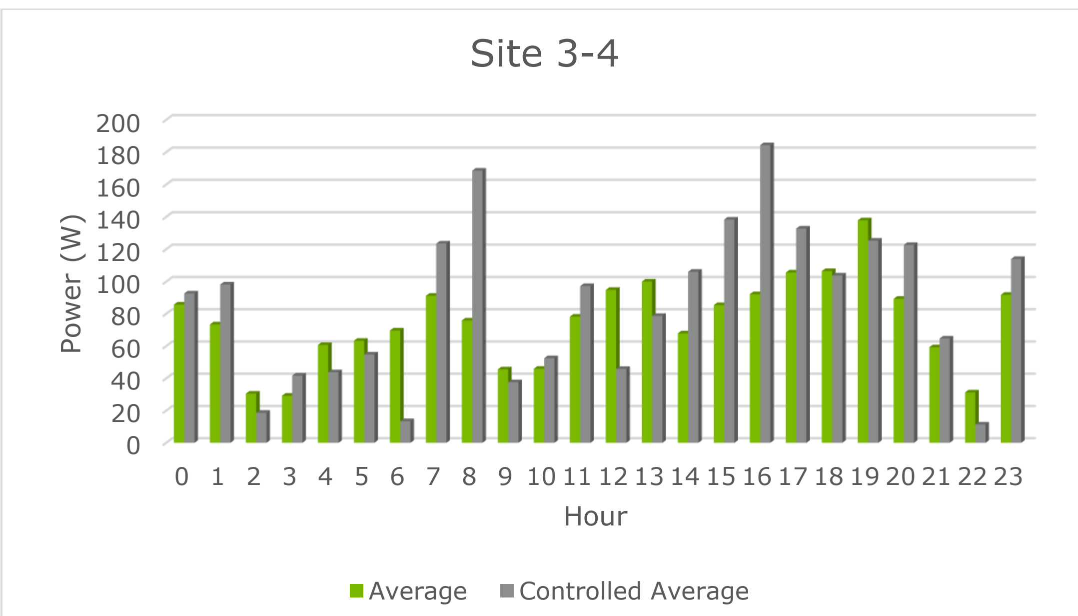
GROUP 3, controlled for peak shaving as well as peak shaving morning and evening, with energy storage.



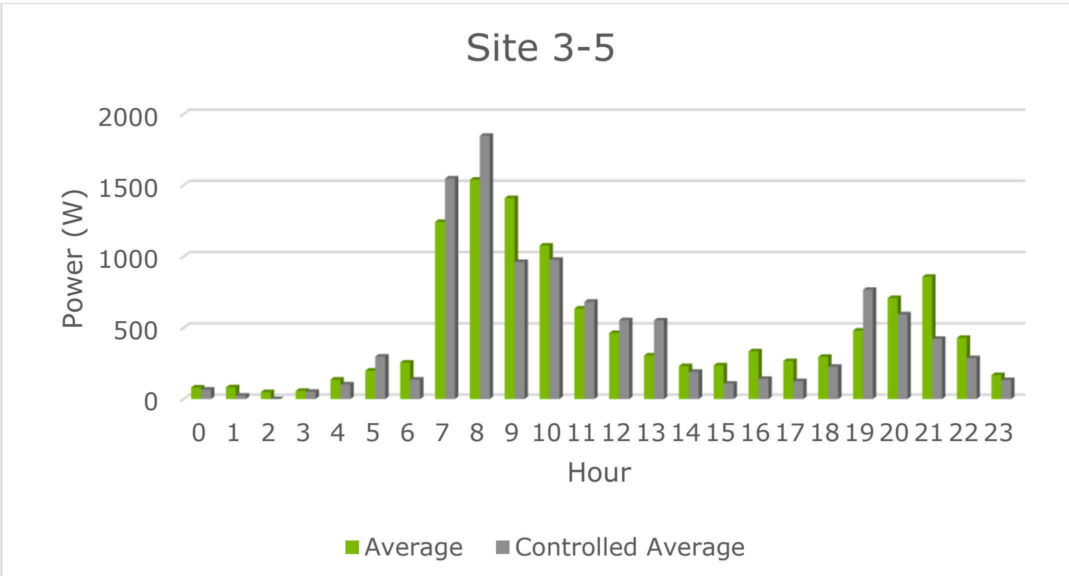


GROUP 3 CONTINUED

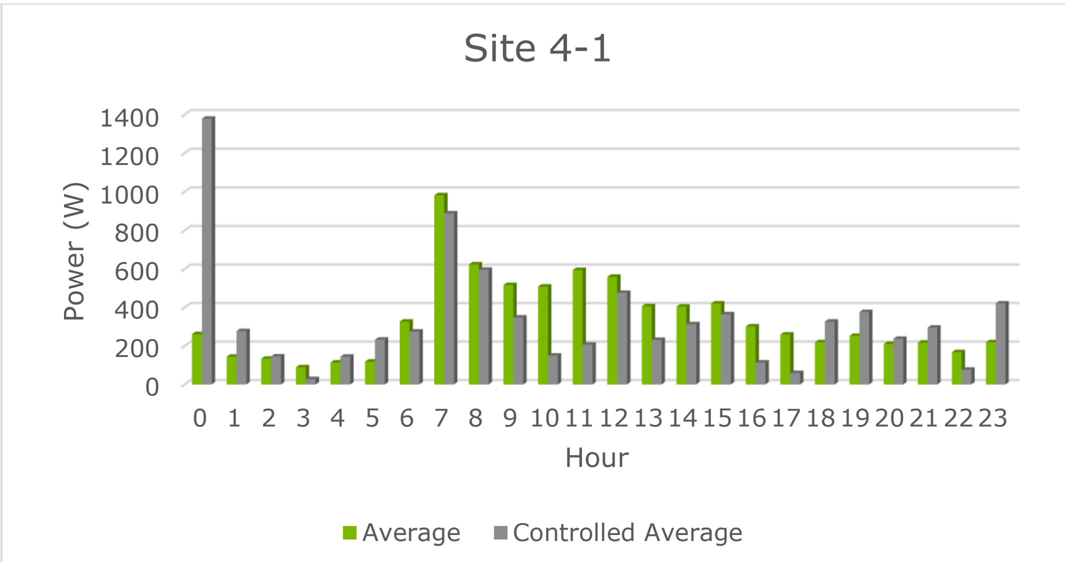


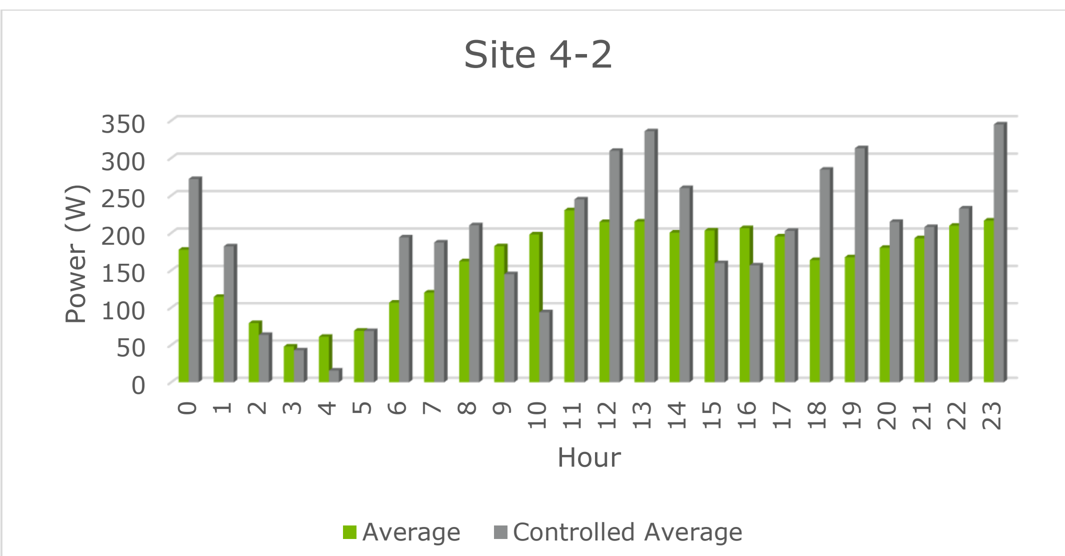


GROUP 3 CONTINUED

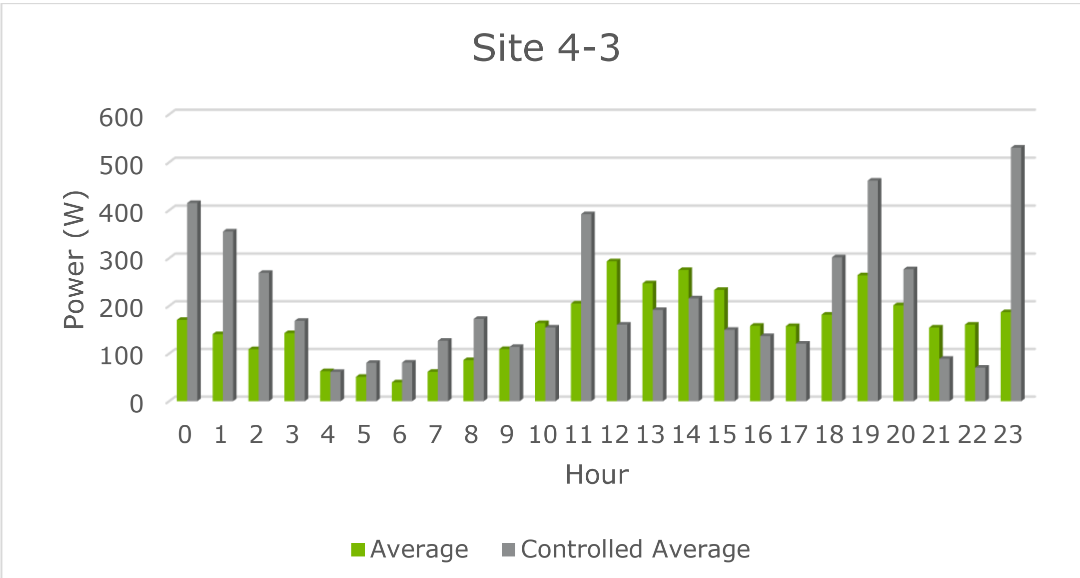


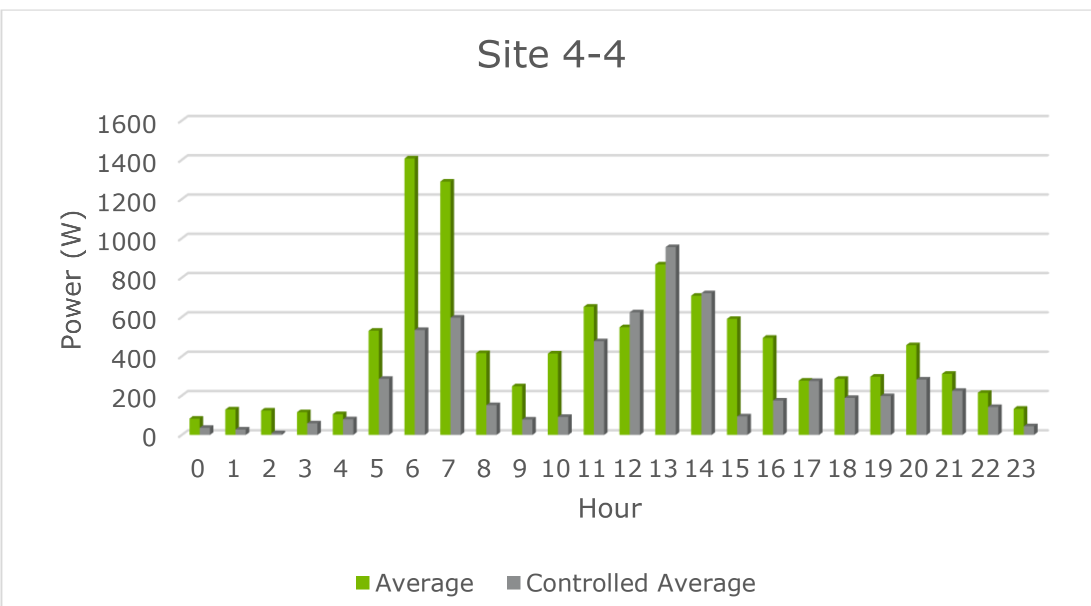
GROUP 4, controlled for peak shaving and energy storage. Note that there are only 4 sites in group 4, one site had a pipe burst during a freeze, destroying the monitoring equipment. We were not able to get the site functioning again for control during the testing period.





GROUP 4 CONTINUED





Note that we gathered no data for Site 4-5.

Appendix C: Water Heater Participation Summary

Group	Site	Data monitored	Control?	Remarks
1	1	Power, tank temp.	Inconclusive	Lost data
1	2	Power, tank temp.	Inconclusive	
1	3	Power, tank temp.	Probable peak shaving	
1	4	Power, tank temp.	Peak shaving	
1	5	Power, outflow temp.	Inconclusive	Thermocouple installed incorrectly.
2	1	Power, tank temp.	Inconclusive	Night showering household. Very different usage patterns.
2	2	Power, tank temp.	Potential peak shaving	Very little water usage. On vacation for part of study
2	3	Power, tank temp.	Inconclusive	
2	4	Power, tank temp.	Inconclusive	
2	5	Power, tank temp.	Inconclusive	Broken heat pump, resistance element only all project.
3	1	Power, outflow temp, flow	Inconclusive	Lost data
3	2	Power, outflow temp, flow	Probable energy storage	
3	3	Power, outflow temp, flow	Probable peak shaving	
3	4	Power, outflow temp, flow	Energy storage	
3	5	Power, outflow temp, flow	Inconclusive	
4	1	Power, outflow temp, flow	Energy storage	
4	2	Power, outflow temp, flow	Potential energy storage	
4	3	Power, outflow temp, flow	Inconclusive	Broken flow meter due to freeze. No data
4	4	Power, outflow temp, flow	Potential energy storage	Resistance element first two weeks due to cold weather.
4	5	Power, outflow temp, flow	Inconclusive	

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