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NEEA Heat Pump Water Heater Field Study Report

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GLOSSARY OF ACRONYMS

ACH	air changes per hour
ACH50	air changes per hour at 50 pascals of pressure
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
Btu	British thermal unit
CAZ	combustion appliance zone
CFM	cubic feet per minute
COP	coefficient of performance
CT	current transducer
Db	decibel
DHP	ductless heat pump
DHW	domestic hot water
EF	energy factor
GPH	gallons per hour
GPM	gallons per minute
HPWH	heat pump water heater
HZ	heating zone
kW	kilowatt
kWh	kilowatt hours
kWh/yr	kilowatt hours per year
NEEA	Northwest Energy Efficiency Alliance

INTRODUCTION

The Northwest Energy Efficiency Alliance (NEEA) is a non-profit organization working to effect market transformation through the acceleration and adoption of energy-efficient products, services and practices. NEEA is an alliance of more than 100 Northwest utilities and energy efficiency organizations working on behalf of more than 12 million energy consumers.

NORTHERN CLIMATE SPECIFICATION

In 2009, NEEA collaborated with regional stakeholders to develop the Northern Climate Heat Pump Water Heater (HPWH) Specification to provide energy efficiency guidance to manufacturers who are interested in developing products that not only meet ENERGY STAR® criteria but are able to provide high levels of consumer satisfaction and energy performance in cooler, northern climates. The specification focuses on northern climates and provides a framework which could be extended in the future for other climate types as appropriate.

The objective of NEEA's HPWH effort is to successfully accelerate innovation and adoption of HPWH products, with the end goal that HPWHs become the standard product for the electric water heating market. Northern Climate Specification-qualified HPWHs have the potential to save the Northwest over 490 aMW by 2030[1], which is the equivalent to powering 381,500 homes each year. The Northern Climate Specification was revised in 2011 introducing three product tiers (Tier 1, Tier 2 and Tier 3) recognizing variations in product performance and installation applications.

In 2010 through 2012, NEEA conducted laboratory tests on ten HPWH models to identify products that met the new specification and modeled how HPWHs interact with whole-house space heating.

EXECUTIVE SUMMARY

NEEA commissioned Fluid, a CLEAResult company, to conduct a field study capturing energy savings data primarily on Tier 2 HPWHs. At the time of this field study, the AirGenerate 66-gallon HPWH (ATI66), was the single Northern Climate Specification qualified Tier 2 unit.

Fluid designed and implemented a field study in 30 single-family homes which were retrofitted with a HPWH. This report details the field study portion of NEEA's robust HPWH portfolio, building upon lab test results by incorporating field study results of 28 AirGenerate ATI66 units and two AirGenerate ATI50 units in 30 homes in the Northwest. The Tier 2 qualified ATI66 model was selected to augment lab data. The ATI50 model was selected to test small tank performance in colder northern climates. The field study was a preliminary study aimed at quickly determining performance and reliability of this relatively new product and not meant to provide a representative sample of HPWHs as a whole. As the first field study of ducted HPWH installations, the study provided in-field installation findings to identify best practices as well as concerns to support NEEA's HPWH market test.

The objectives of the HPWH field study were to:

- Validate energy performance
- Provide data that would confirm or modify lab testing results and protocols to more accurately reflect real life conditions
- Develop best practices for installation of next generation HPWHs in replacement applications of standard electric resistance water heaters

Since the HPWH's energy performance is dependent upon the surrounding ambient air temperature, units installed in warmer locations showed higher COPs than those installed in locations with cooler air temperature. Thus ducted installations in conditioned spaces with warmer ambient air temperatures demonstrated higher COPs on average. The field study also confirmed that HPWH efficiency was affected by several additional key factors, including inlet water temperature, standby losses, and installation standards.

Though this field study did not endeavor to analyze data on space heat interaction of ducted and non-ducted HPWH installations, this field study will provide useful data for NEEA's Validation Study. NEEA's Validation Study, currently being conducted by Ecotope, is a 50 HPWH in field study designed to quantify the HPWH's space heat interactions. Overall, this field study confirms that HPWHs are an efficient technology and developing a better understanding of key factors affecting

[1] Chapter 4: Conservation Supply Assumptions, subchapter Residential Sector, page 4-8 – Sixth Northwest Conservation and Electric Power Plan

performance and incorporating this knowledge into planning and program design efforts will maximize its potential and help ensure successful use of the technology.

METHODOLOGY

SITE SELECTION AND RECRUITMENT

The HPWH field study targeted 30 participants/sites across Heating Zones 1 and 2 to measure the performance of HPWHs. Heating Zone 1 and 2 climate zones are used by the Northwest Power and Conservation Council in the regional power plan.

The site selection and recruitment process was as follows:

- Review NEEA's Ductless Heat Pump (DHP) Program to identify electrically heated, single-family homes in one of three locations in applicable heating zones: the Portland Metropolitan Area (Portland Metro), Puget Sound and central Oregon
  - Screen for characteristics such as foundation type, secondary heat source, home size and number of occupants to ensure a targeted list of homes in each location possessing necessary site characteristics, but varied enough from one another to provide a diverse sample
- Conduct homeowner phone interviews to verify screening data and capture additional information not included in previously collected site data, such as water heater location, ceiling height in water heater location, plumbing pipe type, electric panel location and electric panel characteristics
- Perform select site visits to verify data collected and determine HPWH installation feasibility, such as layout, location and clearances within the water heater location, distance from electric panel, obstacles to metering installation, and potential locations for condensate outlet
- Select sites and offer a complimentary installation of a program purchased new HPWH in return for the homeowner's commitment to participate for the duration of the field study and agreement to data collection protocols

METERING DESIGN AND DATA COLLECTION

The focus of the metering design and data collection plan was to provide a robust and streamlined method of remote data collection and analysis. Fluid began metering equipment installations in December 2011 and completed all installations by February 2012. The metering equipment remained in place through February 2013.

The metering plan for sites was designed around metering goals (defined below), desired data collection period, data load and available equipment. HPWHs were monitored to capture HPWH COP, air temperatures and flow, hot water delivery temperatures and flow, decibel readings, energy content of hot water delivered and resultant energy savings relative to an electric resistance unit. While some of the data points were captured in one-time measurements during installation, the majority of the data was captured continuously at one-minute intervals.

Metering Goals

The metering goals were as follows:

1. Calculate and compare COP at various operating conditions (e.g., inlet water temperature, ambient temperature, installation location)
2. Calculate annual energy savings compared to a standard electric water heater[2]
3. Determine performance impact of various installations and configurations (e.g., installation location, ducted vs. non-ducted)
4. Determine influences of varying hot water draws
5. Provide data for further development of HPWH's space heating/cooling interaction by directly measuring the home's heating/cooling equipment energy use
6. Record the HPWH's operating characteristics (e.g., average hourly demand profiles, average daily compressor runtimes, compressor cycles per days, average daily water consumption)

[2] Standard electric water heater is based on 2012 International Energy Conservation Code (IECC) standard for electric storage water heaters, where energy factor (EF) = 0.97 – 0.00132 x Rated Storage Volume (gallons).

Metering Specification

To complete the metering goals, Fluid captured a series of one-time and continuous data points.

One-time measurements:

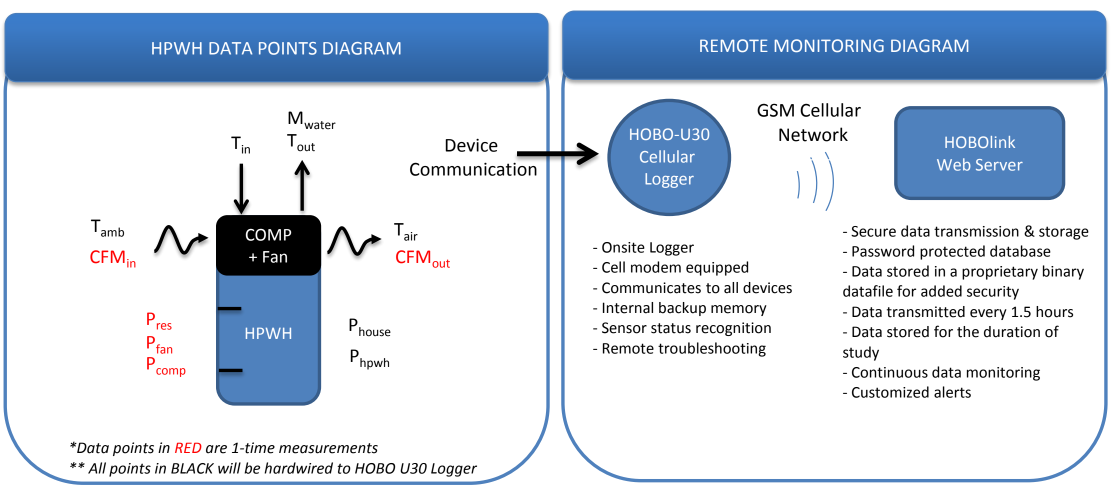
- Fan inlet and outlet airflow (CFM_{in} and CFM_{out})
  - HPWH fan inlet and outlet airflow were measured during the metering installation. The team measured the inlet and outlet airflow with three devices, the Testo 417 vane anemometer and TSI 9535 hot wire anemometer to calculate airflow based on measured air velocity and the DG-700 Manometer to calculate airflow based on measured duct static pressure. Ducted installations utilized a damper to reduce exhaust airflows to 200 CFM, which minimized the amount of conditioned air removed from the home while not drastically reducing HPWH performance. The hot wire anemometer was utilized to ensure proper airflow was set.
- Sound level reading
  - Decibel (Db) readings were recorded during the metering installation. The decibel meter provided frequency weightings A and C, and SLOW time-weighting. The sound level meter conformed to IEC 61672-1 class-2 or ANSI S1.4 type-2 specifications.

Continuous monitoring data points:

- Ambient air temperature (T_{amb})
- Incoming water temperature (T_{in})
- Outgoing water temperature (T_{out})
- Hot water usage (M_{water})
- Fan outlet temp (T_{air})
- Electric usage (P_{hpwh})
- Primary heat source (P_{ac1})
- Secondary heat source (P_{ac2})
- Tertiary heat source (P_{ac3})
- Outdoor temperature ($T_{outdoor}$)

Figure 1 illustrates the various data points and summarizes the remote monitoring equipment used to capture real-time data.

Figure 1 – Continuous Monitoring Data Points



Data Collection and Assembly

The Fluid team monitored each of the 30 sites with an Onset HOBO U30 remote monitoring system. This system included features that monitored current and historical metered data, set alarm notifications and managed the HOBO U30 remote monitoring systems. Each site was assigned a kit with a corresponding serial number for the U30 and for each sensor. Tracking the serial numbers through Hobolink helped correlate the data along with any errors to a particular site and, if needed, sensors could be reset. To ensure data integrity, the team set real-alarms to notify the team of data anomalies or sensor errors. The team also conducted weekly data checks to ensure data was within the expected range. At the completion of the field study, the data (over 150 million data points) was downloaded from the Hobolink server to a Microsoft Access database. A custom visual basic script was developed to analyze the data. Discrepancies in the data were highlighted and remedied to uphold the integrity of the COP calculation.

Data Quality Control

To reliably measure energy consumption of the HPWHs, hot water usage, and heating usage, the metering equipment was well designed and durable in order to last the duration of the field study. The selected equipment included industry-standard CTs, wired thermistors, watt transducers and pulse counters.

The principal advantage of near real-time data retrieval – as opposed to long-term onsite accumulation and one-time retrieval – was to provide an early-warning system for data production and/or quality concerns, providing opportunity for course corrections and/or repairs. This early warning system was highly automated to minimize the need for continuous human monitoring. Intermittent data upload errors to Onset occurred and corrective site visits were made as needed.

The following steps ensured high-quality data stream during all stages of the installation and on-going field study.

- Developed metering installation instructions and schematics to assist the field staff in proper commissioning and installation of the equipment, which included recording metering equipment serial numbers and photo documentation of each installation
- Continuous verification of Onset servers and weekly data verification for each site
- Conducted as-needed site-visits to repair metering equipment or investigate issues with data collection and reporting
- Performed additional site visits as needed to manually collect data and clear device's memory where repairs could not be completed before the data logger's internal storage reached capacity

Decommissioning

In February 2013, Fluid decommissioned and retrieved all installed metering equipment. In November 2012, one participant requested early removal of the HPWH and metering equipment after a failure of the HPWH. The program replaced the HPWH with an efficient standard electric tank water heater. Less than a full year of data was collected at this site.

As part of the decommissioning process, participants were given the option to replace the installed HPWH with an efficient standard electric tank water heater. All but two participants chose to keep the HPWH.

ANALYSIS APPROACHES

This section describes the data analysis approach and the key equations used to help address the following:

- Calculate the HPWH's energy performance using metered energy consumption and heat content of water delivered
- Determine key factors that affect the HPWH's energy performance such as inlet water temperature, ambient temperature, and water usage
- Compare energy savings of a HPWH versus a standard electric water heater
- Provide metrics such as energy performance based on installation location to help guide HPWH best practices

Calculating Energy Content of Water and Coefficient of Performance Measurements

This section provides the fundamental methods used to analyze HPWH energy performance and defines nomenclature used in this report. Figure 2 is a sample view of measured one-minute-interval data collected and analyzed in the field study.

Figure 2 – One-minute-interval data

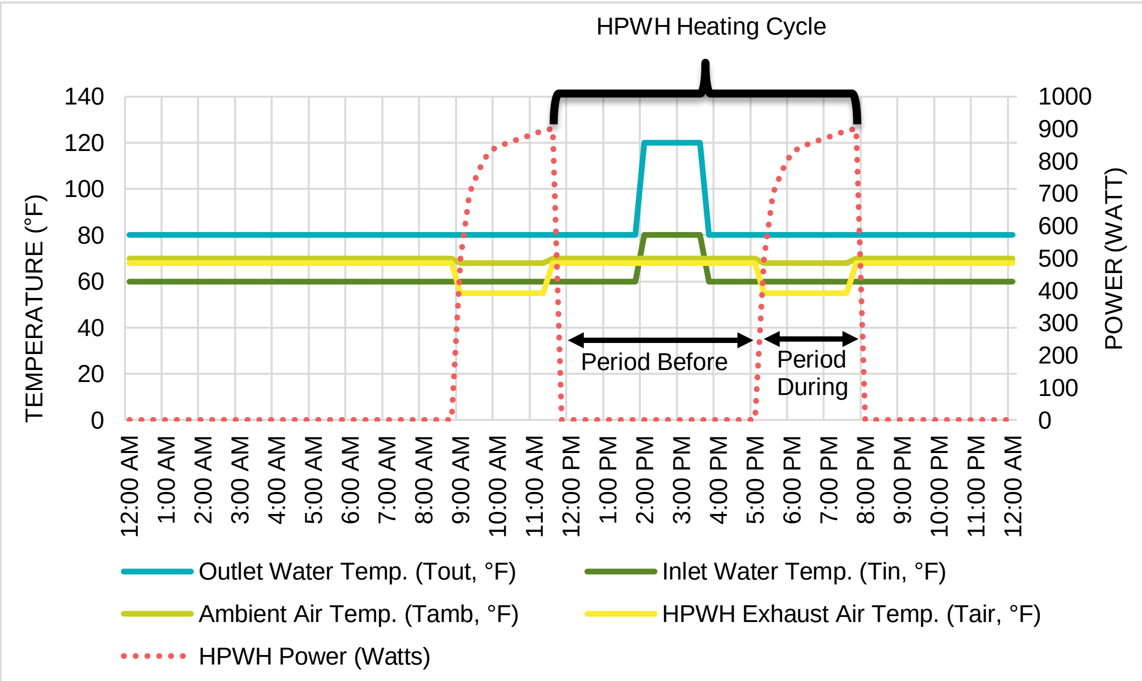


Figure 2 illustrates the typical operating cycle of a HPWH. The cycle can be identified by observing the power draw in watts. An active heating mode is triggered when the HPWH's watt usage reaches above 400 watts, which is the key identifier of each cycle. Each heating cycle is comprised of two time components:

- "Period Before": the period between the end of the last heating cycle and the start of the next HPWH active heating period
- "Period During": the period in which the HPWH active heating period begins and ends

The identification of each cycle is the basis upon which the HPWH's COP is calculated. Other valuable data used to calculate the HPWH's COP are the outlet water temperature (Tout), inlet water temperature (Tin), exhaust air temperature (Tair) and ambient air temperature (Tamb).

The team used a modified version of the U.S. Department of Energy (DOE) test procedure[3] to calculate a HPWH's COP. The COP is defined as the ratio of useful energy output from the water heater to the total amount of energy delivered to the water heater. This calculation method takes into account the energy required to heat water in addition to energy lost due to stand-by losses. Thus, calculated COP values presented throughout this report include the energy impacts of stand-by losses.

As illustrated in Figure 2, the COP is calculated for each heating cycle. These heating cycles can last four hours or longer than 24 hours. Since the HPWH's stand-by loss is a function of ambient temperature, tank temperature, and cycle duration calculating the COP in this fashion helps ensure the stand-by losses are more accurately represented.

The following are the key equations used in this analysis:

$$COP = \frac{Q_{water} + Q_{standby}}{Q_{HPWH} \times Conv}$$

$$Q_{water} = M_{water} \times den \times Cp\left(T_{out} - T_{in}\right)$$

3 10 CFR 430, Subpart B, Appendix E to Subpart B of Part 430 - Uniform Test Method for Measuring the Energy Consumption of Water Heaters

$Q_{standby} = UA \times \left(T_{tank} - T_{amb}\right) \times Cycle$

COP = Coefficient of performance of the heat pump water heater within each heating cycle

Q_{water} = Heat content of water (Btu/cycle)

$Q_{standby}$ = Standby losses observed during cycle (Btu/cycle)

Q_{hpwh} = Electrical energy consumed by heat pump water heater during heating cycle (Whr/cycle)

Conv = Unit conversion from watt-hr to Btu, set constant at 3.412 Btu/Watt-hr

M_{water} = Water consumed during heating cycle (Gallons)

den = density of water, set constant at 8.3 lb/gal

Cp = Specific heat of water, set constant at 1.0 Btu/lb - F

T_{out} = Outlet water temperature observed during heating cycle (F)

T_{in} = Inlet water temperature observed during heating cycle (F)

UA = Stand-by heat loss coefficient, set constant at 3.4 Btu/h - F

T_{tank} = Average tank temperature, set constant at 125 (F)

T_{amb} = Ambient air temperature surround the water heater, observed during cycle (F)

*Additional clarification on T_{amb} follows

Cycle = Duration of heat pump water heater heating cycle (Hours)

A final clarification on data analysis methodology: the average ambient space temperature (T_{amb}) is the average of the temperatures when the HPWH is not actively heating (fan is not running). Since the space temperature metering device was installed directly on the inlet grill of the HPWH, it measures the air immediately surrounding the HPWH when the fan is not running. When the fan is activated the space air temperature sensor measures the air that is immediately entering the HPWH heat exchanger.

HOME CHARACTERISTICS

As noted, the home selection and outreach process utilized data from NEEA's DHP installation database. Fluid refined the data to limit geographic location and electric utility, which streamlined selection and stakeholder coordination.

SITE CHARACTERISTICS

The team pursued specific site characteristics for the installation of HPWHs. Since HPWHs utilize heat from surrounding air, the COP of these units is dependent upon the ambient air temperature surrounding them. For this reason, it was imperative that 10 of the 30 installations were in the colder climate zone of central Oregon. The remaining 20 installations were split between Puget Sound and Portland Metro. To capture data on a variety of installations, Fluid created an installation matrix that was evenly divided to track installation location types and climate zones according to the needs of the study.

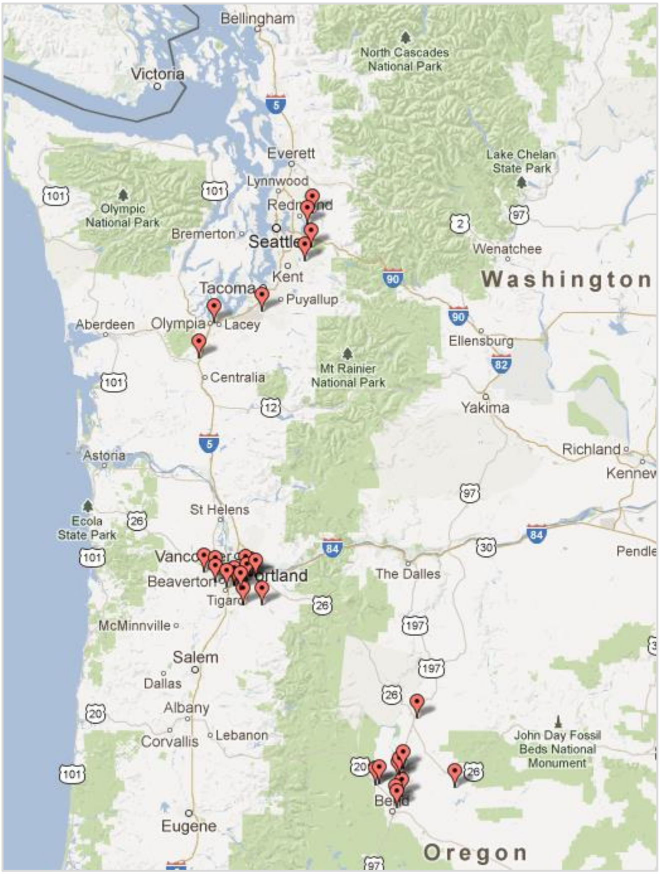
The team encountered challenges identifying basement locations in central Oregon, thus the matrix was adjusted to maintain the 50/50 ratio of conditioned to unconditioned installations while relaxing the ratios of installation location and utility territory. Originally, installations were to be evenly split between garage, basement and conditioned space installations and between central Oregon (representing the coldest climate in this study), the Puget Sound area and Portland Metro.

Table 1 provides a summary of the installation locations and key features of each site, including house square footage, space condition and installation location, all of which have an impact on savings calculations.

Table 1 - Site characteristics and geographic locations

Site #	Utility	City	ST	Heating Zone	SF	In Conditioned Space	Ducted	Installation Type	Location	Tank Size	Number of Occupants
1	PSE	Olympia	WA	HZ 1	952	No	No	Garage (Non-Ducted)	Garage	50-gal.	4
2	PGE	Tigard	OR	HZ 1	1,080	No	No	Garage (Non-Ducted)	Garage	66-gal.	3
3	PGE	Portland	OR	HZ 1	1,500	Yes	Yes	Inside (Ducted)	Laundry	66-gal.	1
4	PGE	Portland	OR	HZ 1	1,770	Yes	Yes	Inside (Ducted)	Laundry	66-gal.	2
5	PGE	Portland	OR	HZ 1	1,475	Yes	Yes	Inside (Ducted)	Laundry	66-gal.	5
6	PGE	Beaverton	OR	HZ 1	1,328	No	No	Garage (Non-Ducted)	Garage	66-gal.	2
7	PGE	Oregon City	OR	HZ 1	2,650	No	No	Basement (Non-Ducted)	Conditioned Basement	66-gal.	2
8	PSE	Sammamish	WA	HZ 1	1,000	No	No	Garage (Non-Ducted)	Garage	66-gal.	4
9	PSE	Issaquah	WA	HZ 1	1,350	No	No	Basement (Non-Ducted)	Conditioned Basement	66-gal.	4
10	PSE	Spanaway	WA	HZ 1	1,872	No	No	Basement (Non-Ducted)	Crawl	66-gal.	2
11	PSE	Renton	WA	HZ 1	2,160	Yes	Yes	Inside (Ducted)	Inside envelope	66-gal.	1
12	PGE	Beaverton	OR	HZ 1	1,125	No	Yes	Garage (Non-Ducted)	Garage	66-gal.	1
13	Central Electric	Bend	OR	HZ 2	1,560	Yes	Yes	Inside (Ducted)	Inside envelope	66-gal.	2
14	PSE	Rochester	WA	HZ 1	1,283	Yes	Yes	Inside (Ducted)	Laundry	66-gal.	2
15	PGE	Hillsboro	OR	HZ 1	1,092	No	No	Garage (Non-Ducted)	Garage	66-gal.	2
16	PGE	Portland	OR	HZ 1	1,258	Yes	Yes	Inside (Ducted)	Inside envelope	66-gal.	2
17	PSE	Redmond	WA	HZ 1	1,460	No	No	Garage (Non-Ducted)	Garage	66-gal.	3
18	PGE	Portland	OR	HZ 1	950	Yes	Yes	Inside (Ducted)	Laundry	66-gal.	2
19	Pacific Power	Madras	OR	HZ 2	2,387	Yes	Yes	Basement (Ducted)	Conditioned Basement	66-gal.	1
20	Central Electric	Bend	OR	HZ 2	1,296	No	No	Garage (Non-Ducted)	Garage	66-gal.	1
21	Central Electric	Redmond	OR	HZ 2	1,324	No	No	Garage (Non-Ducted)	Garage	66-gal.	2
22	Pacific Power	Bend	OR	HZ 2	980	No	No	Garage (Non-Ducted)	Garage	66-gal.	2
23	Central Electric	Redmond	OR	HZ 2	960	Yes	Yes	Inside (Ducted)	Inside envelope	50-gal.	2
24	Central Electric	Bend	OR	HZ 2	1,056	No	No	Garage (Non-Ducted)	Garage	66-gal.	3
25	PGE	Portland	OR	HZ 1	1860	Yes	Yes	Basement (Ducted)	Conditioned Basement	66-gal.	3
26	PGE	Portland	OR	HZ 1	1,920	Yes	Yes	Inside (Ducted)	Inside envelope	66-gal.	2
27	PGE	Oregon City	OR	HZ 1	879	No	No	Garage (Non-Ducted)	Garage	66-gal.	4
28	Central Electric	Redmond	OR	HZ 2	1,665	Yes	Yes	Inside (Ducted)	Inside envelope	66-gal.	3
29	Central Electric	Bend	OR	HZ 2	1,920	Yes	Yes	Inside (Ducted)	Laundry	66-gal.	2
30	Central Electric	Prineville	OR	HZ 2	1,560	Yes	Yes	Inside (Ducted)	Inside envelope	66-gal.	1

Figure 3 - Installation Site Map



PARTICIPANT SURVEYS

Fluid administered two participant surveys one month and nine months after installation. The goal of these surveys was to gauge customer feedback on performance and interaction with the HPWH. A brief overview of findings is addressed in this section and the complete survey questions are located in Appendix C.

Participant's overall satisfaction was very positive and those responding either "extremely satisfied" or "very satisfied" increased from 83% to 87% from the first to the second survey. None of the participants in either survey stated levels of dissatisfaction with the unit.

Figure 4 - First survey customer satisfaction

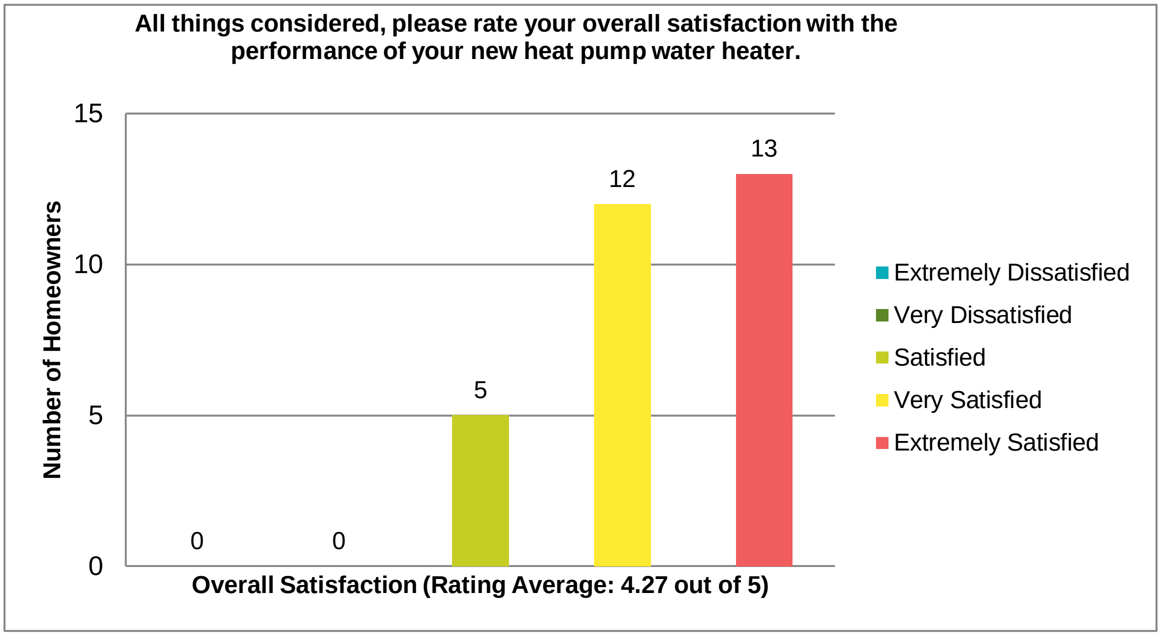
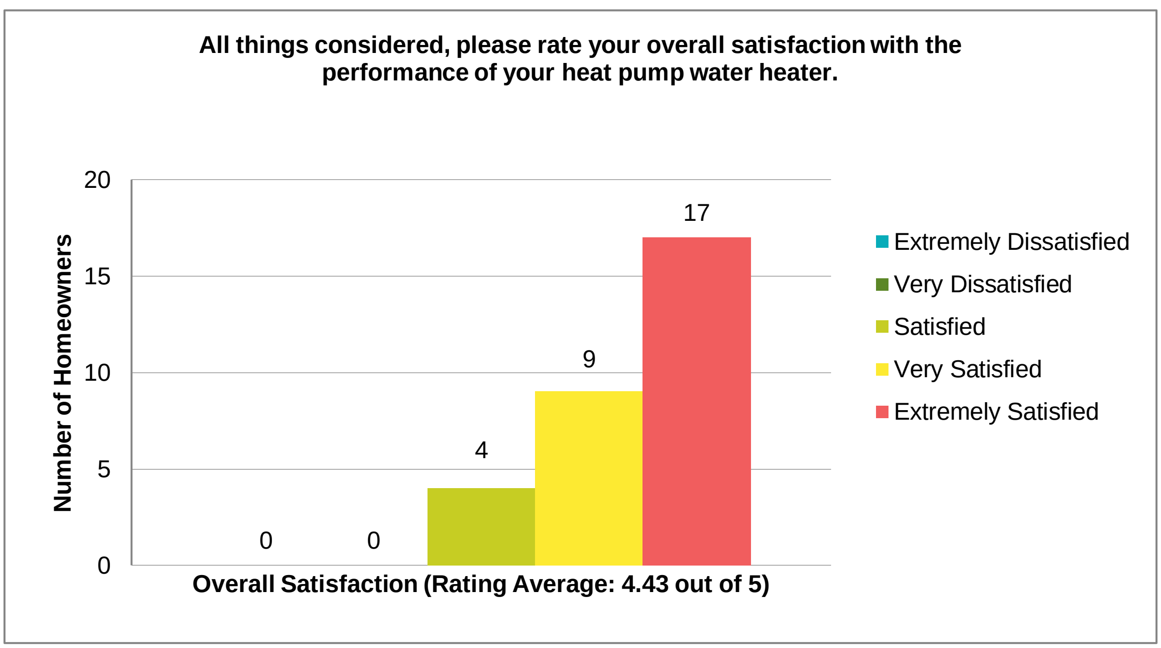
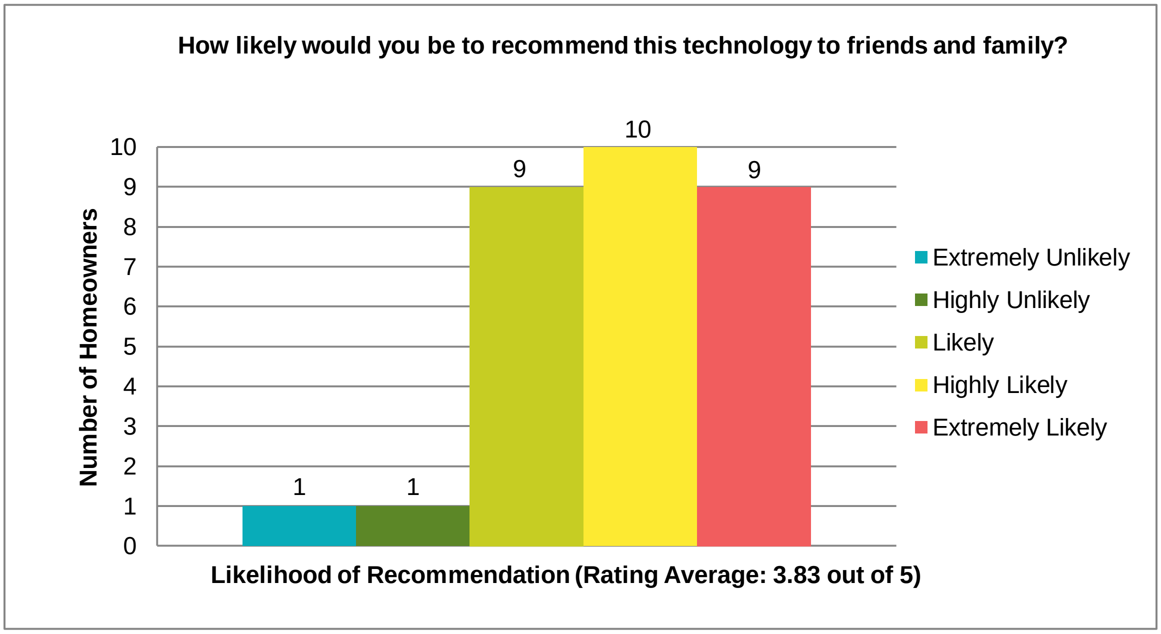


Figure 5 - Second survey customer satisfaction



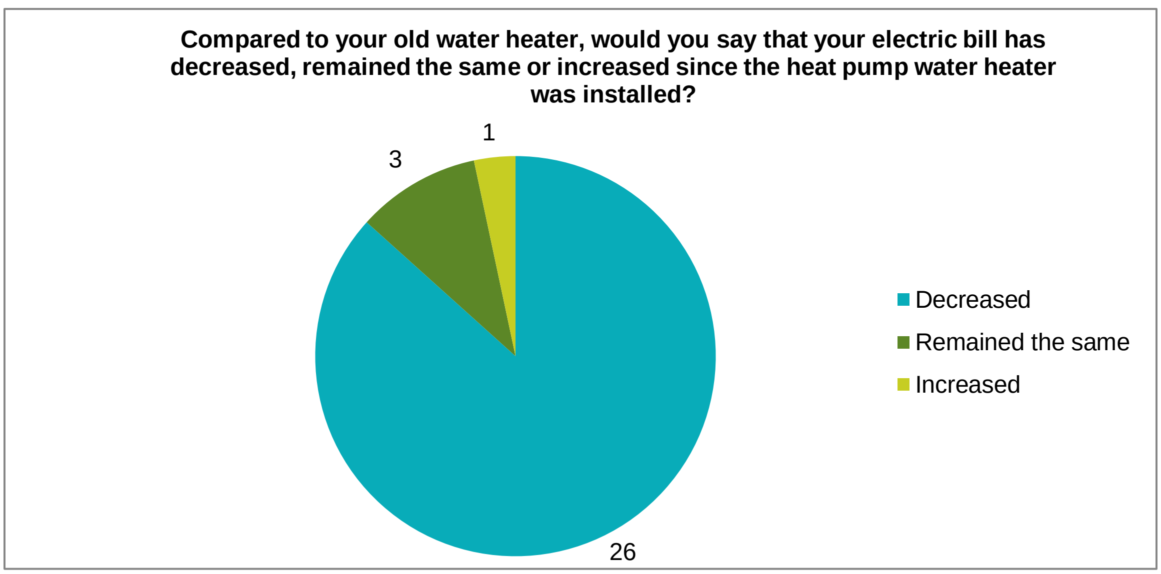
In the second survey, 93% of participants stated they would either be likely, highly likely, or extremely likely to recommend this technology to friends and family.

Figure 6 - Second survey participant recommendation



The second survey examined the participants' perception of their electric bill and whether the HPWH caused an increase or decrease in the monthly amount. Eighty-six percent stated their electric bill decreased, 10% believe it remained the same and 4% noticed an increase.

Figure 7 - Second survey electric bill perception



Participants were asked about how likely they would be to purchase a HPWH the next time they buy a water heater and how much they would be willing to spend on HPWH technology. The participants were given a reference point of $1,200 for an installed standard high-efficiency electric water heater. Ninety-three percent stated that they would either be either likely, highly likely, or extremely likely to make a HPWH their next water heating purchase choice. The price the participants would be willing to spend for HPWH technology varied quite a bit, but 83% felt comfortable with an installed cost below $2,000.

Figure 8 - Second survey future HPWH purchase

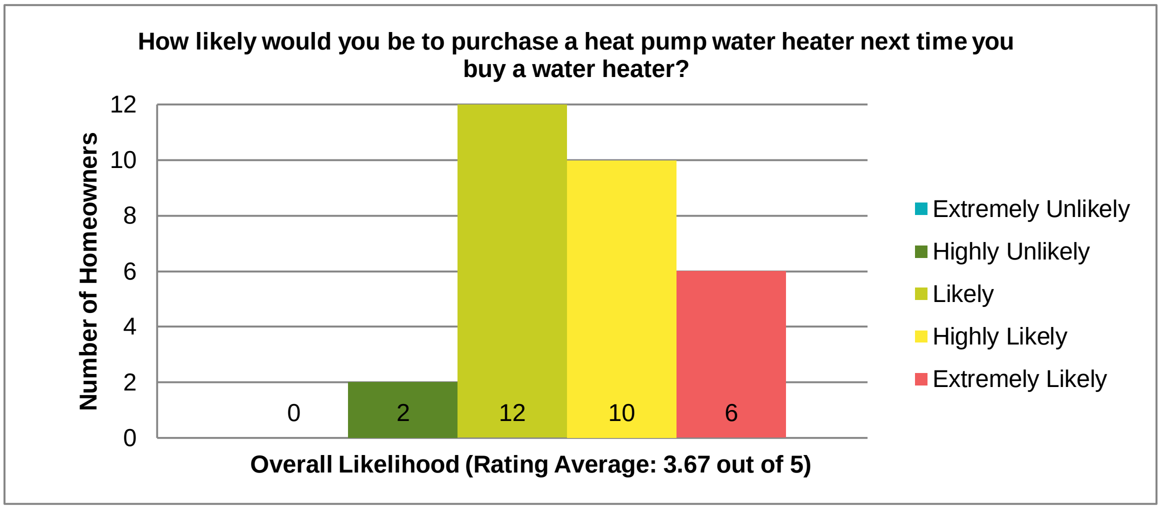
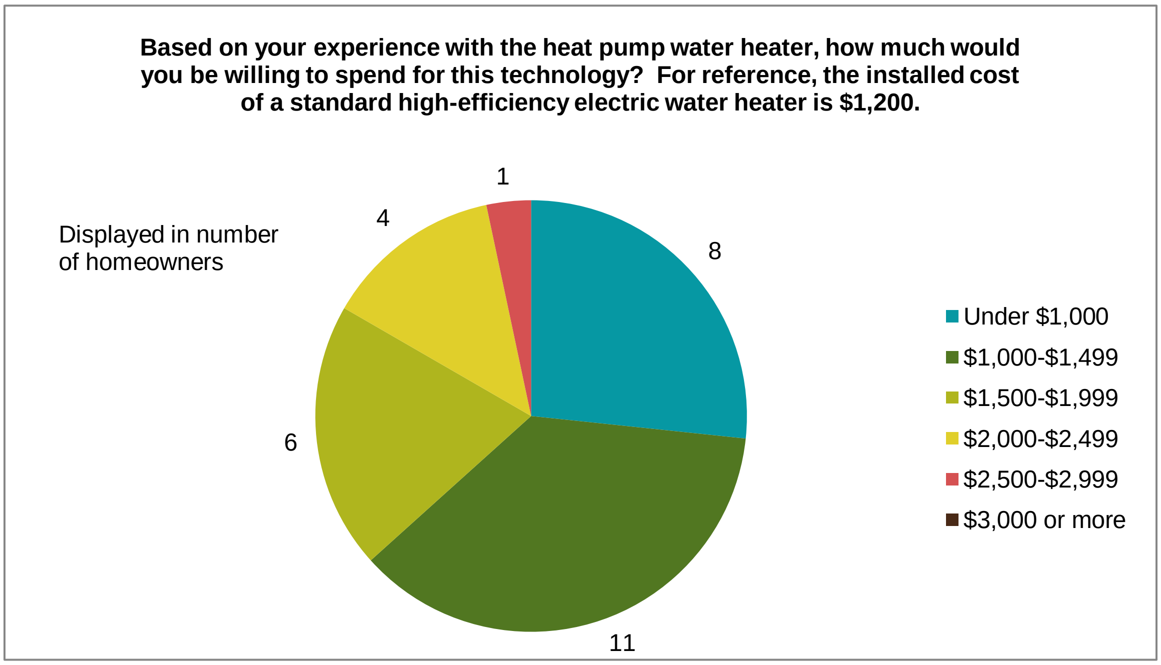


Figure 9 - Second survey estimated cost



Both surveys asked participants to compare the HPWH to their original electric resistance unit with interesting results as shown below. All but one participant in the first survey and two participants in the second survey perceived they had the same or more hot water available as they previously had with an electric resistance unit.

The team followed up with each participant that stated the HPWH produced more noise or vibration in the living space. The results of this follow up showed that noise was not bothersome and was ranked as such because electric resistance water heaters make no noise at all. Most participants stated the HPWH sounded like other home appliances, such as a dishwasher. The decibel readings that were taken in the homes reached 60-75 decibels next to the unit and 30-40 decibels in the adjacent living space. These readings are comparable to normal conversational volumes and refrigerator noise, respectively.

Figure 10 - First survey comparison between HPWH and old water heater

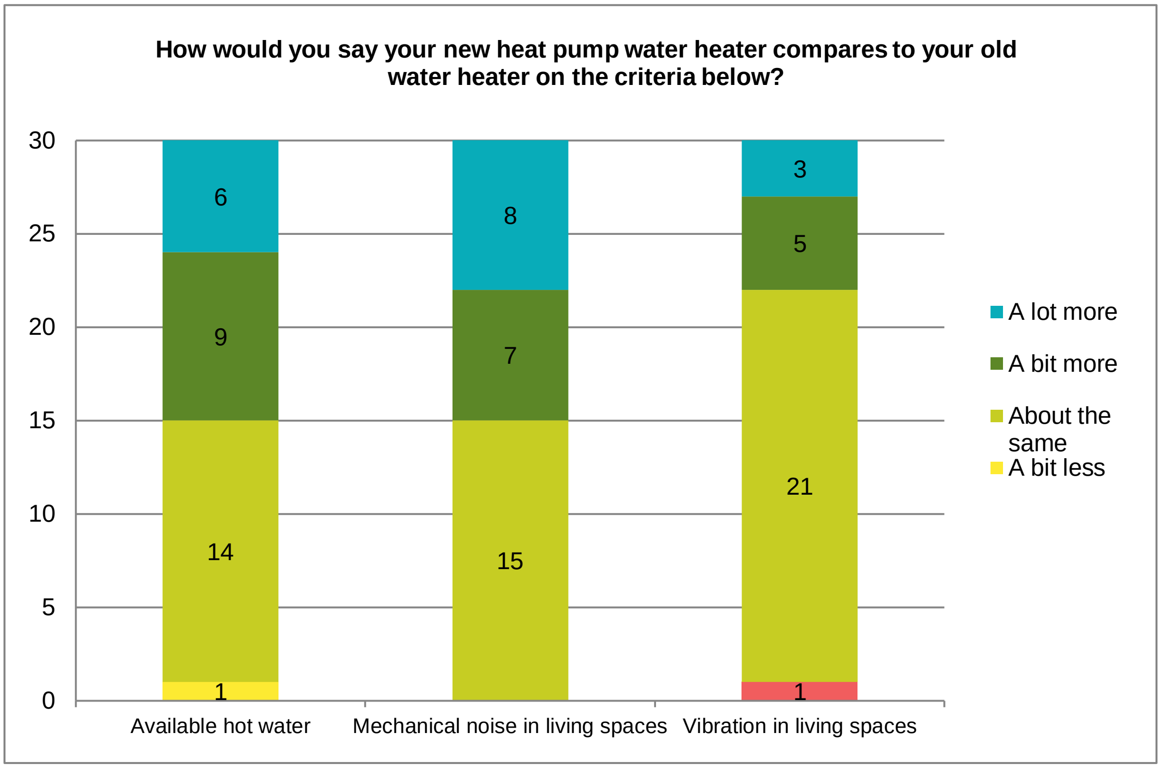
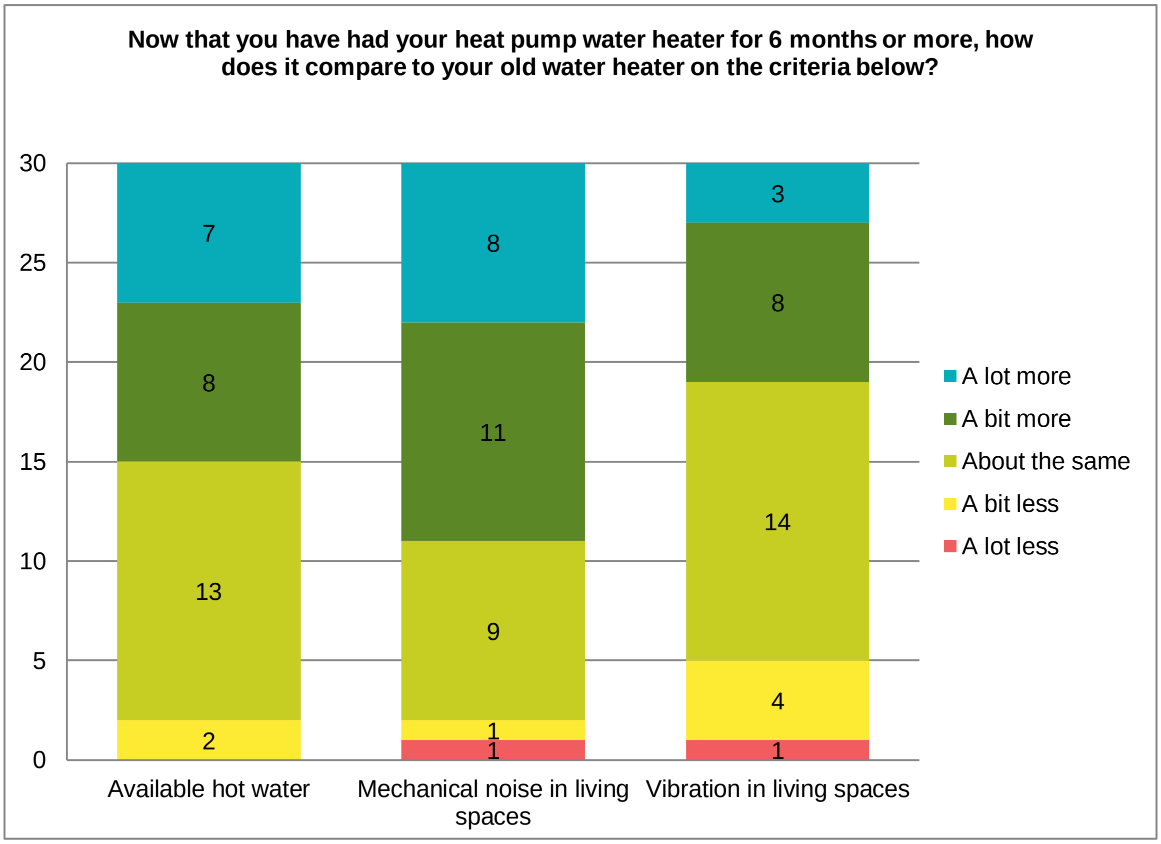


Figure 11 - Second survey comparison between HPWH and old water heater



When asked about the control functions of the HPWH in the first survey, 93% of participants responded they were aware of both temperature settings and different operating mode settings, but only 66% felt confident they knew how to make adjustments, roughly 15-35% having done so by the time of the first survey.

By the second survey 96% of participants were aware of temperature and mode settings and 77% felt confident they knew how to make adjustments. Additionally, 33-47% made temperature and/or operating mode settings adjustments.

Figure 12 - First survey controls and functions

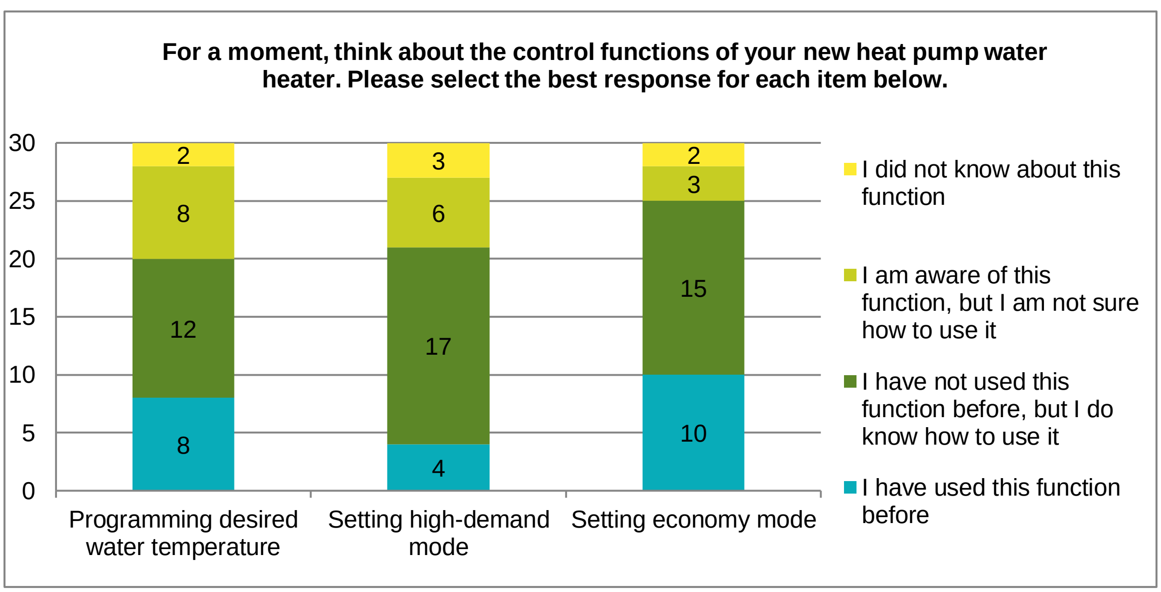
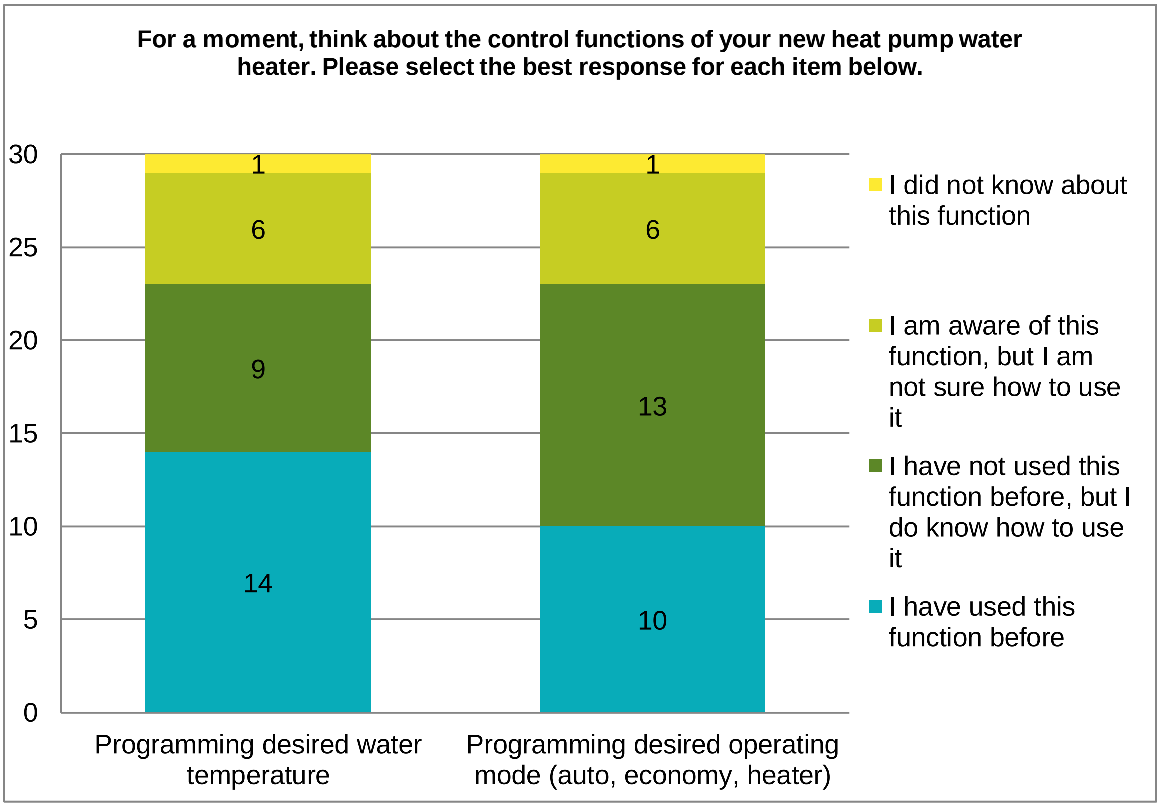
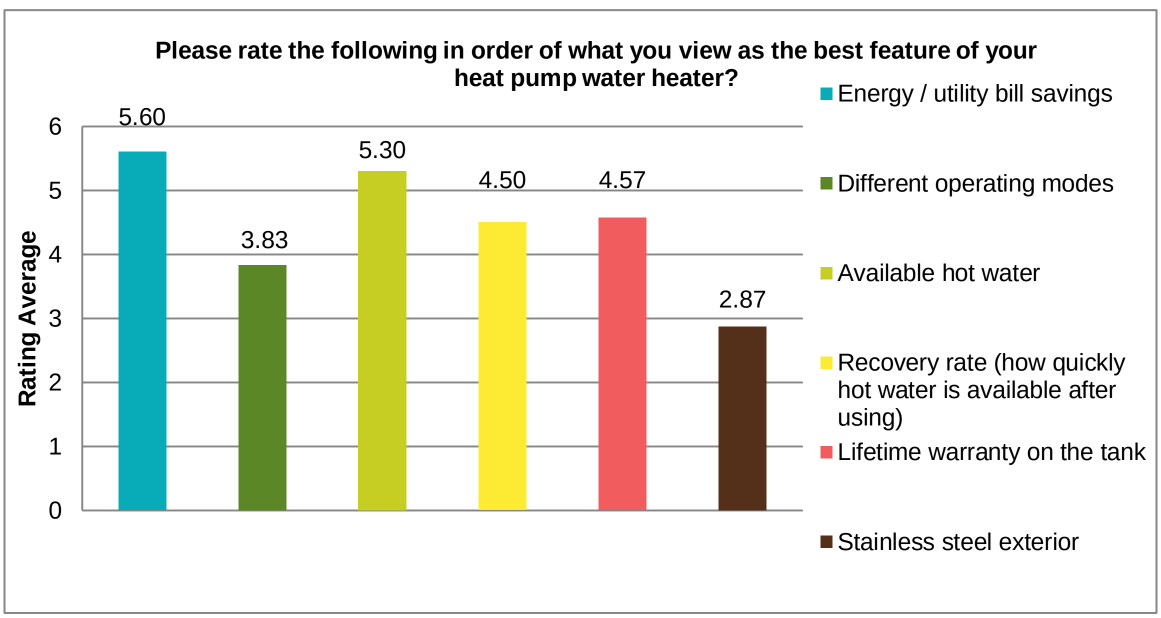


Figure 13 - Second survey controls and functions



Participants were asked in the second survey to rank six different HPWH features in order of what they viewed as the best. Energy/utility bill savings was the highest rated feature with a rating average of 5.6 and available hot water was the second highest rated feature with a rating average of 5.3.

Figure 14 - Second survey ranking



METERED FINDINGS AND OBSERVATIONS

This section presents key findings and observations from data collected during this metering study. The figures describe the HPWH's energy performance and key factors influencing its performance. Based on data collected, key factors influencing the HPWH's energy performance were as follows:

- Installation location (conditioned vs. unconditioned space)
- Outdoor and/or ambient temperature
- Inlet water temperature
- Hot water usage

HPWH PERFORMANCE

Figure 15 and 16 provide an overall summary of the data analysis. Figure 15 shows an average COP of 2.0 for Heating Zone 1 and 2. Figure 16 shows an average inlet water temperature of 62.5° F for Heating Zone 1 and 64.2° F for Heating Zone 2. The average space temperature was 67° F for Heating Zone 1 and 66.8° F for Heating Zone 2. As anticipated, the average COP of units installed inside conditioned (warmer) spaces was higher on average given the higher ambient air temperatures. Figure 16 shows that HPWHs installed inside the conditioned space had higher ambient air temperatures than those installed in basements and garages. In addition, the average COP for ducted systems was higher on average than non-ducted systems.

Figure 15 - Average COP

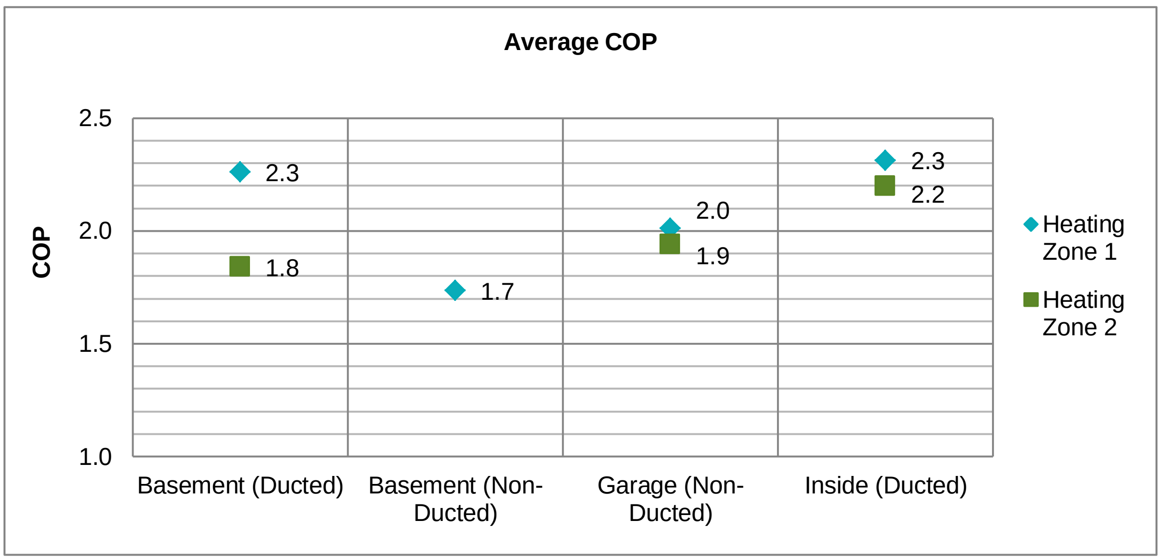
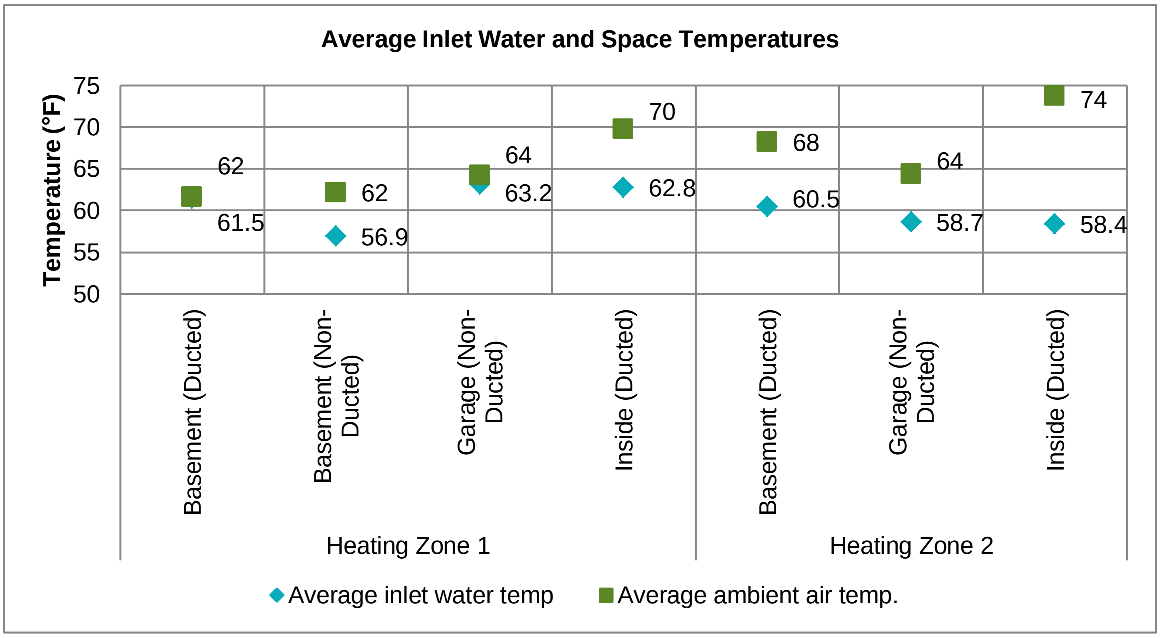


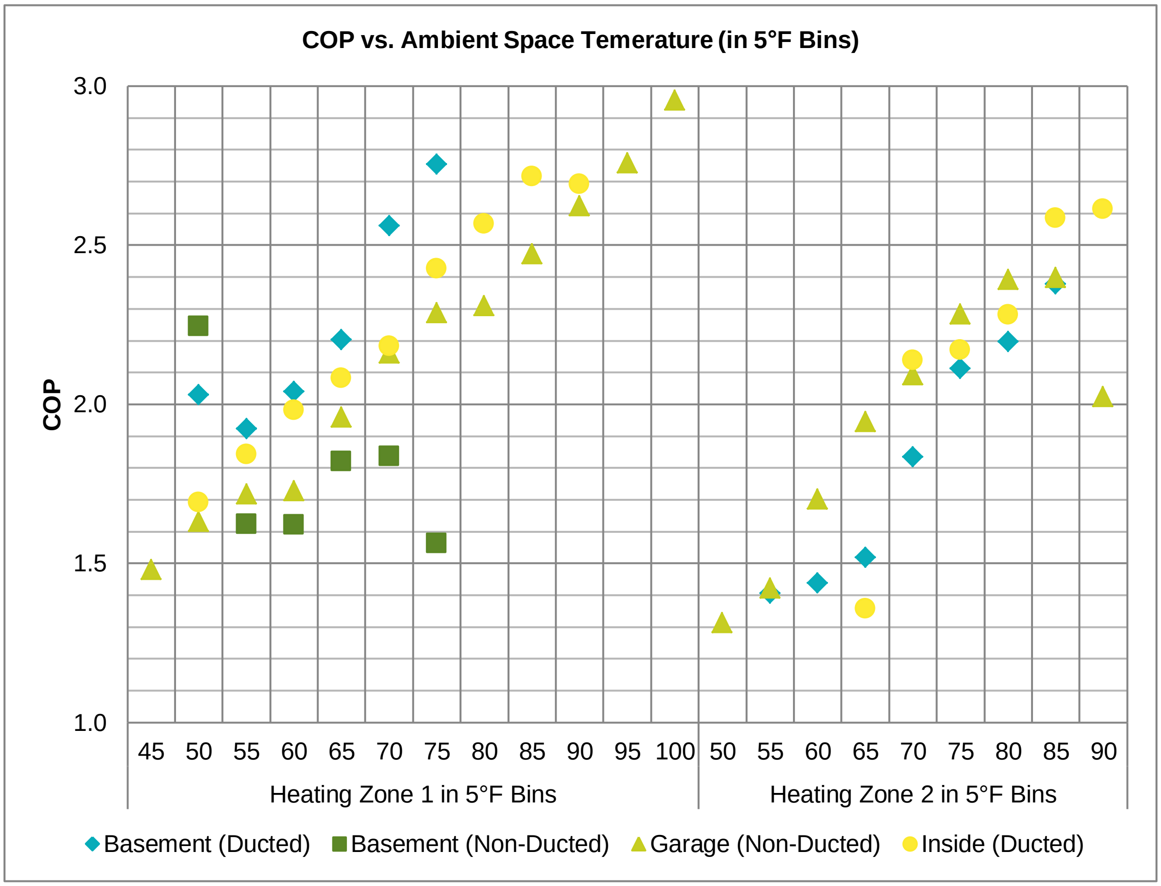
Figure 16 – Average Inlet Water and Space Temperatures



HPWH COP vs. Ambient Space Temperature

Figure 17 provides detail on average COP per location type according to average ambient space temperature, grouped into five degree temperature bins. This analysis confirms expectations that installations in conditioned spaces with warmer ambient air temperatures demonstrate higher COPs on average. COP differentials, based on location, varied from an average of 2.3 for interior installations to 1.9 for basements to 1.9 for garages. Additionally, COP increased as ambient air temperatures increased.

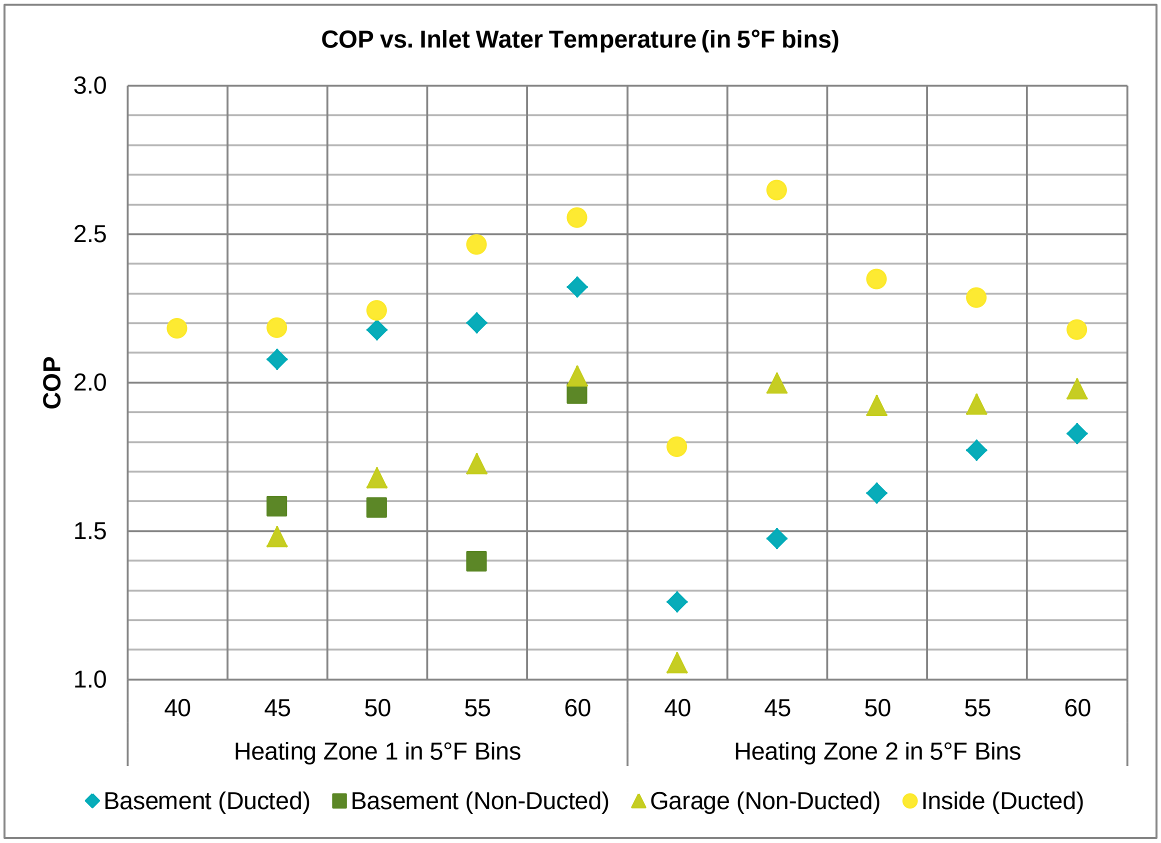
Figure 17 - COP vs. Ambient Space Temerature (in 5° F Bins)



HPWH COP vs. Inlet Water Temperature

Figure 18 provides insight into the correlation between average COP and inlet water temperature, separated into five degree temperature bins. This data is separated according to heating zone and installation location. The average COP for units located inside conditioned spaces (ducted units) is higher than unconditioned spaces (non-ducted).

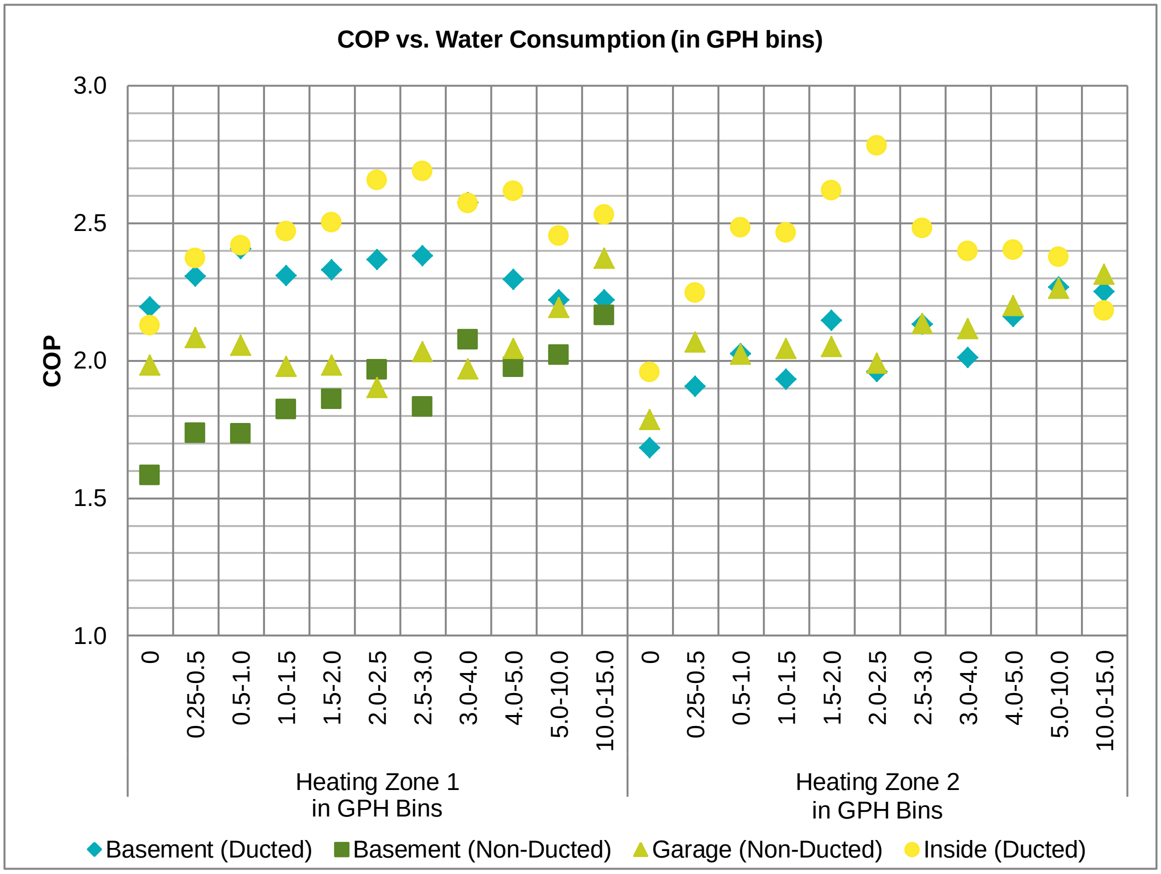
Figure 18 - COP vs. Inlet Water Temperature (in 5° F bins)



HPWH COP vs. Water Consumption

Figure 19 summarizes average COP compared to water consumption of each site, expressed in gallons per hour (GPH). The sites are separated by heating zone and installation location, and water consumption is separated into bins of gallons consumed.

Figure 19 - COP vs. Water Consumption



HPWH Hourly Demand Profile Usage

Figure 20 and 21 represent the HPWH's average hourly demand profile along with a standard electric water heater hourly demand profile. These figures compare the hourly usage profiles for HPWHs and electric water heaters – grouped by weekday/weekday and season. The HPWH hourly peak demand is lower than the electric water heater, but usage is distributed throughout the day. In contrast, electric water heaters have a higher peak demand and energy use is shifted to the earlier part of the day. Thus, a HPWH can deliver the same amount of heat using less energy and with a lower peak demand.

Figure 20 – HPWH Hourly Demand vs. Electric Water Heater Hourly Demand – Weekday

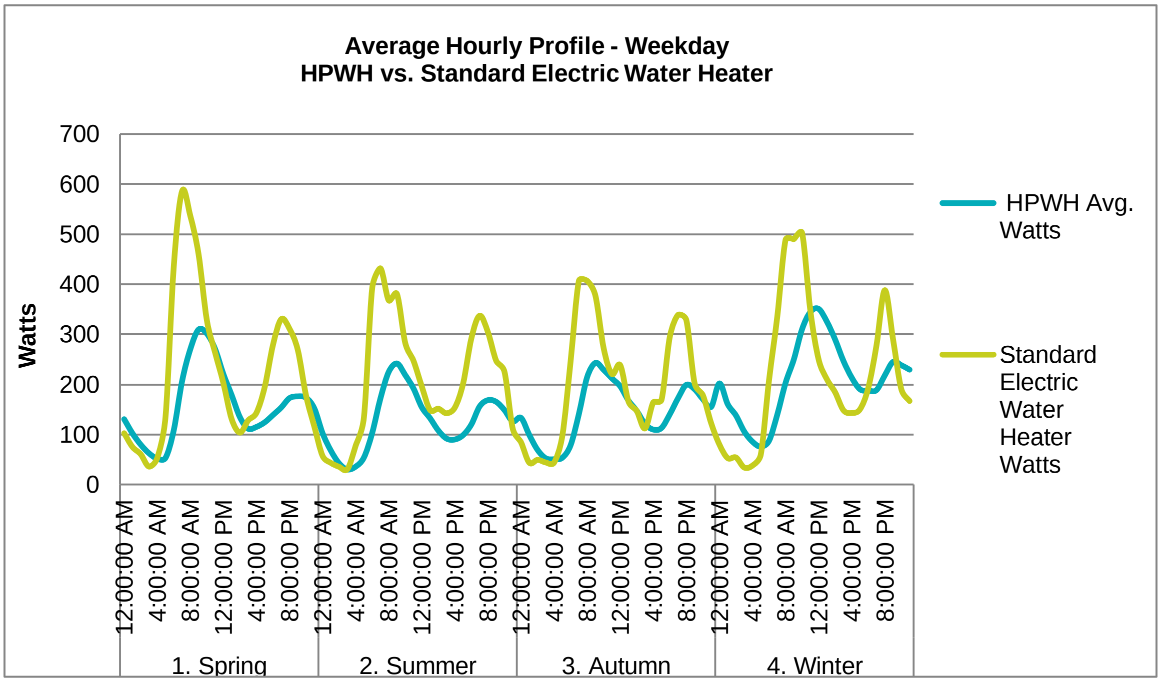
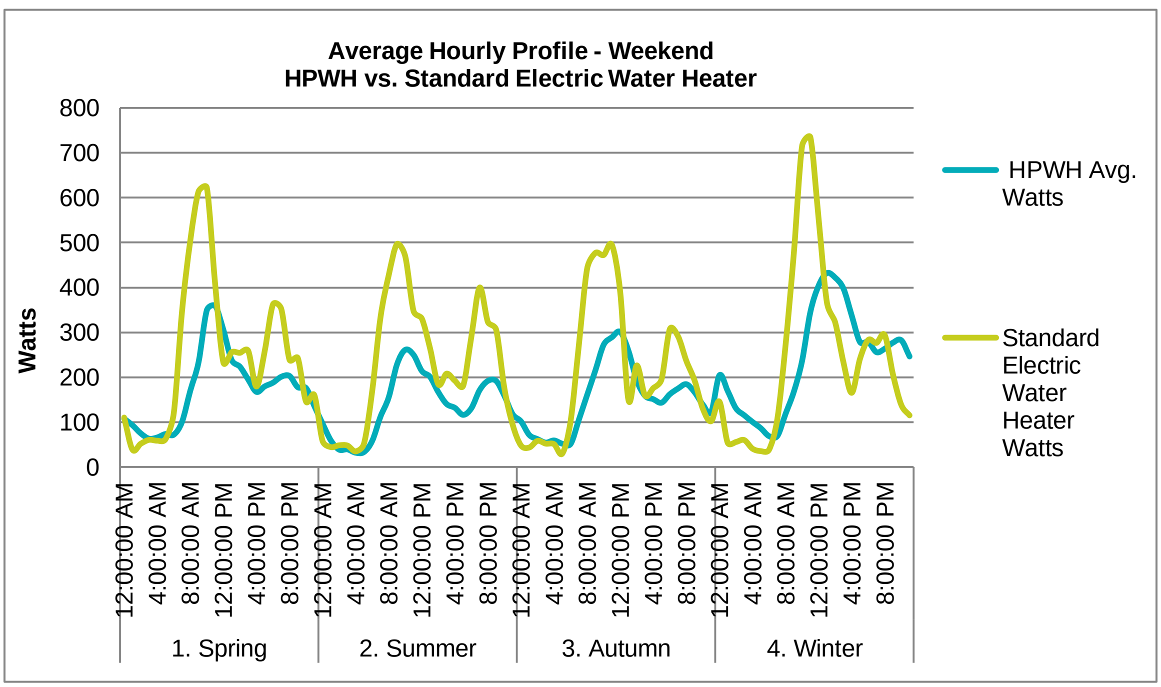


Figure 21 – HPWH Hourly Demand vs. Electric Water Heater Hourly Demand – Weekend



Energy Savings Relative to Standard Electric Water Heaters

Table 2 provides a comparison of HPWH performance to an electric resistance water heater. To make this comparison, the electric resistance unit was defined as a 50 gallon storage water heater with an energy factor of 0.90 (roughly corresponding to a 2.5 Btu/hr-F stand-by loss). Standard electric water heater is based on 2012 International Energy Conservation Code (IECC) standard for electric storage water heaters, where energy factor (EF) = 0.97 – 0.00132 x Rated Storage Volume (gallons). Analysis of this field study data show an average 43% energy savings. These energy savings do not take into account space heat interaction.

Table 2 - Energy Savings Comparison Heat Pump Water Heater vs. Electric Resistance Water Heater

Installation Location	HPWH (66gal, Q = 3.4 Btuh/F)					Electric Storage Water Heater (50 gal, 0.90 EF, Q = 2.5 Btuh/F)				Total Energy Savings (kWh)	% Energy Savings
	Avg. COP	Total Measured HPWH Electrical Energy (kWh)	HPWH Stand-By Energy Loss (kWh)	Total Heat Content of Water (kWh)	HPWH % Stand-by Losses	Calculated EWH Electrical Energy (kWh)	EWH Stand-By Energy Loss (kWh)	Total Heat Content of Water (kWh)	EWH % Stand-by Losses		
Basement (Ducted)	2.0	2738	1081	4303	20%	5034	731	4303	15%	2296	46%
Site19	1.8	1338	498	1844	21%	2181	337	1844	15%	842	39%
Site25	2.3	1400	583	2459	19%	2853	394	2459	14%	1453	51%
Basement (Non-Ducted)	1.7	5767	1590	7937	17%	9012	1075	7937	12%	3245	36%
Site07	1.4	2137	568	2304	20%	2688	384	2304	14%	551	21%
Site09	2.0	2109	501	3467	13%	3806	339	3467	9%	1697	45%
Site10	1.7	1521	520	2166	19%	2518	352	2166	14%	997	40%
Garage (Non-Ducted)	2.0	19864	5944	28625	17%	32646	4021	28625	12%	12782	39%
Site01	2.3	571	562	688	45%	1068	380	688	36%	497	47%
Site02	1.7	1746	606	2082	23%	2492	410	2082	16%	747	30%
Site06	1.9	2608	519	4143	11%	4494	351	4143	8%	1886	42%
Site08	2.4	1256	410	2400	15%	2678	278	2400	10%	1421	53%
Site12	2.1	2288	406	2880	12%	3154	274	2880	9%	866	27%
Site15	2.3	619	376	975	28%	1229	254	975	21%	611	50%
Site17	2.2	1049	562	1643	25%	2023	380	1643	19%	974	48%
Site20	2.0	762	473	1024	32%	1344	320	1024	24%	582	43%
Site21	1.4	2159	452	1800	20%	2106	306	1800	15%	-53	-3%
Site22	2.4	2342	526	4945	10%	5300	356	4945	7%	2958	56%
Site24	1.7	1847	521	2292	19%	2644	353	2292	13%	797	30%
Site27	1.8	2618	530	3754	12%	4112	358	3754	9%	1494	36%

Table 2 - Energy Savings Comparison Heat Pump Water Heater vs. Electric Resistance Water Heater (cont.)

Installation Location	HPWH (66gal, Q = 3.4 Btuh/F)					Electric Storage Water Heater (50 gal, 0.90 EF, Q = 2.5 Btuh/F)				Total Energy Savings (kWh)	% Energy Savings
	Avg. COP	Total Measured HPWH Electrical Energy (kWh)	HPWH Stand-By Energy Loss (kWh)	Total Heat Content of Water (kWh)	HPWH % Stand-by Losses	Calculated EWH Electrical Energy (kWh)	EWH Stand-By Energy Loss (kWh)	Total Heat Content of Water (kWh)	EWH % Stand-by Losses		
Inside (Ducted)	**2.3**	**13888**	**5348**	**24976**	**18%**	**28594**	**3618**	**24976**	**13%**	**14706**	**51%**
Site03	2.4	689	409	1225	25%	1501	277	1225	18%	812	54%
Site04	2.4	2878	479	4566	9%	4890	324	4566	7%	2013	41%
Site05	2.2	1769	502	3404	13%	3743	340	3404	9%	1975	53%
Site11	1.9	686	572	791	42%	1177	387	791	33%	491	42%
Site13	2.0	1148	435	1869	19%	2164	294	1869	14%	1016	47%
Site14	3.0	940	182	2655	6%	2778	123	2655	4%	1838	66%
Site16	2.1	659	489	888	35%	1219	331	888	27%	560	46%
Site18	2.2	426	279	628	31%	817	189	628	23%	391	48%
Site23	1.8	1169	399	1734	19%	2004	270	1734	13%	835	42%
Site26	2.4	746	469	1357	26%	1674	317	1357	19%	928	55%
Site28	3.0	1498	440	3955	10%	4253	297	3955	7%	2755	65%
Site29	1.9	547	306	749	29%	955	207	749	22%	408	43%
Site30	2.1	734	388	1154	25%	1417	262	1154	19%	682	48%
Average	**2.1**				**21%**				**16%**		**43%**

SPACE HEAT INTERACTION

Supporting NEEA's larger effort to understand space heat interactions, home audits were performed at all 30 field study sites detailed in Table 1. The home audit data was provided to NEEA and will contribute to further space heat interaction analysis by Ecotope and inform NEEA's Validation Study, an in-field test of 50 HPWHs currently underway.

ON-SITE AUDITS

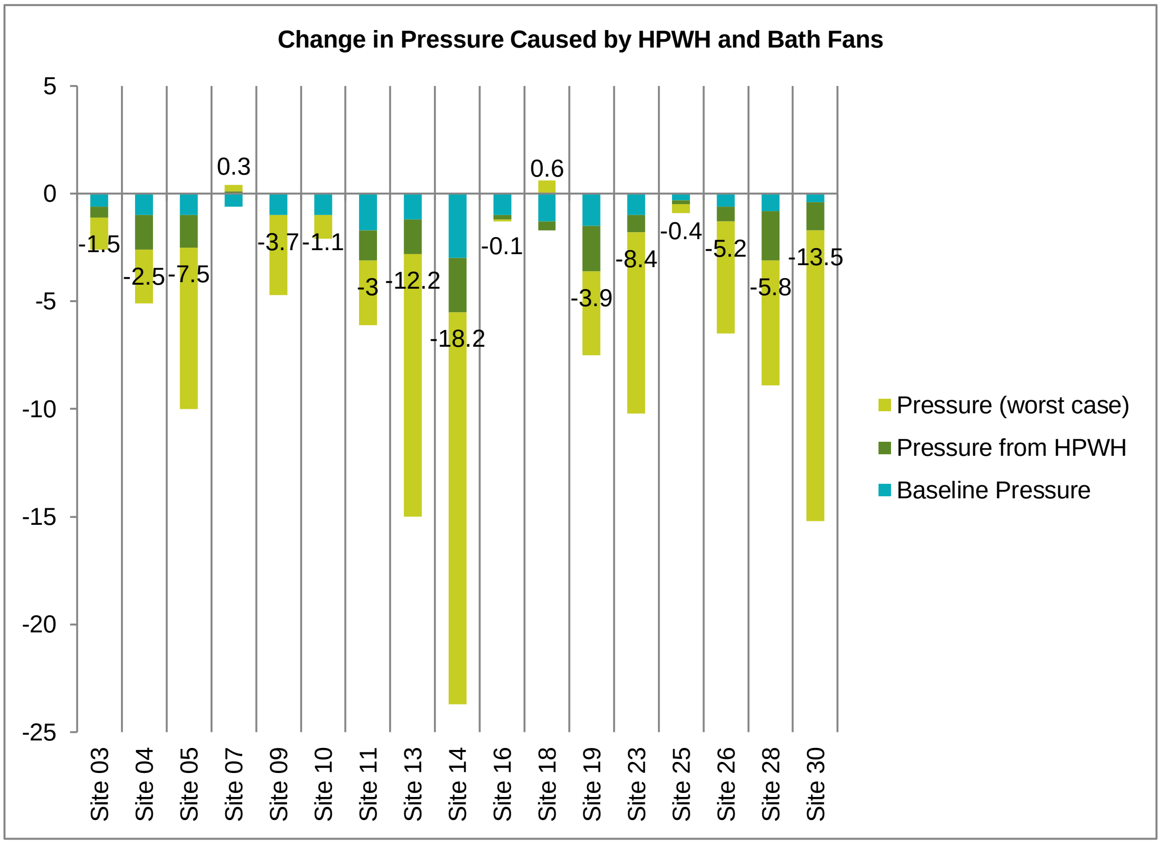
Of the participating sites, only those with HPWH installations inside the home or basement received a full audit, including blower door and CAZ tests to record and collect data on house tightness and potential depressurization resulting from the HPWH installation. The 13 garage installations received an audit of the garage space only, as well as the home's HVAC system, without blower door or CAZ tests. For this reason, characteristics of garage installations are only briefly detailed below.

Seventeen of the 30 HPWHs were installed within the thermal boundary of the home. The vintage of these 17 homes ranged from 1930 to 2005 with the majority of homes constructed with 2x4 wall framing. Of the 17 homes, five were constructed in the 1970s, four in the 1940s, and two in each of the 1930s, 50s, 60s, and the 2000s. The average square footage of the 17 sites was calculated at 1,681 ft^2 with the smallest measuring 960 ft^2 and the largest, which was also the oldest home in the study, measuring 2,650 ft^2. Based on energy audit reports, all homes contained insulated wall and ceiling assemblies and presumably met residential building codes for each era in which the home was constructed. Nine of the 17 homes (53%) contained two occupants while 24% of the homes contained one occupant with the remaining occupancy as follows: two homes with three occupants, and one each with four and five occupants. There was no apparent correlation between size of home and number of occupants. A single occupant was found to occupy the largest home and the home containing five occupants was one of the smaller homes in the study.

For sites with the HPWH located within the thermal boundary or basement of the home, location of the HPWH within the envelope of each site is as follows: three are located in unconditioned basements, five are located within conditioned basements, six units are located in laundry rooms and three are listed as being located within utility rooms. The three units located in unconditioned basements were not ducted to the outside. In the remaining 17 homes, the HPWH exhaust airflow was ducted to a location outside the envelope of the home, terminating either into a buffer zone, such as an attic or outside the structure entirely.

In order to quantify potential depressurization attributable to the addition of HPWHs in existing homes, worst-case depressurization or combustion appliance zone (CAZ) tests were conducted and recorded for each site with the exception of one site. The average change in pressure caused by the HPWH alone measured -2.3 pascals. When homes were configured into worst-case depressurization conditions (HPWH and all exhaust fans running and all doors closed) the average house depressurization measured was -4.9pa. Depressurization tests across the 17 sites where the heat pump water heater was located inside the thermal boundary ranged from 0pa to -18.2pa.

Figure 21 - Pressure changes during depressurization



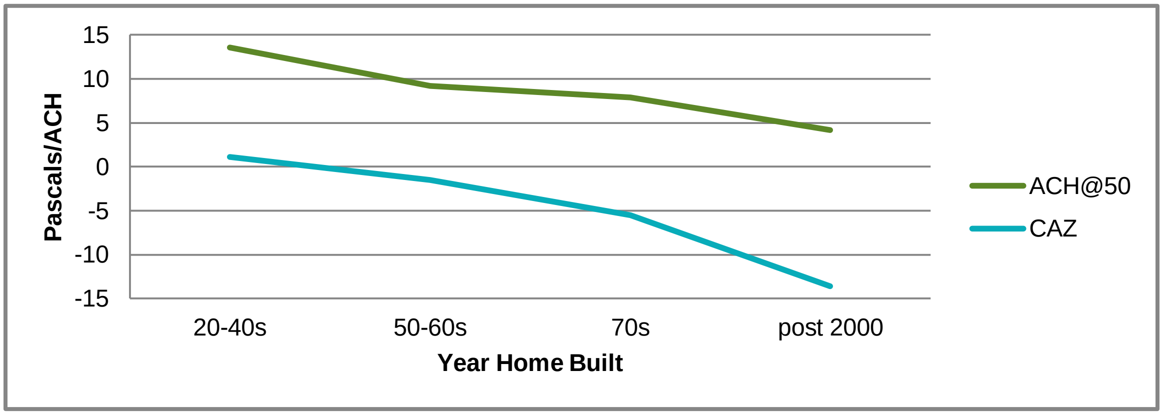
Site 14 recorded the highest depressurization at -18.2pa. It was noted on the audit form that the participant reported the wood burning fireplace would backdraft when starting fires, but after the fire began burning, adequate draft was produced and thus back drafting of the fireplace ceased. To remedy the initial back drafting at the residence, Fluid completed the following:

- Reduced the HPWH exhaust to 150 CFM
- Installed a passive make-up air grill near the HPWH
- Installed a CO monitor near the fireplace

No explanation was recorded on the audit forms as to what may have caused a pressurization of sites 4, 5, 18, and 26. For the purposes of this study, some assumptions were made by NEEA's HPWH Field Study team as to the results recorded by the energy auditors. Generally, the audit data shows that the older homes in the study had higher tested infiltration rates (blower door test) and smaller changes in pressure when setup for worst-case depressurization conditions.

Figure 22 compares blower door and CAZ test results for the seventeen homes where HPWHs were installed inside the envelope.

Figure 22 - Blower door and CAZ test results



Blower door tests were conducted and recorded on 13 of the 17 sites where a HPWH was located inside the envelope. Results ranged from a low of 3.3 ACH@50pa to a high of 13.6 ACH@50pa. As expected, newer homes (constructed after 1970) demonstrated tighter envelopes than older homes (constructed prior to 1970) with a median measurement for homes constructed in the 1970s at 7.9 ACH@50pa.

Twelve of the 13 sites with garage HPWH installations participated in a home audit. Of these 12 sites, eight were constructed of 2x4 framing and four of 2x6 framing. Eleven of the 12 garages had fiberglass insulation, R11 or greater, in their exterior walls while five garages contained no ceiling insulation. While none of these garages were considered conditioned spaces for the purposes of this field study, two of the sites were observed to have plug-in 120 volt heaters in use. Eight of the 12 sites had laundry equipment within the garage. Three of the sites with laundry equipment present also had a refrigerator in the garage. Five of the sites with laundry equipment present and one site without laundry equipment had a freezer in the garage; six sites in all had freezers located in the garage. One garage in this study contained laundry equipment, a refrigerator and a freezer.

DEVELOPMENT OF ENERGY MODEL

Fluid and Ecotope are working together to maximize NEEA's efforts to further define energy savings of HPWHs and the impacts of space heat interaction. The onsite audits were performed to capture all of the homes' energy components informing Ecotope's development of the SEEM energy model[4]. Ecotope will compare the ambient space temperature and outdoor temperature ensuring the model is simulating the home's thermal envelope appropriately. In addition, Ecotope will use the space heating energy data (HPWH, DHP, baseboard, etc.) to help calibrate its building simulation.

CONCLUSIONS AND RECOMMENDATIONS

HPWH installation location has the most significant impact on COP. Units installed in locations with warmer air temperatures showed higher COPs than those installed in locations with cooler air temperatures. Ambient temperatures for conditioned space installations were consistently warmer across all sites throughout the duration of the field study. In locations with a conditioned space installation, the HPWH's exhaust air was ducted outside of the conditioned space. The absence of exhaust air, which is cooler than ambient temperature, played some part in maintaining higher ambient temperatures in conditioned spaces. On the other hand, for HPWHs installed in an unconditioned space such as a garage, the HPWH's exhaust air was not ducted to the outside. In these cases, lower ambient temperatures of an unconditioned space such as a garage were made even cooler by exhaust air temperatures entering the space and causing lower COP than conditioned space installation locations.

[4] SEEM energy model – http://rtf.nwcouncil.org/measures/support/SEEM/Default.asp

Inlet water temperature also affected HPWH performance, though not as significantly. As inlet water temperature increased, COP of the HPWH increased. The inlet water temperature is directly proportional to ambient temperature such that the performance increase can be interpreted as a function of higher ambient temperatures and inlet water temperatures. In Figure 17, conditioned sites have a relatively constant ambient temperature (and constant COP performance) whereas unconditioned sites displayed varying ambient temperatures (and varying COP performance). Unconditioned sites do not change significantly with inlet water and ambient temperatures, but the unconditioned site COPs improve as inlet water temperature and ambient temperatures increase.

Another factor in this study was water consumption. There was not a clear trend across all sites that demonstrated a strong correlation between water consumption, draw schedule, and HPWH performance. However, it should be noted that periods of no water consumption consistently reduced COP. If there was no water consumption for a period—for instance, when the resident was on vacation—then standby losses increased and COP decreased.

Lastly, installation standards for HPWHs must be closely followed in order for installations to achieve optimal performance. Space restrictions should be considered before determining whether a location is ideal for HPWH installation. For example, if the HPWH is installed in a small closet, air flow to the unit could be reduced, and performance could suffer as a result. Restricted spaces can also create installation challenges, due to size and weight of HPWH units, location of plumbing connections, and the need for ducting as well as condensate drains. Pipe insulation should be installed and maintained as needed. The HPWH owner should perform regular maintenance on the HPWH and call a qualified professional to inspect the unit if necessary.

Though this study did not endeavor to analyze data on space heat interaction of ducted and non-ducted HPWH installations, data collected in this field study will make it possible to quantify these effects in future efforts. Data collected as part of this study should prove useful in examining interactive effects of ducting HPWH exhaust air from conditioned spaces, as well as effects that HPWH units installed in buffer zones adjoining the home have on overall home energy consumption. Such an effort would be helpful in informing energy simulation for use in savings prediction and planning efforts. The study data confirms that HPWHs are an efficient technology and developing a better understanding of key factors affecting performance and incorporating this knowledge into planning and program design efforts will maximize its potential and help ensure successful use of the technology.

APPENDICES

APPENDIX A – HPWH PERFORMANCE

A1 – Installation Summary by Site

Summary of each HPWH installation grouped by heating zone and installation type.

Table 3 – Installation Summary by Site

Install Type	Site #	Avg. COP	Avg. Daily Draw (gal.)	Avg. Ambient Space Temp. (F°)	Avg. Exhaust Air Temp. (F°)	Exhaust Air Temp. Diff. (F°)	Avg. Inlet Water Temp. (F°)	Avg. Comp. Runtime (hours)	Avg. Comp. Cycles (hours)	Avg. Stand-by Energy	Electric Resistance Heat On	Data logging Sampling Size
Basement (Ducted)	Site19	1.8	8.54	68	49	13	37	4.3	1.3	30%	1.2%	361
	Site25	2.3	7.08	62	48	15	43	3.5	1.2	29%	1.4%	378
Basement (Non-Ducted)	Site07	1.4	5.95	65	52	3	41	6.0	1.2	22%	1.6%	392
	Site09	2.0	17.41	62	49	5	52	7.7	1.8	14%	0.0%	331
	Site10	1.8	10.43	61	44	7	41	5.3	1.6	24%	2.8%	336
Garage (Non-Ducted)	Site01	2.3	12.23	58	45	6	45	1.9	1.3	56%	0.7%	350
	Site02	1.7	12.09	60	52	5	43	5.6	1.3	33%	1.0%	363
	Site06	1.9	26.87	69	53	7	42	7.6	1.7	13%	1.7%	384
	Site08	2.4	13.71	65	43	14	50	4.3	1.4	17%	1.8%	332
	Site12	2.1	23.81	68	44	13	47	4.5	1.1	22%	3.1%	343
	Site15	2.3	3.82	67	61	-9	45	2.1	1.0	34%	0.6%	335
	Site17	2.2	6.39	58	44	7	42	3.7	1.6	29%	0.6%	345
	Site20	2.0	2.74	66	50	8	40	2.8	1.3	37%	0.1%	313
	Site21	1.4	4.19	63	53	3	47	8.7	1.3	29%	0.4%	261
	Site22	2.4	12.98	68	49	11	41	3.9	1.4	19%	1.5%	377
	Site24	1.7	8.70	61	49	5	39	6.6	1.6	27%	0.5%	327
	Site27	1.8	24.07	67	51	8	43	7.6	1.6	16%	2.0%	374
Inside (Ducted)	Site03	2.4	12.11	68	51	15	43	2.7	1.3	30%	0.0%	297
	Site04	2.4	40.01	74	54	19	43	3.8	1.4	21%	0.9%	386
	Site05	2.2	30.94	72	52	19	39	5.2	1.8	15%	0.8%	398
	Site11	2.0	1.19	64	54	13	49	2.1	1.1	50%	0.0%	374
	Site13	2.0	6.78	75	45	29	39	3.9	1.2	24%	2.0%	348
	Site14	3.5	43.35	74	56	17	48	5.1	1.9	7%	4.0%	230
	Site16	2.1	5.51	62	57	4	41	2.5	1.3	46%	2.0%	289
	Site18	2.2	2.37	70	52	18	41	2.6	1.4	38%	0.0%	212
	Site23	1.8	10.09	73	51	20	39	4.1	1.9	23%	1.7%	320
	Site26	2.4	5.89	70	51	17	45	2.8	1.4	33%	0.2%	321
	Site28	3.0	19.92	74	63	8	41	8.4	1.5	11%	1.7%	364
	Site30	2.3	2.90	74	48	23	42	3.8	1.3	29%	0.1%	264

- Exhaust Temp. Diff. (Tdiff) – The temperature difference (F) between the ambient space temperature and exhaust air when the heat pump water heater is actively heating in heat pump mode. This is a good indicator of how much energy is being extracted from the surrounding air.
- Avg. Standby Energy – The average percentage of energy that the heat pump water heater lost due to standby losses compared to the total energy delivered. % Standby Energy = Standby Energy Loss (Btu) / [Standby Energy Loss (BTU) + Water Heating Energy (BTU)]. This is a good indicator of how much energy is attributed to standby losses.
- Avg. Comp. Runtime – The average daily runtime of active heating in heat pump mode. This is good indicator of daily duration of each compressor run.
- Electric Resistance – The average percentage of time electric resistance heat was on during an active heating mode.

A2 – Weighted Average COP vs. Average Space Temperature by Site (in 5° F bins)

Summary of COP versus average space temperature of each HPWH installation grouped by heating zone and installation type. Red represents lower COP averages, whereas green represents higher COP averages.

Table 4 – Weighted Average COP vs. Average Space Temperature by Site (5° F bins)

Installation Location	Average COP vs Average Space Temperature (5°F Bin)											
	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	Avg
HZ1													
Basement (Ducted)		**2.0**	**1.9**	**2.0**	**2.2**	**2.6**	**2.8**						**2.3**
Site25		2.0	1.9	2.0	2.2	2.6	2.8						2.3
Basement (Non-Ducted)		**2.2**	**1.6**	**1.6**	**1.8**	**1.8**	**1.6**						**1.7**
Site07			1.0	1.4	1.3	1.3	1.5						1.4
Site09			1.6	1.7	2.1	2.3							2.0
Site10		2.2	1.7	1.6	1.7	1.9	2.1						1.7
Garage (Non-Ducted)	**1.5**	**1.6**	**1.7**	**1.7**	**2.0**	**2.2**	**2.3**	**2.3**	**2.5**	**2.6**	**2.8**	**3.0**	**2.1**
Site01	1.8	1.9	1.9	2.1	2.6	2.9	3.1	3.2	3.2				2.3
Site02	1.2	1.3	1.4	1.5	1.9	2.0	2.2	2.3	2.4	2.3	2.8	2.7	1.7
Site06			1.4	1.7	1.8	1.8	1.9	2.1	2.3	2.5	2.6	2.9	1.9
Site08	1.8	1.9	2.0	2.0	2.2	2.3	2.5	2.7	2.8	2.9	3.4		2.3
Site12		1.2	1.3	1.5	1.7	1.9	2.2	2.4	2.6	2.7	2.7	3.3	2.0
Site15			1.6	1.5	1.5	2.1	2.4	2.4	2.5				1.9
Site17	1.6	1.8	1.9	2.2	2.3	2.6	2.9	2.6	2.9				2.2
Site27			1.4	1.5	1.6	1.8	2.0	2.1	2.3	2.6	2.9		1.8
Inside (Ducted)		**1.7**	**1.8**	**2.0**	**2.1**	**2.2**	**2.4**	**2.6**	**2.7**	**2.7**			**2.3**
Site03			1.7	2.2	2.2	2.3	2.5	2.6	2.9				2.4
Site04						2.4	2.3	2.5	2.7				2.4
Site05					2.1	2.1	2.2	2.3	2.4	2.3			2.2
Site11			1.9	1.9	1.9	2.0	2.0						1.9
Site14					0.5	3.1	3.1	3.0	2.9	3.1			3.0
Site16		1.7	1.8	2.0	2.2	2.3	2.5	2.7					2.1
Site18					2.0	2.0	2.3	2.3	3.6				2.2
Site26					2.0	2.2	2.6	2.8	2.7				2.4
HZ2													
Basement (Ducted)			**1.4**	**1.4**	**1.5**	**1.8**	**2.1**	**2.2**	**2.4**				**1.8**
Site19			1.4	1.4	1.5	1.8	2.1	2.2	2.4				1.8
Garage (Non-Ducted)		**1.3**	**1.4**	**1.7**	**1.9**	**2.1**	**2.3**	**2.4**	**2.4**	**2.0**			**1.9**
Site20		1.7	1.6	1.8	1.9	2.1	2.2	2.4	2.6	2.6			2.0
Site21		1.2	1.1	1.2	1.6	1.6	1.7	1.7	1.7	1.7			1.4
Site22		2.0	2.0	2.1	2.3	2.4	2.5	2.7	2.7				2.4
Site24		1.2	1.4	1.6	1.9	2.0	2.0	2.2	2.4				1.7
Inside (Ducted)					**1.4**	**2.1**	**2.2**	**2.3**	**2.6**	**2.6**			**2.2**
Site13						1.9	2.0	2.0	2.2	2.3			2.0
Site23						1.6	1.8	2.0	2.0				1.8
Site28						3.4	3.0	2.9	2.8	3.0			3.0
Site29					1.4	1.8	1.9	2.0	2.1				1.9
Site30						1.3	2.0	2.5					2.1
Average	**1.5**	**1.6**	**1.7**	**1.8**	**1.9**	**2.1**	**2.3**	**2.4**	**2.5**	**2.6**	**2.8**	**3.0**	**2.1**

A3 – Weighted Average COP vs. Inlet Water Temperature by Site (in 5° F bins)

Summary of COP versus inlet water temperature of each HPWH installation grouped by heating zone and installation type. Red represents lower COP averages, whereas green represents higher COP averages.

Table 5 – Weighted Average COP vs. Inlet Water Temperature by Site (5° F bins)

Installation Location	Average COP vs Average Inlet Water Temperature (5°F Bin)													
	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100	Avg.
Heating Zone 1														
Basement (Ducted)		**2.1**	**2.2**	**2.2**	**2.3**	**2.4**	**2.4**	**2.4**	**2.6**	**2.3**	**2.2**	**1.7**	**2.3**	**2.3**
Site25		2.1	2.2	2.2	2.3	2.4	2.4	2.4	2.6	2.3	2.2	1.7	2.3	2.3
Basement (Non-Ducted)		**1.6**	**1.6**	**1.4**	**2.0**	**1.7**	**1.8**	**1.8**	**1.8**	**2.1**		**1.0**	**1.3**	**1.7**
Site07		1.2	1.4	1.3	1.3	1.4	1.5	1.4	1.3			1.0	1.0	1.4
Site09				1.4	2.1	2.2	2.0	2.0	2.1	2.1			1.7	2.0
Site10		1.7	1.7	1.5	1.6	1.9	1.9							1.7
Garage (Non-Ducted)		**1.5**	**1.7**	**1.8**	**2.1**	**2.2**	**2.3**	**2.4**	**2.3**	**2.3**	**2.0**	**2.2**	**1.9**	**2.1**
Site01		1.8	2.0	2.0	2.6	2.8	2.4	2.5	2.3	2.5	2.3	2.4	2.0	2.3
Site02		1.1	1.6	1.7	2.1	2.1	1.7	1.7	1.5	1.5	1.3	1.1	1.4	1.7
Site06		1.4	1.8	1.8	1.9	2.1	2.1	2.0	2.0	2.0	1.3	0.8	1.5	1.9
Site08				2.0	2.2	2.2	2.5	2.6	2.5	2.7	2.5	1.9		2.4
Site12			1.4	1.5	1.8	2.2	2.5	2.7	2.9	2.4	2.6	2.2		2.1
Site15		1.7	1.8	2.0	2.4	2.3	2.4	2.4	2.2	2.4	2.4	2.7	2.6	2.3
Site17		1.8	1.9	2.1	2.2	2.4	2.6	2.4	2.3	2.7	1.7	2.4		2.2
Site27		1.1	1.6	1.6	1.8	2.0	2.1	2.2	1.9	2.4	2.1		1.1	1.8
Inside (Ducted)	**2.2**	**2.2**	**2.2**	**2.5**	**2.6**	**2.4**	**2.4**	**2.3**	**2.2**	**2.2**	**2.0**	**2.0**	**1.8**	**2.3**
Site03		2.4	2.3	2.3	2.5	2.5	2.5	2.5	2.3	2.4	1.8	2.0		2.4
Site04		2.2	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.1	2.0	1.8	2.4
Site05	2.2	2.1	2.1	2.2	2.3	2.3	2.3	2.2	2.2	2.2	2.1	2.0	1.6	2.2
Site11			2.2	2.1	2.2	2.1	2.0	2.0	1.9	2.0	1.9	1.9	1.7	1.9
Site14			3.4	3.0	3.0	3.4	3.8	3.6		3.6	3.7	3.7	2.3	3.0
Site16		1.8	2.0	2.2	2.4	2.4	2.2	2.0	2.3	2.2	2.0	2.1	2.1	2.1
Site18		2.4	2.3	2.0	2.0	2.2	2.3	2.2	2.3	2.3	1.4	1.0	0.9	2.2
Site26		2.3	2.5	2.4	2.6	2.5	2.4	2.4	2.3	2.1	2.0	1.8	1.8	2.4
Heating Zone 2														
Basement (Ducted)	**1.3**	**1.5**	**1.6**	**1.8**	**1.8**	**2.0**	**2.1**	**2.1**	**1.9**	**1.3**	**1.4**	**1.6**		**1.8**
Site19	1.3	1.5	1.6	1.8	1.8	2.0	2.1	2.1	1.9	1.3	1.4	1.6		1.8
Garage (Non-Ducted)	**1.1**	**2.0**	**1.9**	**1.9**	**2.0**	**2.0**	**2.0**	**2.2**	**2.1**	**2.2**	**2.0**	**1.9**	**1.9**	**1.9**
Site20	1.6	1.9	2.0	1.9	2.3	2.3	2.1	2.1	1.9	2.2	2.0	2.1	1.9	2.0
Site21			1.3	1.7	0.9	1.4	1.5	1.7	1.4	1.7	1.7	1.2	1.7	1.4
Site22		2.3	2.2	2.3	2.5	2.7	2.4	2.4	2.6	2.4		2.2	2.3	2.4
Site24	1.0	1.9	1.5	1.3	1.8	1.9	2.0	1.8	1.9	2.0	2.4		2.0	1.7
Inside (Ducted)	**1.8**	**2.6**	**2.3**	**2.3**	**2.2**	**2.0**	**2.0**	**2.0**	**2.0**	**1.8**	**1.9**	**1.5**	**1.5**	**2.2**
Site13	1.9	2.0	2.0	2.1	2.0	2.1	2.0	2.0	2.0	1.9	1.8	1.8	1.4	2.0
Site23	1.6	1.6	1.7	1.9	2.0	1.9	1.9	1.8	1.9	1.8	1.8	1.8		1.8
Site28		3.4	2.9	2.8	2.6	2.6	2.7	2.7	2.6					3.0
Site29	1.9		2.1	2.0	2.0	2.0	1.9	1.9	1.9	1.9	1.6	1.4	1.4	1.9
Site30		2.0	1.9	2.1	2.7	2.3	2.0	2.1	2.1	2.1	2.8	1.6	1.5	2.1
Average	**1.4**	**2.1**	**2.0**	**2.0**	**2.2**	**2.1**	**2.2**	**2.3**	**2.2**	**2.2**	**1.9**	**1.9**	**1.8**	**2.1**

A4 – Percent of Time Electric Resistance Is On vs. Water Consumption

Insight into how often the electric resistance component of the HPWH was energized. The table details the number of hours electric resistance was energized throughout the monitoring period.

Table 6 – Number of hours electric resistance heating element on (Hrs/Month) by site

Installation Location	Site Number	Number of hours electric resistance heating element on per month (Hrs./Month) by site														Total Hrs./Yr.
		2012												2013		
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Feb	Mar	
	Site08	0.0	0.0	0.0	0.0	2.6	2.2	0.9	1.1	0.8	1.6	1.8	2.9	8.8	2.6	25
	Site12	0.0	0.0	0.0	0.0	6.8	1.7	2.5	2.7	2.3	2.9	5.1	8.7	8.2	7.0	48
	Site15	0.0	0.0	0.0	0.0	0.8	0.3	0.0	0.2	0.2	0.3	0.6	1.8	0.0	0.0	4
	Site17	0.0	0.0	0.0	0.2	0.7	0.6	0.2	0.2	0.5	0.7	0.2	2.2	2.6	0.3	8
Garage (Non-Ducted)	Site20	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1
	Site21	0.0	0.2	2.8	0.0	0.6	0.0	0.0	0.0	0.4	0.4	0.5	0.4	1.4	1.9	8
	Site22	0.0	1.3	2.0	3.6	1.2	0.8	1.0	0.7	0.6	1.5	2.5	1.5	2.2	2.9	22
	Site24	0.0	1.5	1.5	1.4	0.2	0.0	0.0	0.7	0.2	0.2	1.9	1.4	1.7	1.0	12
	Site27	0.0	3.1	8.5	7.3	4.6	3.0	3.9	3.0	3.2	0.0	0.0	0.0	12.1	7.7	56
	Site03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
	Site04	0.6	1.9	0.0	0.0	2.7	0.8	0.4	0.2	0.2	1.1	2.0	2.4	0.7	0.6	13
	Site05	1.9	0.0	0.0	0.6	1.7	1.0	1.2	0.0	0.4	1.0	1.1	1.5	2.4	0.4	13
	Site11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
	Site13	0.0	5.1	7.3	0.6	1.2	0.9	0.9	1.3	1.1	1.1	1.3	2.5	1.6	2.5	27
	Site14	0.0	0.0	0.0	0.4	5.9	7.3	5.4	4.0	6.9	8.1	4.0	0.0	0.0	0.0	42
Inside (Ducted)	Site16	0.0	0.0	2.1	1.5	1.8	0.2	0.2	0.3	0.3	0.8	1.6	3.2	2.4	0.0	14
	Site18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
	Site23	0.0	0.0	0.0	1.0	0.6	2.9	3.6	3.1	2.4	3.4	1.3	1.1	2.5	0.7	23
	Site26	0.0	0.0	0.9	0.0	0.4	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2
	Site28	0.0	0.4	5.4	6.5	4.8	5.5	4.6	3.0	2.5	1.9	0.9	8.0	5.5	2.5	52
	Site29	0.0	0.0	0.0	0.0	0.2	0.4	0.5	0.0	0.0	0.2	0.0	0.0	0.0	0.0	1
	Site30	0.0	0.0	0.2	0.5	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	1

A5 – Number of Readings of Weighted Average Stand-By Losses

Summarizes number of readings of average stand-by losses for each installation location; calculated by observing units during periods of zero or near-zero to low water usage.

Table 7 – Number of Readings of Weighted Average Stand-By Losses

Installation Location	Weighted Average Stand-By Losses Coefficient (BTU/hr-°F)	Average Space Temperature (°F)	# of Readings
Basement (Ducted)	**4.15**	**65**	**500**
Site19	4.79	67	254
Site25	3.50	61	246
Basement (Non-Ducted)	**5.07**	**62**	**559**
Site07	4.34	64	221
Site09	5.62	62	111
Site10	5.51	61	227
Garage (Non-Ducted)	**4.53**	**63**	**2224**
Site01	4.06	58	324
Site02	3.81	59	213
Site06	6.24	70	87
Site08	4.49	64	119
Site12	4.22	70	99
Site15	3.97	67	207
Site17	4.86	58	269
Site20	4.37	65	255
Site21	4.70	63	201
Site22	4.97	68	154
Site24	4.78	61	191
Site27	5.49	68	105
Inside (Ducted)	**4.70**	**70**	**2663**
Site03	4.76	68	201
Site04	4.82	74	220
Site05	5.77	72	209
Site11	3.63	64	340
Site13	4.55	75	251
Site14	4.26	76	1
Site16	3.88	62	226
Site18	4.95	70	175
Site23	7.32	73	258
Site26	4.26	69	252
Site28	5.52	74	90
Site29	4.22	71	183
Site30	3.63	73	257
Average	**4.62**	**66**	**5946**

A6 – Underperforming HPWHs

Results from three sites (Site 08, 12, 15) exhibited poor performance at some point during the field study due to mechanical issues. These underperforming HPWHs exhibited excessive compressor runtimes (at times greater than 24 hours) and very low intake to exhaust air temperature differentials. The data collected during these times of underperformance was excluded from overall data analysis because it did not represent true performance.

Table 8 – Sites with underperforming HPWHs before replacement

Install Type	Site	Avg. COP	Avg. Daily Draw	Avg. Ambient Space Temp.	Avg. Exhaust Air Temp.	Exhaust Air Temp. Diff.	Avg. Inlet Water Temp.	Avg. Comp. Runtime	Avg. Comp. Cycles	Avg. Stand-by Energy	Electric Resistance Heat On	Data logging Sample Size
			Gal/Day	°F	°F	°F	°F	Hrs/Day	Cycles/ Day	%	Hrs	Days
Garage (Non-Ducted)	08	1.6	19.81	63	51	3	53	8.2	1.1	12%	0.7	57
	12	1.0	220.48	64	58	0	50	28.4	1.0	18%	105.3	59
	15	0.7	1.85	62	59	1	45	10.0	1.0	35%	32.9	84

During the month of May 2012, the underperforming units were replaced with new HPWHs. Table 9 is the summary performance after new units were installed.

Table 9 - Sites with underperforming HPWHs after replacement

Install Type	Site	Avg. COP	Avg. Daily Draw	Avg. Ambient Space Temp.	Avg. Exhaust Air Temp.	Exhaust Air Temp. Diff.	Avg. Inlet Water Temp.	Avg. Comp. Runtime	Avg. Comp. Cycles	Avg. Stand-by Energy	Electric Resistance Heat On	Data logging Sample Size
			Gal/Day	°F	°F	°F	°F	Hrs/Day	Cycles/ Day	%	Hrs	Days
Garage (Non-Ducted)	08	2.4	16.49	65	43	14	50	5.1	1.6	17%	25.3	276
	12	2.1	28.66	68	44	13	47	5.4	1.3	22%	47.8	285
	15	2.3	5.08	67	61	-9	45	2.8	1.3	34%	4.0	252

Figure 23 represents daily COP for Sites 8, 12, and 15. The figure illustrates how COP changed throughout the year after malfunctioning HPWHs were replaced, which occurred during the month of May 2012.

Figure 23 – Daily COP of underperforming sites

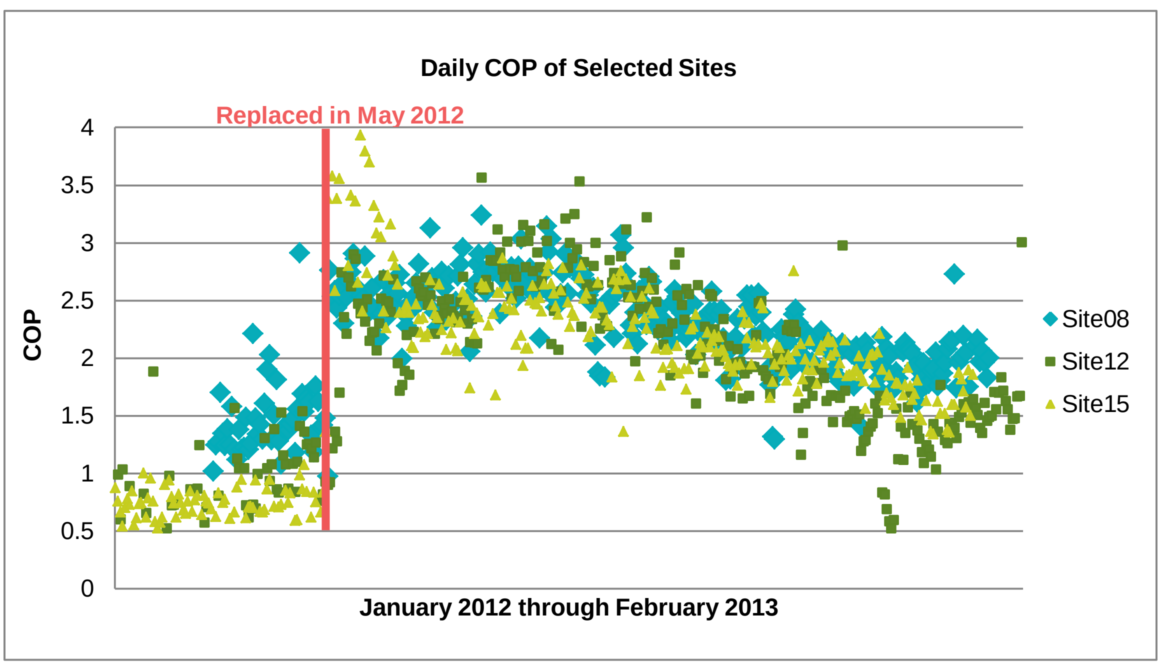
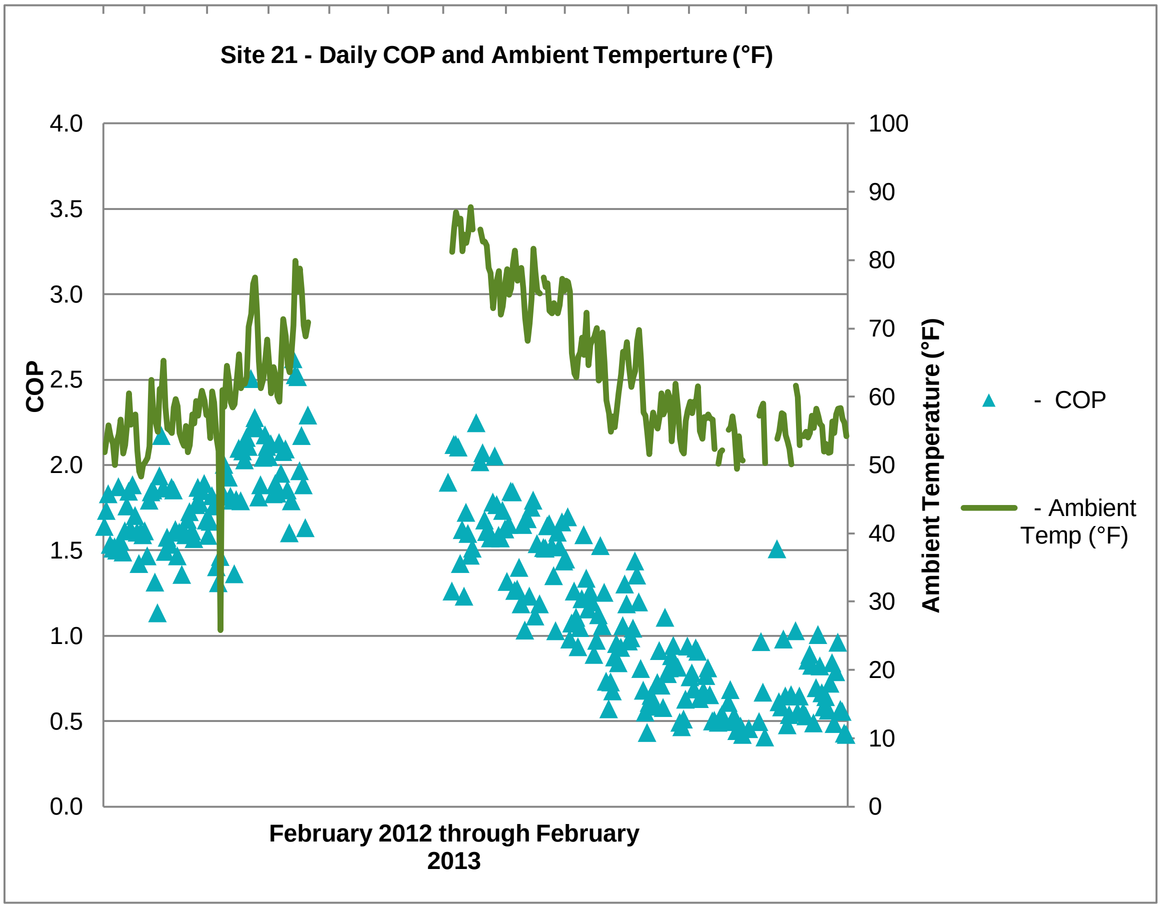


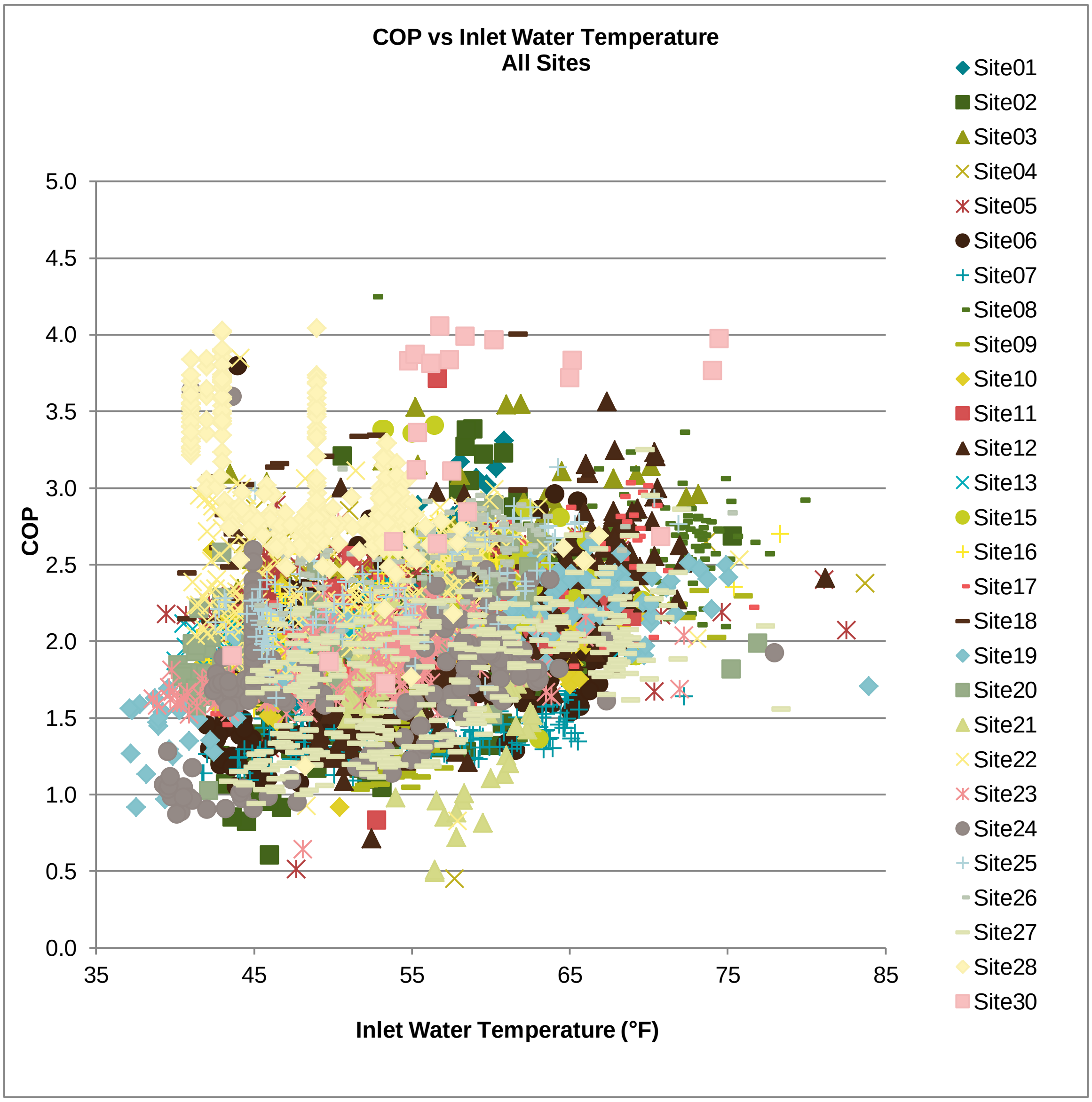
Figure 24 is the daily COP for Site 21. As noted in Table 2, Site 21 had negative energy savings when compared to a standard electric water heater. After further review of the data, it was observed that Site 21's energy performance declined during the latter part of the year. For example, site 21's COP was consistently above 1.5 however starting in November 2012 COP was consistently under 1.0. Initially the drop in COP was believed to be due to colder ambient temperatures or inlet water temperature. However based on the figure below the temperatures did not deviate much. Possible issues could be restrictions to air flow, loss in refrigerant, dirty filter, or a mechanical failure. During release of the report, it was not identified what caused this loss in performance thus Site 21's data was included in the overall performance values presented. Also noted in the figure below is the loss of data during the months of June and July 2012. While this is not believed to affect the performance, it did lower the overall average annual COP performance because during the hotter summer months the HPWHs COP performance was expected to be higher.

Figure 24 – Daily COP and Ambient Temperature (°F) for Site 21



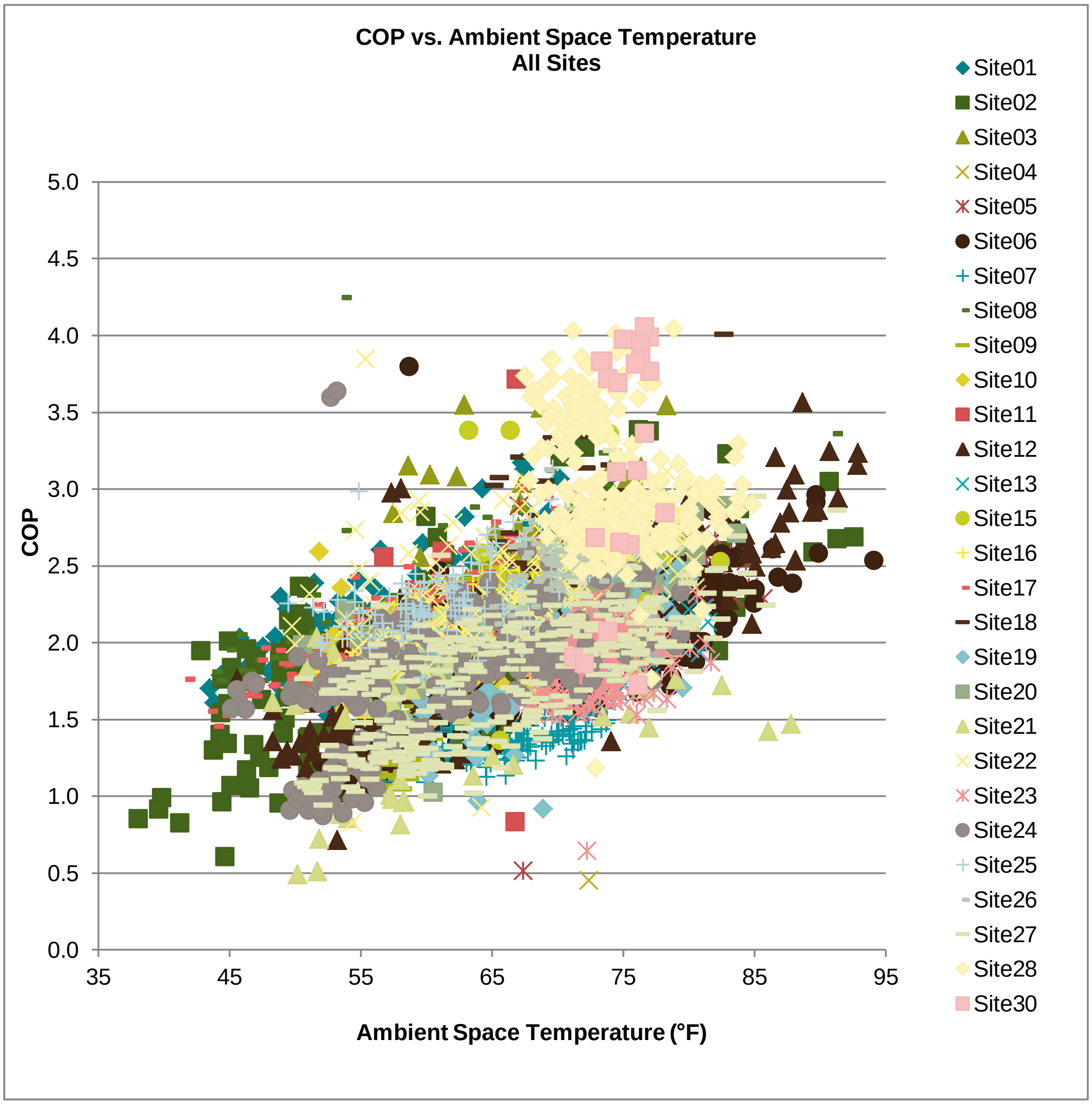
A7 – Scatter Plot of COP vs. Inlet Water Temperature

Table 10 – Scatter Plot of COP vs. Inlet Water Temperature



A8 – Scatter Plot of COP vs. Ambient Temperature

Table 11 – Scatter Plot of COP vs. Ambient Temperature



APPENDIX B – INDOOR ENVIRONMENT AND SPACE TEMPERATURES

B1 – Weighted Average Hourly Ambient Space Temperature grouped by Outside Air Temperature (in 5° F bins)

The average ambient space temperature is grouped by outside air temperature in 5° F bins. This table visually compares the average temperature inside the install location to the outside air temperature. The purpose of this table is to determine what the average temperature difference is between the space where the heat pump water heater is installed and the outdoor temperature. For example, on average the non-ducted basement installations experienced space temperatures of 53° F compared to 58° F for ducted basement installations within the outdoor temperature bin of 30° – 35° F. This implies that ducted basement installations experienced warmer space temperature than the non-ducted basement installations. Green represents lower temperature averages, whereas red represents higher temperature averages.

Table 10 – Weighted Average Hourly Ambient Space Temperature grouped by Outside Air Temperature (in 5° F bins)

Installation Type / Site #	Average Hourly Ambient Space Temperature grouped by Outside Air Temp Bins																		
	Outside Air Temperature 5°F Bins																		Hourly Avg
	< 10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	> 95	
HZ1																			
Basement (Ducted)					**53**	**55**	**56**	**58**	**59**	**62**	**65**	**67**	**67**	**67**	**67**	**66**	**66**	**65**	**62**
Site25					53	55	56	58	59	62	65	67	67	67	67	66	66	65	62
Basement (Non-Ducted)			**54**	**50**	**52**	**53**	**55**	**56**	**58**	**61**	**63**	**64**	**64**	**65**	**66**	**67**	**68**	**67**	**60**
Site07			54	50	53	55	57	59	61	63	65	65	65	66	67	68	69	70	62
Site09				49	53	53	55	56	58	60	61	62	63	63	64	66	67	66	59
Site10				51	51	52	52	54	57	60	64	65	65	65	65	64	66	66	58
Garage (Non-Ducted)			**43**	**46**	**47**	**50**	**52**	**55**	**58**	**63**	**67**	**70**	**70**	**69**	**70**	**70**	**71**	**73**	**62**
Site01					44	46	48	51	55	61	65	68	68	69	72	74	75		59
Site02				40	42	44	47	51	54	60	67	71	69	68	67	67	67	68	59
Site06				58	51	52	54	57	60	65	70	72	72	72	73	73	75	75	65
Site08				41	45	47	52	54	59	64	67	70	70	69	70	71	72	76	62
Site12				48	49	51	53	56	59	66	70	74	71	69	69	68	69	72	63
Site15				50	54	56	58	59	61	65	68	70	70	70	70	70	70	72	64
Site17				41	42	47	49	51	56	61	64	66	66	67	66	67	68	68	58
Site27			43	48	48	51	55	58	61	66	67	67	70	71	72	74	75	79	64
Inside (Ducted)				**64**	**62**	**62**	**64**	**66**	**67**	**69**	**70**	**71**	**71**	**71**	**72**	**73**	**74**	**74**	**68**
Site03					50	52	56	60	61	64	68	71	72	72	73	74	75	78	65
Site04				74	73	73	73	73	74	74	75	75	75	74	74	74	74	75	74
Site05				70	69	68	68	69	70	71	74	75	75	75	76	76	77	77	72
Site11				53	52	52	58	61	64	67	68	68	67	66	67	69	70	72	63
Site14				64	72	74	73	73	73	74	74	73	71	71	71	71	71	70	73
Site16				52	52	52	54	57	60	63	65	66	66	67	67	68	69	72	62
Site18					68	67	67	68	68	70	72	73	72	72	72	73	75	76	70
Site26					66	66	67	68	68	69	70	71	71	72	72	73	74	76	69
HZ2																			
Basement (Ducted)	**57**	**60**	**59**	**61**	**61**	**61**	**63**	**63**	**64**	**67**	**68**	**69**	**70**	**70**	**71**	**72**	**73**	**75**	**66**
Site19	57	60	59	61	61	61	63	63	64	67	68	69	70	70	71	72	73	75	66
Garage (Non-Ducted)	**48**	**48**	**50**	**52**	**54**	**55**	**57**	**59**	**62**	**65**	**67**	**69**	**70**	**71**	**72**	**73**	**75**	**74**	**62**
Site20	45	44	47	51	52	54	56	59	63	67	70	72	72	74	74	75	77	78	63
Site21	37	42	46	50	52	54	56	60	61	64	66	68	71	72	74	75	77	79	60
Site22	77	62	65	62	61	61	61	62	65	67	69	70	70	71	73	74	76	77	66
Site24		50	48	49	50	52	53	56	59	61	63	64	66	67	68	68	68	69	59
Inside (Ducted)	**68**	**68**	**69**	**70**	**70**	**70**	**71**	**72**	**73**	**73**	**74**	**74**	**74**	**74**	**74**	**74**	**75**	**75**	**72**
Site13	72	73	73	73	74	74	75	75	76	76	76	76	75	75	74	74	74	76	75
Site23	69	70	70	70	71	71	72	72	73	73	74	73	73	73	73	73	74	75	72
Site28	70	70	71	71	71	71	72	73	73	74	75	75	75	75	76	77	78	80	73
Site29	61	62	62	62	63	63	64	66	68	70	71	72	73	73	73	73	73	73	68
Site30	70	71	71	72	72	73	73	73	74	74	74	74	74	74	74	74	74	74	73
Grand Total	**65**	**64**	**63**	**62**	**61**	**60**	**60**	**61**	**63**	**66**	**68**	**70**	**70**	**70**	**71**	**72**	**73**	**73**	**65**

B2 – Average Hourly Ambient Space Temperature grouped by Installation Type

The average ambient space temperature is grouped by installation type, heating zone, hour of day and includes number of sites per category. The purpose of the table is to show how ambient space temperature changes throughout the day for each installation type. As expected, inside (ducted) installations had a steady average space temperature throughout the day. Interestingly, the non-ducted basement installations showed to have warmer space temperatures in the early morning. This may imply that basement installations could be benefiting from heat loss from conditioned space above. While these are very interesting results, there are multiple variables in play here. Further study would be necessary to explain overall building envelope and space heating interactions, associated with each installation type. Green represents lower temperature averages, whereas red represents higher temperature averages.

Table 11 – Average Hourly Ambient Space Temperature grouped by Installation Type

Time of Day (hr)	Average Hourly Ambient Space Temperature grouped by Installation Type						
	Basement (Ducted)		Basement (Non-Ducted)	Garage (Non-Ducted)		Inside (Ducted)	
	HZ 1	HZ 2	HZ 1	HZ 1	HZ 2	HZ 1	HZ 2
	1 site	1 site	3 sites	8 sites	4 sites	8 sites	5 sites
0	61	67	60	62	63	69	72
1	61	67	60	62	63	68	72
2	60	66	61	62	62	68	72
3	60	66	61	61	62	68	72
4	60	66	61	61	61	67	71
5	59	66	61	60	61	67	71
6	60	65	60	59	60	67	71
7	60	65	59	58	59	67	71
8	61	64	58	58	59	68	71
9	62	64	57	58	58	68	71
10	62	65	57	58	58	69	71
11	63	65	58	59	59	69	72
12	63	66	59	60	60	69	72
13	63	66	60	62	61	70	72
14	63	67	60	63	62	70	73
15	63	67	61	64	64	70	73
16	64	67	61	65	64	70	73
17	64	69	61	66	65	71	73
18	63	68	61	65	65	70	73
19	63	68	61	65	65	70	73
20	63	67	60	64	65	70	73
21	63	67	60	64	65	70	73
22	62	67	60	63	64	69	73
23	62	67	59	63	64	69	73
Average	**62**	**66**	**60**	**62**	**62**	**69**	**72**

B3 – Space Ambient Temperature Total Bin Hours (in 5° F bins)

Illustrates the number of hours each unit spent within each ambient temperature bin. Sites are categorized by heating zone and installation location of basement, garage, or inside (the house). Ambient space temperatures are separated into 5° outdoor air temperature bins. Green represents lower number of hours, whereas red represents higher number of hours.

Table 12 –Space Ambient Temperature Total Bin Hours (in 5° F bins)

Installation Type / Site #	Average Hourly Ambient Space Temperature grouped by Outside Air Temp Bins															
	Outside Air Temperature 5°F Bins															Total Hours
	< 30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	> 95	
HZ1																
Basement (Ducted)																
Site25				4	200	1301	2124	2346	2294	924	18					9211
Basement (Non-Ducted)																
Site07				70	473	1041	1998	2444	2119	1285	23					9453
Site09					472	1427	2475	2532	1029	1						7936
Site10			105	489	498	1901	1591	1407	1880	219						8090
Garage (Non-Ducted)																
Site01		10	71	463	1188	1763	1177	1484	1288	808	353	95	24	2		8726
Site02		21	282	915	1745	1483	1021	1023	1044	770	481	342	222	94	41	9484
Site06			4	151	797	954	1490	1466	1176	1227	1001	636	256	48	7	9213
Site08		1	68	298	691	1200	1215	1237	1299	990	661	281	90	13	1	8045
Site12		6	107	452	1054	1519	1362	1118	961	882	768	537	384	231	189	9569
Site15			41	144	166	620	2234	1697	1626	1819	672	49	1			9069
Site17		7	114	575	1341	1755	1229	1491	1219	631	171	31				8564
Site27			1	186	690	1249	1470	1375	1304	1343	1002	346	90	5		9061
Inside (Ducted)																
Site03				49	416	730	1001	2370	1998	1829	829	188	34			9444
Site04							21	20	191	6510	2685	29				9456
Site05						1	17	701	2965	3350	2145	385	26			9590
Site11		10	1		71	569	1808	2584	2966	1341	68					9506
Site14						2	38	482	1287	2361	2235	323	40			6768
Site16					176	1129	1831	1860	1896	858	83					7833
Site18							50	659	2607	1924	496	118	11	3		5868
Site26								450	5128	2570	350	1				8499
HZ2																
Basement (Ducted)																
Site19					1	238	1525	2520	2082	1546	1103	74	1	2	1	9093
Garage (Non-Ducted)																
Site20		6	60	364	905	1455	1256	1064	1086	1098	1055	597	114	8		9068
Site21	5	25	194	407	825	1336	1279	977	614	561	482	390	169	39	4	7307
Site22			3	45	346	806	1603	1433	1535	1595	1312	380	32			9090
Site24			44	284	1428	1774	1254	1104	993	823	403	82				8189
Inside (Ducted)																
Site13								3	122	5161	2892	529	66	1		8775
Site23								25	1846	5079	1398	51				8399
Site28								28	1672	4757	1914	405	14			8790
Site29						27	1985	1782	682	2540	1663	84				8763
Site30									1103	5369	2218	73				8763
Grand Total	**5**	**86**	**1095**	**4896**	**13483**	**24280**	**33054**	**37682**	**48012**	**60171**	**28481**	**6026**	**1574**	**446**	**243**	**259622**

B4 – Outdoor Air Temperature Total Bin Hours (in 5° F bins)

The number of hours each unit spent within each outdoor air temperature bin is highlighted. Sites are categorized by heating zone and installation location of basement, garage or inside. Ambient space temperatures are separated into 5° bins. Green represents lower number of hours, whereas red represents higher number of hours.

Table 13 – Outdoor Air Temperature Total Bin Hours (in 5° F bins)

Installation Type / Site #	Average Hourly Ambient Space Temperature grouped by Outside Air Temp Bins																		
	Outside Air Temperature 5°F Bins																		Total Hours
	< 10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	> 95	
HZ1																			
Basement (Ducted)																			
Site25					65	363	773	1386	1452	1166	1084	1056	614	420	296	175	101	260	9211
Basement (Non-Ducted)																			
Site07			1	34	175	524	1005	1415	1386	1241	1071	807	512	402	277	262	177	164	9453
Site09				3	108	313	740	1233	1230	1170	1249	869	483	314	144	57	18	5	7936
Site10				34	184	615	1050	1489	1211	815	751	654	351	193	144	85	71	443	8090
Garage (Non-Ducted)																			
Site01					48	279	798	1494	1498	1168	1237	1151	610	316	88	28	11		8726
Site02				7	119	373	906	1481	1529	1231	990	908	592	439	289	223	171	226	9484
Site06				5	91	308	788	1273	1422	1197	991	893	604	410	356	341	241	293	9213
Site08				9	99	291	644	1177	1190	1083	1088	903	534	345	267	216	117	82	8045
Site12				21	158	431	915	1338	1349	1091	946	817	558	437	318	312	265	613	9569
Site15				29	194	458	941	1260	1318	1134	968	828	499	394	264	199	129	454	9069
Site17				37	179	462	1040	1400	1294	1137	1105	742	441	274	207	104	64	78	8564
Site27			1	34	156	454	894	1230	1203	1156	1154	1010	508	388	274	258	177	164	9061
Inside (Ducted)																			
Site03					30	255	670	1355	1562	1241	1062	1070	738	481	350	294	132	204	9444
Site04				3	65	354	820	1499	1579	1222	1058	1000	611	458	306	262	130	89	9456
Site05				9	89	397	882	1403	1489	1188	1057	1063	677	474	323	248	160	131	9590
Site11				3	128	559	1119	1795	1505	1229	1274	873	483	314	144	57	18	5	9506
Site14				2	39	187	414	867	1014	1061	1090	778	449	305	171	96	57	238	6768
Site16				4	93	322	656	986	1044	1001	1085	910	574	419	343	214	101	81	7833
Site18					76	315	608	1085	1035	722	619	526	275	210	156	128	52	61	5868
Site26					54	418	952	1252	1154	985	1124	1006	665	445	261	108	60	15	8499
HZ2																			
Basement (Ducted)																			
Site19	1	38	108	227	417	720	911	853	947	937	832	727	497	457	387	341	297	397	9094
Garage (Non-Ducted)																			
Site20	29	61	95	326	629	968	1099	1004	955	892	729	596	434	335	297	259	205	155	9068
Site21	30	76	196	379	650	880	844	938	806	667	441	332	244	222	172	160	119	151	7307
Site22	16	55	106	271	637	979	1063	991	944	873	696	612	460	380	368	313	221	105	9090
Site24		3	108	314	542	887	926	969	853	748	636	533	408	329	272	208	142	311	8189
Inside (Ducted)																			
Site13	44	126	232	427	647	914	875	916	763	686	539	432	302	246	190	178	188	1070	8775
Site23	75	121	211	480	839	872	865	709	703	663	608	543	451	379	357	237	154	132	8399
Site28	75	132	234	549	947	946	896	730	724	683	619	544	452	379	357	237	154	132	8790
Site29	71	172	227	358	687	931	921	955	841	728	536	466	372	291	229	190	176	612	8763
Site30	99	97	197	369	743	984	1006	950	808	667	488	416	344	296	227	215	159	698	8763
Grand Total	**440**	**881**	**1716**	**3934**	**8888**	**16759**	**26021**	**35433**	**34808**	**29782**	**27127**	**23065**	**14742**	**10752**	**7834**	**6005**	**4067**	**7369**	**259623**

B5 – Basement (Ducted) Space Temperatures Grouped by Outdoor 5° F Temp Bins and Hour of day

The average hourly ambient space temperature for ducted basement installations is grouped by hour of day and month of year, shows how the average ambient space temperatures change throughout the day and over the course of the year. Green represents lower temperature average, whereas red represents higher temperature average.

Table 14 – Basement (Ducted) Space Temperatures Grouped by Outdoor 5° F Temperature Bins and Hour of the day

Time of Day (hr)	Average Hourly Ambient Space Temperature grouped by Installation Type																							
	Basement (Ducted)																							
	HZ 1												HZ 2											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
0	54	56	56	61	63	65	69	71	68	64	60	55	62	61	60	63	68	71	76	77	74	67	63	63
1	54	55	56	59	62	64	68	70	67	64	59	55	62	61	58	63	67	70	75	77	73	67	62	63
2	53	55	55	59	61	64	68	69	66	64	59	55	62	61	58	63	67	70	76	78	73	67	62	63
3	53	54	55	59	60	63	67	69	66	63	58	55	62	60	58	63	67	70	75	77	73	66	61	63
4	53	54	55	59	59	63	67	68	65	62	58	55	62	60	58	62	67	69	75	77	72	66	62	63
5	53	54	56	59	59	62	67	68	64	62	58	55	62	60	58	62	66	69	74	76	72	66	62	63
6	53	54	57	60	60	63	66	68	64	61	58	54	62	60	58	62	66	69	73	76	72	65	61	63
7	55	55	57	61	61	63	67	68	64	61	59	55	61	60	58	62	65	68	73	75	71	64	60	62
8	56	55	58	61	62	64	68	69	65	62	59	55	61	60	58	61	65	67	73	75	70	64	59	61
9	56	56	58	62	63	66	68	69	66	62	59	56	60	59	57	61	65	68	73	75	70	64	59	59
10	56	58	59	63	64	66	68	69	67	63	61	57	60	59	58	62	66	69	74	75	71	65	59	60
11	56	58	59	63	64	66	69	70	68	63	62	58	60	59	59	63	67	69	75	76	72	65	61	61
12	55	59	60	62	64	66	69	70	68	64	62	58	59	59	60	63	68	70	75	77	72	66	63	61
13	55	58	60	63	64	66	69	70	69	64	62	59	60	60	61	63	68	71	75	76	73	67	63	61
14	55	58	60	63	64	66	70	71	69	65	63	59	60	61	61	63	68	71	75	76	74	67	63	63
15	55	58	60	63	64	66	70	71	69	65	62	58	62	62	62	63	68	70	75	77	74	67	63	64
16	55	58	60	63	65	67	70	71	70	65	62	57	63	62	61	65	68	71	76	78	74	68	63	64
17	55	58	61	63	66	67	70	72	70	65	62	57	63	73	61	65	68	71	76	78	74	68	63	64
18	55	57	61	63	65	67	71	72	70	65	61	56	63	63	61	65	68	72	77	78	74	68	62	64
19	55	57	60	63	65	67	71	72	70	65	61	57	63	63	61	64	69	71	77	78	73	68	62	64
20	55	57	59	63	64	66	71	72	70	65	61	56	62	63	60	64	69	71	77	78	74	67	62	63
21	54	57	58	63	64	66	71	72	69	65	61	57	63	62	60	64	69	71	76	77	74	67	62	63
22	54	56	58	62	64	65	71	71	69	64	60	56	62	61	59	63	69	70	76	77	73	67	62	62
23	54	56	57	62	64	65	70	71	68	64	60	55	62	62	59	64	68	70	76	77	74	67	61	62
Average	**55**	**56**	**58**	**62**	**63**	**65**	**69**	**70**	**68**	**64**	**60**	**56**	**62**	**61**	**59**	**63**	**67**	**70**	**75**	**77**	**73**	**66**	**62**	**62**

B6 – Basement (Non-Ducted) Space Temperatures Grouped by Outdoor 5° F Temp Bins and Hour of day

The average hourly ambient space temperature for non-ducted basement installations, grouped by hour of day and month of year, shows how average ambient space temperatures change throughout the day and over the course of the year. Green represents lower temperature average, whereas red represents higher temperature average.

Table 15 – Basement (Non-Ducted) Space Temperatures Grouped by Outdoor 5° F Temperature Bins & Hour of Day

Time of Day (hr)	Average Hourly Ambient Space Temperature grouped by Installation Type											
	Basement (Non-Ducted)											
	HZ 1											
	1	2	3	4	5	6	7	8	9	10	11	12
0	53	56	54	58	60	63	66	68	66	61	58	54
1	54	56	54	60	62	64	67	69	67	63	59	55
2	54	55	55	61	62	64	67	69	67	63	60	55
3	54	56	55	61	62	64	67	68	67	63	60	56
4	54	56	55	60	61	63	66	68	66	63	60	56
5	54	56	55	60	61	63	66	68	66	63	60	56
6	55	56	55	59	60	62	65	68	65	62	59	56
7	54	56	54	56	57	61	64	66	64	60	59	56
8	54	54	51	55	56	60	63	65	62	59	58	55
9	52	52	49	55	56	60	63	65	62	59	57	54
10	51	51	49	56	58	61	64	66	63	59	56	53
11	51	51	50	57	60	62	65	67	64	61	57	52
12	51	52	52	60	61	63	66	68	65	62	58	53
13	52	53	53	61	62	64	66	68	66	63	58	54
14	53	55	54	61	63	64	66	68	66	63	59	54
15	54	56	55	61	62	64	67	68	67	63	60	55
16	55	57	56	61	62	64	67	68	67	64	60	56
17	55	57	56	61	62	64	67	69	68	64	60	57
18	55	58	56	61	62	63	67	69	67	63	60	57
19	55	57	55	60	61	62	66	69	66	63	60	57
20	55	56	55	60	60	62	65	68	66	62	59	56
21	54	56	55	59	60	62	66	68	66	62	59	56
22	54	56	55	59	60	62	66	68	65	61	58	55
23	54	55	54	58	59	62	66	67	65	61	58	55
Average	**54**	**55**	**54**	**59**	**60**	**63**	**66**	**68**	**66**	**62**	**59**	**55**

B7 – Garage (Non-Ducted) Space Temperatures Grouped by Outdoor 5° F Temp Bins and Hour of day

The average hourly ambient space temperature for non-ducted garage installations grouped by hour of the day and month of year, shows how the average ambient space temperatures change throughout the day and over the course of the year. Green represents lower temperature average, whereas red represents higher temperature average.

Table 16 – Garage (Non-Ducted) Space Temperatures Grouped by Outdoor 5° F Temperature Bins & Hour of Day

Time of Day (hr)	Average Hourly Ambient Space Temperature grouped by Installation Type																							
	Garage (Non-Ducted)																							
	HZ 1												HZ 2											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
0	50	53	54	61	66	69	75	77	72	64	57	53	53	54	55	61	66	69	77	79	73	64	58	55
1	50	53	54	61	65	68	74	76	72	64	57	53	53	54	54	60	65	68	76	78	72	63	58	55
2	50	54	53	61	64	68	73	75	71	63	57	53	52	54	54	59	65	68	75	78	72	63	58	54
3	50	54	53	60	64	67	72	74	70	63	57	53	52	53	54	59	64	68	74	77	71	63	57	54
4	50	53	53	60	63	66	71	73	69	62	57	53	52	52	53	59	64	67	74	76	71	62	57	54
5	49	53	53	59	62	66	70	72	68	62	57	52	52	52	53	59	63	66	73	76	70	62	57	54
6	49	53	52	58	61	65	70	71	67	60	57	52	51	52	53	58	63	66	72	74	69	62	57	53
7	48	52	51	57	60	64	69	71	66	59	55	52	51	52	52	57	62	65	72	72	67	60	56	53
8	47	51	50	56	59	63	68	70	65	59	54	51	50	51	51	56	61	65	71	72	66	59	56	53
9	46	50	50	56	59	64	68	70	66	59	54	50	50	50	51	56	61	65	71	72	66	59	55	52
10	46	50	50	57	60	65	70	72	67	60	53	49	49	49	50	56	61	65	72	73	67	60	55	51
11	46	50	50	58	62	66	71	73	69	62	54	50	49	49	50	57	61	66	73	74	68	60	55	51
12	47	51	52	59	64	67	73	75	70	63	55	50	49	49	52	58	63	66	74	75	69	61	56	51
13	48	53	53	61	66	69	74	77	72	64	56	51	51	50	53	60	65	67	75	77	71	62	57	53
14	49	54	54	63	68	70	76	79	74	65	57	51	52	52	54	61	66	69	76	79	73	64	58	54
15	50	55	55	65	69	71	78	80	76	66	58	52	53	53	55	62	67	70	77	80	74	65	58	54
16	50	56	56	66	70	72	79	82	77	66	58	52	54	54	56	63	68	71	78	81	76	66	59	54
17	50	56	56	66	71	72	80	83	77	66	59	52	55	55	57	63	69	71	79	82	76	66	58	55
18	50	56	56	66	71	73	80	82	77	66	58	52	54	55	57	63	69	71	80	82	77	67	58	55
19	50	55	56	65	70	72	79	82	77	66	58	52	55	55	58	63	69	72	80	82	76	67	58	56
20	50	54	55	64	69	71	79	81	76	65	57	52	55	55	58	63	69	71	79	81	75	66	59	56
21	50	53	55	63	68	70	78	79	75	65	57	52	54	55	57	63	68	71	78	81	75	66	58	56
22	49	53	55	63	67	70	76	78	74	64	57	52	54	55	57	62	68	70	78	80	74	65	58	55
23	50	53	54	62	67	70	75	78	73	64	57	52	53	55	56	62	67	70	77	80	74	64	58	55
Average	**49**	**53**	**53**	**61**	**65**	**68**	**74**	**76**	**72**	**63**	**57**	**52**	**52**	**53**	**54**	**60**	**65**	**68**	**76**	**78**	**72**	**63**	**57**	**54**

B8 – Inside (Ducted) Space Temperatures Grouped by Outdoor 5° F Bins and Hour of day

The average space temperature for inside conditioned space ducted installations grouped by outside air 5° F bins and by hour of the day and month of the year highlights temperature variations throughout the day. As expected, since these sites are inside a conditioned space, the average space temperatures do not vary significantly throughout the day. Green represents lower temperature average, whereas red represents higher temperature average.

Table 17 – Inside (Ducted) Space Temperatures Grouped by Outdoor 5° F Temperature Bins and Hour of the day

Time of Day (hr)	Average Hourly Ambient Space Temperature grouped by Installation Type																							
	Inside (Ducted)																							
	HZ 1												HZ 2											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
0	64	67	66	68	69	70	73	74	72	70	68	66	69	69	69	71	73	73	77	77	75	73	71	70
1	63	67	66	68	68	70	73	73	72	69	67	66	70	69	69	71	73	73	76	77	75	73	71	70
2	63	67	66	68	68	69	72	73	71	69	67	65	69	69	68	70	72	73	76	76	74	73	71	70
3	63	66	65	67	68	69	72	72	71	69	67	65	69	69	68	70	72	73	75	76	74	73	71	70
4	63	66	65	67	67	69	71	72	70	68	66	65	69	69	69	70	72	73	75	75	73	72	71	70
5	62	66	65	67	67	68	71	72	70	68	66	64	69	69	68	70	71	72	74	75	73	72	71	70
6	62	66	65	67	67	68	71	71	70	68	66	64	69	68	68	69	71	72	73	74	73	72	71	70
7	63	66	65	67	67	69	71	71	70	68	66	64	69	68	68	69	71	72	74	74	72	72	71	69
8	63	66	65	67	68	69	71	72	70	69	67	64	69	68	68	69	71	72	74	74	72	72	71	69
9	63	66	66	68	68	70	72	72	71	69	67	65	69	68	68	70	72	72	74	75	73	73	71	69
10	63	67	67	68	69	70	72	73	71	70	68	65	69	68	68	70	72	72	75	75	73	73	71	69
11	63	68	67	69	70	71	73	73	72	70	68	65	69	68	69	70	72	73	76	76	74	73	71	69
12	63	68	68	69	70	71	73	74	73	71	68	65	69	68	69	71	73	73	76	77	75	73	71	69
13	64	68	68	69	71	71	73	74	73	71	68	66	69	69	69	68	73	74	77	77	75	74	71	70
14	64	69	68	69	71	71	74	75	74	71	69	66	69	69	69	71	74	74	77	78	76	74	72	70
15	65	69	68	70	71	72	74	75	74	71	69	66	70	69	70	71	74	74	78	78	76	74	72	70
16	65	69	68	70	71	72	74	75	74	71	69	67	70	69	70	72	75	75	78	79	77	74	72	70
17	66	69	68	70	71	72	75	75	74	71	69	67	70	69	70	72	75	75	79	79	77	74	72	70
18	66	68	68	70	71	72	75	76	75	71	69	66	70	69	70	72	75	75	79	79	77	74	72	70
19	65	68	68	70	71	72	75	76	74	71	68	66	70	69	70	72	75	75	79	79	77	74	72	70
20	65	68	67	69	71	72	74	76	74	71	68	66	70	69	70	71	75	75	78	79	77	74	72	70
21	64	68	67	69	70	71	74	75	74	71	68	66	69	69	69	71	75	75	78	78	76	74	72	70
22	64	68	67	69	70	71	74	75	73	71	68	66	69	69	69	71	74	74	78	78	76	74	72	70
23	64	68	66	68	69	70	73	74	73	70	68	66	69	69	69	71	74	74	77	77	75	73	72	70
Average	**64**	**67**	**67**	**68**	**69**	**70**	**73**	**74**	**72**	**70**	**68**	**66**	**69**	**69**	**69**	**70**	**73**	**73**	**76**	**77**	**75**	**73**	**71**	**70**

APPENDIX C – PARTICIPANT SURVEYS

Two surveys were administered to participants one month and nine months after installation. The goal of the surveys was to gauge customer feedback on performance and their interaction with the HPWH.

Survey One Questions

Dear Survey Participant,

Thank you for participating in field study. As part of this research effort we are asking for your early feedback on your new heat pump water heater. We will administer a short survey one more time in approximately six months to gather your final feedback. Your responses will always remain anonymous and will be used in aggregate to help us determine customer satisfaction and improve on any technical glitches. We appreciate your honesty. Please understand that there are no right or wrong answers.

Section One - HPWH Identification

To get started, please provide us with some basic information about your new Heat Pump Water Heater.

*** 1. What is the storage capacity of your new Heat Pump Water Heater?**

- ◯ 50 gallons
- ◯ 66 gallons
- ◯ Unsure

*** 2. Where was your new Heat Pump Water Heater installed in your home?**

- ◯ Basement
- ◯ Main floor in a dedicated enclosed space
- ◯ Main floor with other equipment (e.g. furnace, laundry room, etc.)
- ◯ Garage

*** 3. For a moment, think about the control functions of your new Heat Pump Water Heater. Please select the best response for each item below. Remember, there are no right or wrong answers, and your honesty is appreciated.**

	I did not know about this function	I am aware of this function, but I am not sure how to use it	I have not used this function before, but I do know how to use it	I have used this function before
Setting economy mode	◯	◯	◯	◯
Setting high-demand mode	◯	◯	◯	◯
Setting vacation mode	◯	◯	◯	◯
Programming desired water temperature	◯	◯	◯	◯

Section Two - HPWH Comparison

For this section, please think about how your new Heat Pump Water Heater compares to your previous hot water heater.

*4. What brand of water heater was installed in your home before installing your new Heat Pump Water Heater?

- ◯ Kenmore
- ◯ Rheem
- ◯ AO Smith
- ◯ GE
- ◯ Unsure
- ◯ Some other brand

*5. How would you say your new Heat Pump Water Heater compares to your old water heater on the criteria below?

	A lot less	A bit less	About the same	A bit more	A lot more
Mechanical noise in living spaces	◯	◯	◯	◯	◯
Vibration in living spaces	◯	◯	◯	◯	◯
Available hot water	◯	◯	◯	◯	◯

*6. Compared to your old water heater, how much energy do you think your new heat pump water heater will use?

◯ A lot less ◯ A bit less ◯ About the same ◯ A bit more ◯ A lot more

Section Three - Ecological Conditions and Changes

*7. To the best of your knowledge, about when was your home built?

- ◯ Before 1970
- ◯ 1970 to 1979
- ◯ 1980 to 1986
- ◯ 1987 to 1992
- ◯ 1993 to 2000
- ◯ After 2000
- ◯ Don't Know

*8. Since installing your new Heat Pump Water Heater, have you installed a new major appliance besides your Heat Pump Water Heater?

◯ Yes ◯ No

If yes, please identify the appliance(s) that you have added or updated in you home.

*9. Since installing your new Heat Pump Water Heater, has there been an increase or decrease in the number of people living in the home?

◯ Yes ◯ No

If yes, please identify the number of people that currently live in the home and the number of people prior to the installation of your new Heat Pump Water Heater.

*10. Since installing your new Heat Pump Water Heater, has there been a significant increase or decrease in time spent at home for any household member?

◯ Yes ◯ No

If yes, briefly describe the change in the overall amount of time spent at home (e.g. retired; started or stopped working from home).

*11. Since installing your new Heat Pump Water Heater, has there been an interior or exterior home renovation?

◯ Yes ◯ No

If yes, please describe the nature of your home renovation and do you expect these renovations will help you use less energy?

*12. Including yourself, how many people between the ages of 13 and 20 currently live in your household?

Section Four - HPWH Installation

For this section, please think about your experiences installing your new Heat Pump Water Heater, including ease of scheduling, and resolution of any major problems.

*13. Please rate your satisfaction with each of the following

	Extremely Dissatisfied				Extremely Satisfied
Amount of information provided about the process before installation (over the phone or in person)	◯	◯	◯	◯	◯
Ease of scheduling an installation appointment	◯	◯	◯	◯	◯
Length of installation	◯	◯	◯	◯	◯
Cleanup of installation	◯	◯	◯	◯	◯
Courtesy of installer	◯	◯	◯	◯	◯
Explanation of equipment operation and controls after installation	◯	◯	◯	◯	◯

14. Have you experienced any of the following major mechanical or functional issues with your new Heat Pump Water Heater? Please select any that apply.

- [ ] Water or moisture on the floor
- [ ] Excessive noise or vibration
- [ ] Complete failure
- [ ] Excessive increase of cold air near unit
- [ ] Some other problem

15. If you have had any of the issues from the previous question, please rate how well the installer helped you resolve these issues using a scale where 1 is extremely dissatisfied and 5 is extremely satisfied.

	Extremely Dissatisfied				Extremely Satisfied
Satisfaction with installer	○	○	○	○	○

Section Five - General Product Evaluation

***16. All things considered, please rate your overall satisfaction with the performance of your new Heat Pump Water Heater.**

	Extremely Dissatisfied				Extremely Satisfied
Overall Satisfaction	○	○	○	○	○

17. Please use the space below for your general impressions of the product, including your overall experience with it, any major problems or benefits that were not addressed above, or anything else you feel we did not cover in this survey.

***18. Thank you for your time and input. Please provide the following information about yourself.**

Name:

Phone Number:

Survey Two Questions

Dear Survey Participant,

Thank you for participating in the field study. As part of this research effort we are asking for your feedback on your heat pump water heater. Your responses will always remain anonymous and will be used in aggregate to help us determine customer satisfaction and improve on any technical glitches. We appreciate your honesty. Please understand that there are no right or wrong answers.

Section One - HPWH Operation

To get started, please provide us with some basic information about your heat pump water heater.

***1. For a moment, think about the control functions of your new heat pump water heater. Please select the best response for each item below. Remember, there are no right or wrong answers, and your honesty is appreciated.**

	I did not know about this function	I am aware of this function, but I am not sure how to use it	I have not used this function before, but I do know how to use it	I have used this function before
Programming desired water temperature	◯	◯	◯	◯
Programming desired operating mode (auto, economy, heater)	◯	◯	◯	◯

***2. Which of the following modes is your heat pump water heater currently set at?**

◯ Econ ◯ Auto ◯ Heater ◯ Don't know

***3. Have you changed the mode of your heat pump water heater in the past 6 months?**

◯ Yes ◯ No

If yes, how many times?

***4. Do you feel that changing the mode affects the amount of energy used?**

◯ Yes ◯ No

***5. What is the current set temperature of your heat pump water heater? Please provide numbers only. The temperature can be viewed on the upper-right corner of the display.**

Section Two - HPWH Comparison

For this section, please think about how your heat pump water heater compares to your previous hot water heater.

***6. Now that you have had your heat pump water heater for 6 months or more, how does it compare to your old water heater on the criteria below?**

	A lot less	A bit less	About the same	A bit more	A lot more
Available hot water	◯	◯	◯	◯	◯
Mechanical noise in living spaces	◯	◯	◯	◯	◯
Vibration in living spaces	◯	◯	◯	◯	◯

***7. Compared to your old water heater, would you say that your electric bill has decreased, remained the same or increased since the heat pump water heater was installed?**

◯ Decreased ◯ Remained the same ◯ Increased

Section Three - Ecological Conditions and Changes

***8. Since you completed the previous survey, have you installed a new major appliance?**

◯ Yes ◯ No

If yes, please identify the appliance(s) that you have added or updated in your home.

***9. Since you completed the previous survey, has there been a change in the number of people living in the home?**

◯ Yes ◯ No

If yes, please indicate the number of people that currently live in the home and the number of people who lived there prior to the installation of your new heat pump water heater.

***10. Since you completed the previous survey, has there been a significant change in the amount of time spent at home for any household member?**

◯ Yes ◯ No

If yes, briefly describe the reason(s) for change in the overall amount of time spent at home (e.g. retired; started or stopped working from home).

***11. Since you completed the previous survey, has there been an interior or exterior home renovation?**

◯ Yes ◯ No

If yes, please describe the nature of your home renovation and whether or not you expect these renovations will help you use less energy.

***12. How many people between the ages of 13 and 20 currently live in your household?**

Section Four - General Product Evaluation

For this section, please think about your experiences with your heat pump water heater.

*13. How would you describe a heat pump water heater to family and friends?

*14. How likely would you be to recommend this technology to friends and family?

	Extremely Unlikely	Highly Unlikely	Likely	Highly Likely	Extremely Likely
Likelihood	◯	◯	◯	◯	◯

*15. Which of the following statements best describes how you feel about your heat pump water heater?

- ◯ My heat pump water heater cuts energy waste and helps me be part of the solution
- ◯ My heat pump water heater helps me save money and conserve resources by cutting wasted energy at home
- ◯ My heat pump water heater helps me reduce wasted energy and makes me think there may be other wasted energy hiding in my home
- ◯ My heat pump water heater maintains the level of comfort I am used to while lowering my water heating bill

16. Since the last survey, have you experienced any of the following mechanical or functional issues with your heat pump water heater? Please select any that apply.

- ☐ Excessive increase of cold air near unit
- ☐ Excessive noise or vibration
- ☐ Water or moisture on the ductwork (if applicable)
- ☐ Heat pump runs for a long time
- ☐ Water or moisture on the floor
- ☐ Slow hot water recovery
- ☐ Some other problem

17. If you had any of the issues from the previous question, did you report the issue(s) to any of the following parties?

- ◯ Contractor
- ◯ Manufacturer
- ◯ Heat Pump Water Heater Field Study

If yes, was the issue addressed to your satisfaction?

***18. All things considered, please rate your overall satisfaction with the performance of your heat pump water heater.**

	Extremely Dissatisfied	Very Dissatisfied	Satisfied	Very Satisfied	Extremely Satisfied
Overall Satisfaction	◯	◯	◯	◯	◯

***19. Please rate the following in order of what you view as the best feature of your heat pump water heater?**

	Least important					Most important
Energy / utility bill savings	◯	◯	◯	◯	◯	◯
Recovery rate (how quickly hot water is available after using)	◯	◯	◯	◯	◯	◯
Different operating modes	◯	◯	◯	◯	◯	◯
Lifetime warranty on the tank	◯	◯	◯	◯	◯	◯
Stainless steel exterior	◯	◯	◯	◯	◯	◯
Available hot water	◯	◯	◯	◯	◯	◯

***20. What do you like least about your heat pump water heater?**

***21. How likely would you be to purchase a heat pump water heater next time you buy a water heater?**

	Extremely Unlikely	Highly Unlikely	Likely	Highly Likely	Extremely Likely
Likelihood	◯	◯	◯	◯	◯

***22. Based on your experience with the heat pump water heater, how much would you be willing to spend for this technology? For reference, the installed cost of a standard high-efficiency electric water heater is $1,200.**

◯ Under $1,000
◯ $1,000-$1,499
◯ $1,500-$1,999
◯ $2,000-$2,499
◯ $2,500-$2,999
◯ $3,000 or more

*23. If you were to purchase a new heat pump water heater, where would you go?

- Chain (Sears)
- Hardware chain (Ace, True Value)
- Home improvement chain (Home Depot, Lowe's)
- Local non-chain
- Buying club (Costco, Sam's Club)
- Plumber
- Plumbing supply (George Morlan, Ferguson's)
- Online store
- Don't know
- Other (please specify)

*24. Thank you for your time and input. Please provide the following information about yourself.

Name:

Phone Number: