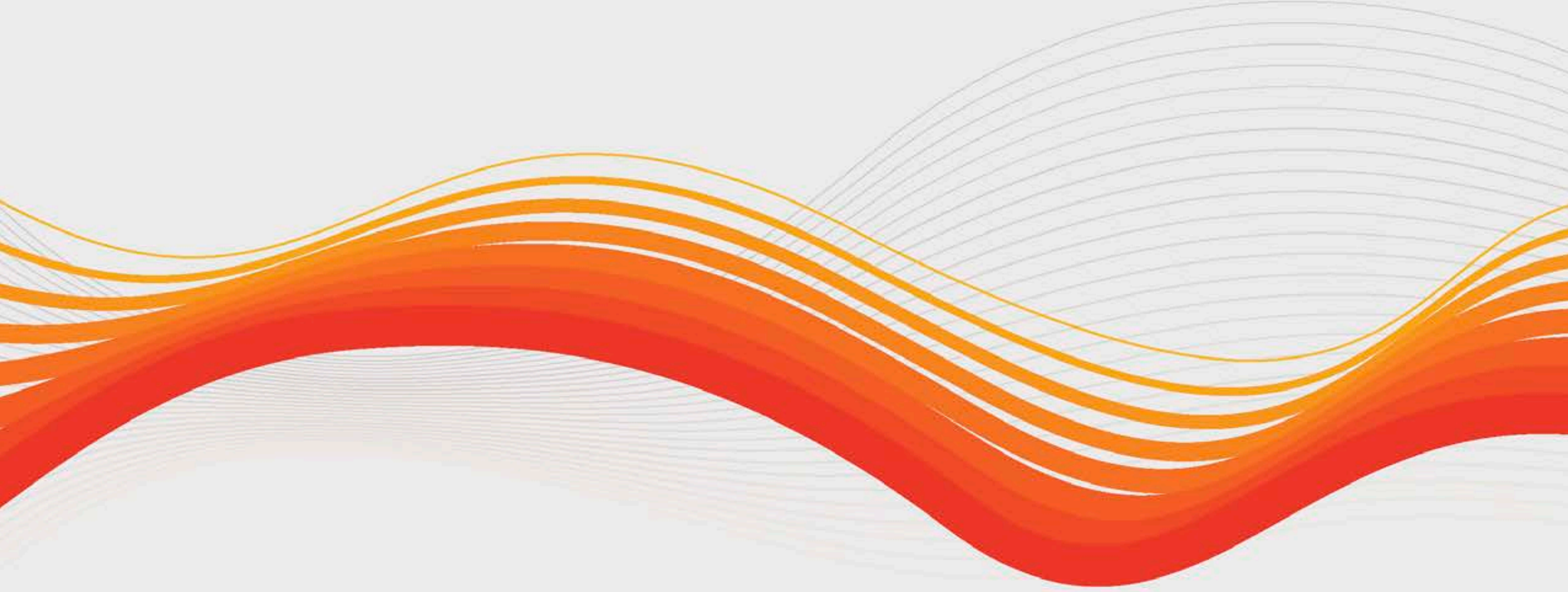
January 6, 2016

Sacramento Municipal Utility District Heat Pump Water Heater Field Testing Report

ADM Associates, Inc.



Powering forward. Together.

SMUD®

Heat Pump Water Heater Field Testing Report

Sacramento Municipal Utility District

January 6, 2016

Prepared by:

ADM Associates, Inc.
3239 Ramos Circle
Sacramento, CA 95827

TABLE OF CONTENTS

About the Customer Advanced Technologies Program

SMUD's Customer Advanced Technologies (C.A.T.) program works with customers to encourage the use and evaluation of new or underutilized technologies. The program provides funding for customers in exchange for monitoring rights. Completed demonstration projects include lighting technologies, light emitting diodes (LEDs), indirect/direct evaporative cooling, non-chemical water treatment systems, daylighting and a variety of other technologies.

For more program information, please visit:
https://www.smud.org/en/business/save-energy/rebates-incentives-financing/customer-advanced-technologies.htm

1. Executive Summary

This project evaluates the performance of 22 heat pump water heaters (HPWH) installed as part of SMUD's Home Performance Program. The program was aimed primarily at customers with existing electric resistance water heaters.

SMUD recruited 22 customers that had recently installed HPWHs. Eighteen of the 22 HPWHs are GE GeoSpring™ models with the remainder filled in with Rheem, Whirlpool and A.O. Smith models. Metering equipment was installed by ADM Associates, Inc. to measure electric energy use of the HPWHs, hot and cold water temperatures, hot water use, and ambient conditions. Data was recorded in one-minute intervals for approximately one year.

In the Sacramento region water heaters are predominantly located in the garage, which is an ideal location for HPWHs in this climate. The summer heat that builds up in garages is captured by the HPWH and used to make hot water. Most of the HPWHs were installed by mechanical contractors, with a few installed by the customer. Four of the systems had hot water circulation pumps.

The Energy Factor (EF) is the efficiency rating provided by testing standards for water heaters and used by government agencies for such things as Energy Star ratings. A value of 1.0 means all of the energy input into the system is output as usable hot water. The higher the EF value the more efficient the water heater. Because HPWHs move heat from one place to another (like air conditioners), their EFs can be greater than 1.0. A regression of the data to testing standard conditions for study units without circulation pumps yields an EF of 2.12. The GeoSpring™ models claim an EF of 2.4. The current federal standards are 0.95 EF for 50 gallon tanks and 1.99 EF for 60 gallon tank electric water heaters (the federal efficiency requirement varies with tank size, but steps up dramatically at 55 gallons).

For comparison to other studies the coefficient of performance (COP) is presented. COP is the efficiency the unit can convert ambient heat into hot water, whereas the EF also includes system losses from the tank over time. Thus, COP values are higher than EF values. The average COP for HPWH without circulation pumps was 2.60.

The average energy use for typical installation of the HPWH was 966 kWh per year. For the same houses the estimated baseline energy use (with an electric resistance water heater) is 2,004 kWh. This is a 1,038 kWh savings per year, or 52 percent as shown in Figure 1.

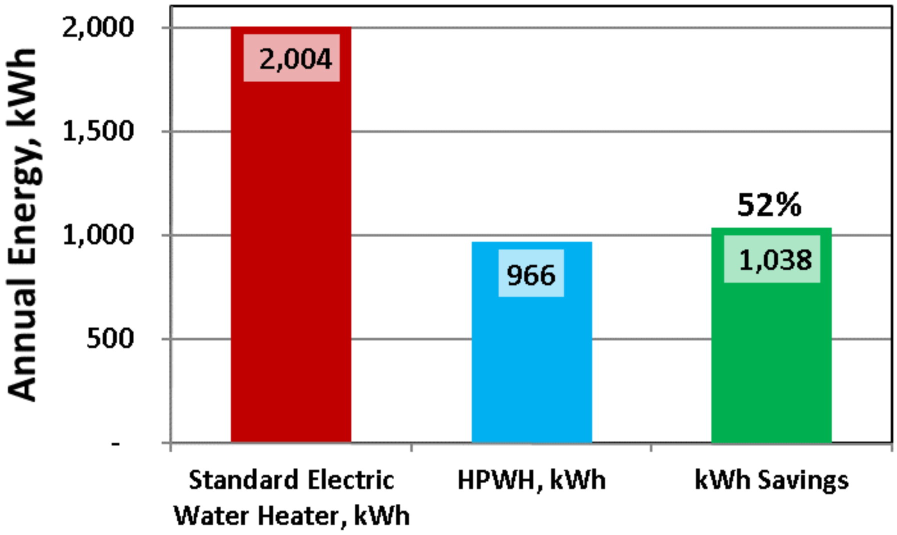


Figure 1: Water Heater Annual Energy Use and Savings

Feedback obtained from the survey effort was very favorable towards the new HPWHs with all respondents being either satisfied or extremely satisfied. The surveyed customers had a high level of awareness of how to operate their HPWH and knew that it could be set to different operating modes. Noise and vibration are not a problem with the HPWHs. A majority of the customers using contractors to install the HPWHs were pleased with the work done.

Each customer received an incentive of $1,000 for installing an HPWH. The average cost of the HPWH was $1,118 and the average installation cost was $1,265. Using an average of $0.1292/kWh the 1,038 kWh in annual energy savings translates to $134 per year. The customer's simple payback is 3.6 years. Sooner payback occurs with reduced installation costs.

2. Project Description

2.1 Background

HPWHs extract heat from the air and transfer it to water in the tank. HPWHs use the same mechanical principle as air conditioning units, but transfer the heat in the opposite direction. They have a compressor, refrigerant loop, condenser, and evaporator. As a backup they also have an electric resistance heater just like a standard electric water heater. The controls are more sophisticated and can alternated between modes of operation depending on the demand for hot water. Figure 2 shows the components of a typical HPWH.[1]

HPWHs were first introduced in the U.S. market in the 1970s. There were a dozen brands by the early 1980s. The early HPWHs had notoriously poor reliability and most were removed from the market. Over the years there have been various attempts to revive the technology. There have been several studies in recent years conducting field testing. Some of these have been in climates where the HPWHs are placed in basements or conditioned space. This study is specific to the Sacramento area climate, and placement of the HPWH is predominantly in unconditioned garages.

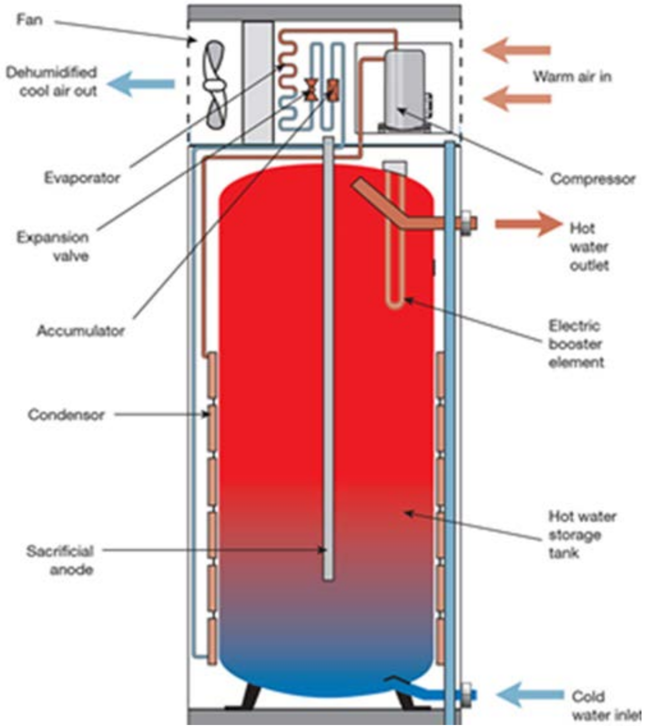


Figure 2: Typical HPWH Schematic[2]

Residential water heaters in the Sacramento region are typically heated using natural gas. However, not all areas of SMUD's territory have gas available and some customers prefer the use of electricity to gas. For those customers the primary option for hot water has been to use an electric resistance water heater. Through this study SMUD is investigating the performance of more efficient HPWHs.

SMUD worked with Portland Energy Conservation, Inc. (PECI) to market and help to deliver 450 HPWHs into SMUD's territory by July 2014. PECI used the plumbing industry to push the HPWHs to SMUD's all-electric customers, aiming to connect with the early adopters and early replacements while trying to influence "time of fail" change

---

[1] Reprinted with permission. © 2015 Home Power Inc., www.homepower.com.

outs as well. During PECI's training it was evident that there would be no "time of fail" change outs included in the program. In late March 2014 SMUD significantly increased the incentives to $1,000 (see Figure 4). This program tactic resulted in program participation of over 70 customers.

Figure 3: Local Billboard Promoting SMUD's HPWH Incentive

2.2 Assessment Objectives

The objective of this project is to evaluate the performance of the HPWHs in SMUD's service area, along with customer satisfaction with the installed devices. Specifically, SMUD's aims were to:

- Calculate the energy savings that could be achieved by future program participants;
- Evaluate the performance of HPWHs relative to values claimed by manufacturers;
- Find out whether customers are satisfied with the performance and other characteristics of the HPWHs;
- Generate suggestions for program improvement;
- Find out how the efficiency of the heat pumps varies as a function of temperature set-point, incoming water temperature, and surrounding ambient dry bulb temperature; and
- Find out whether HPWHs can maintain outgoing hot water temperature at the customer's chosen set-point.

2.3 Methodology

To assess performance and satisfaction, the chosen methodology was to conduct long-term (one year), on-site testing of the HPWHs, together with two online surveys of the homes' occupants—one in the winter and one in the summer.

Long-term testing was chosen because the performance of heat pumps is dependent on inlet water temperature and ambient air temperature, and so is expected to change seasonally. Winter is critical because this will help to collect important information on the utilization of resistive heating elements during the coldest part of the year. Summer is critical because the water heaters may reach their peak efficiency, and also because operational characteristics during the peak usage period are of general interest to a summer-peaking electric utility.

Winter and summer online surveys were included to capture any dissatisfaction with performance that might be apparent only in one season or the other, due to seasonal changes.

The target sample size was 20 units for on-site evaluation. This sample size was not intended to achieve statistical significance for impact evaluation purposes, but was based on available resources. There was no target sample size for the online surveys; the intent was to obtain as many surveys as possible.

Some technical challenges were encountered during the installation of loggers, and some data quality issues became evident after the data was downloaded. These are detailed in the Appendix, Section 7.2.

Screening and Sampling for On-Site Surveys

SMUD’s initial approach was to create a sample of customers for long-term monitoring that had diversity of characteristics, by stratifying the population according to the number of occupants in each home, and according to the installation method (self-install vs. contractor install). Other characteristics could have been chosen (income level, annual energy use), but due to the small sample size only the first two were used, because these were thought to be (respectively) the biggest determinant of energy use, and the biggest determinant of satisfaction.

An alternative approach would have been to stratify the sample to reflect the program population, but this would have created a sample with very few larger households. This would have made it impossible to draw any conclusions about the effect of household size on energy or water use.

Another reason for oversampling from larger households was that the program team believed that if the program increases in volume, program participants would resemble SMUD’s overall population more closely, and would no longer be dominated by smaller households.

SMUD's market research staff conducted screening calls with customers who had received an HPWH incentive, to identify customers willing to participate in a study, and at the same time to gather information for sample stratification.

Incentives

Customers were offered a $200 incentive to participate in the long-term, on-site monitoring study, and $20 to participate in each online customer survey.

The level of incentive chosen was deliberately generous, to try to avoid self-selection bias (i.e,, to avoid oversampling high-income customers).

On-Site Data Collection

The monitoring approach includes manual downloads to retrieve data from the loggers. Six months after the monitoring equipment installation, staff visited all sites and downloaded data from all the loggers. During this visit batteries were replaced in all the loggers to insure continued data collection through the remainder of the study period. Data was collected again at the end after removal of the monitoring equipment.

The following data points were collected, averaged, and logged at one-minute intervals. A diagram showing the location of these measurements is provided in Figure 4.

- Energy (kWh);
- Cold water flow into water heater (gallons);
- Incoming (cold) water temperature;
- Outgoing (hot) water temperature;
- Air dry-bulb temperature entering HPWH fan;
- Air relative humidity entering HPWH fan; and
- Air temperature exiting HPWH fan.

There were several systems that had existing hot water circulation pumps which returned water back to the tank through the drain valve at the bottom of the tank. The water circulated through these loops was not metered.

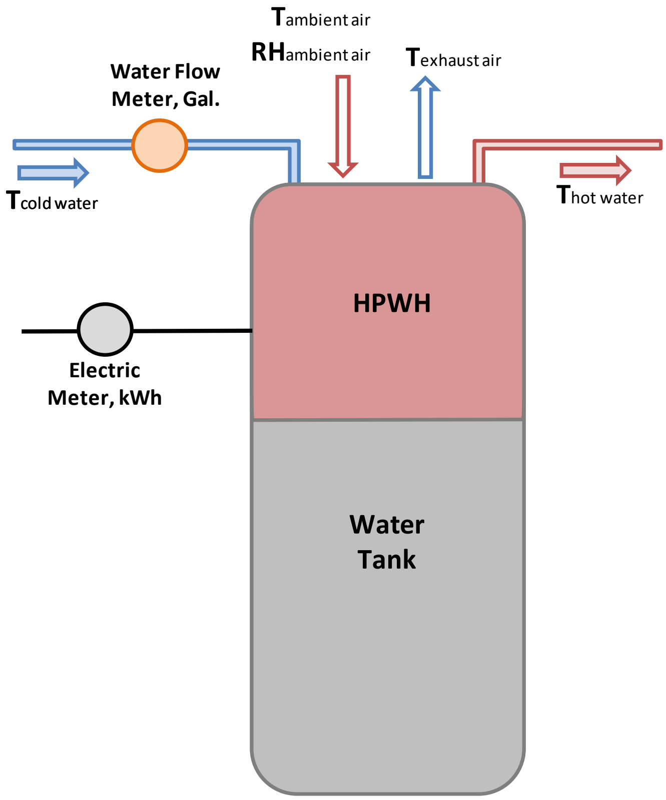


Figure 4: Diagram Showing Metering Points for HPWH

Four battery operated HOBO® loggers were installed to record and store data. Two of them were single-channel pulse loggers—one for the pulse output watthour transducer, and one for the pulse output water flow meter. A four-channel thermocouple logger recorded three of the temperatures: incoming cold water, outgoing hot water, and air temperature exiting the HPWH fan. Finally, a two-channel temperature and relative humidity logger was used to record the air entering the HPWH fan coil, also considered the same as the ambient temperature. Pictures of typical metering are shown in Figure 5. Further details on the monitoring equipment can be found in the Appendix, Section 7.1.

Figure 5: Pictures of Metering Equipment in Place: Loggers (Left), Water Flow Meter (Middle), Power Meter (Right)

Data Validation and Analysis

The data was downloaded from the first 10 sites after a month of data collection to identify any systematic monitoring installation issues. A spreadsheet template was developed to process the data. First, ranges of values for each sensor were compared with expected values. A calculation of daily energy factor was then made and plotted to see that the group of sensors were working together to provide results in the expected range. Trends in the data were also viewed to identify changes in operation, sensor failures, or behavior changes. Issues that could be identified while on site during the data downloads were corrected immediately, while others that were less obvious were revisited to correct the data collection equipment.

Data was downloaded from all the sites after six months and again at the end of the monitoring period, and run through the same data validation procedures. Data was marked as good if it passed all the validation procedure checks. Good data was used for analysis results provided in this report. Inspection of the data led to another data flag labeled as “away.” This allows for analysis to focus on operation of the HPWH when actually in active use.

Energy Use Calculations

Mode of operation and temperature set points are operational characteristics that can be changed by the owner, but in practice only happen occasionally. These parameters, and any changes to them, are not directly recorded but can be inferred from the level of data collected during this study. For example, several of the units were set to heat pump only mode and the electrical load data confirmed the heating elements did not turn on.

The thermal output of hot water from the HPWH was calculated using the temperature differential of the hot water output and the incoming cold water multiplied by the water flow rate and a scaling factor. The equation that follows was applied to every one-minute of data collected.

$$\text{kBTU} = [(T_{hot} – T_{cold}) * \text{gallons} * 8.33 \text{ lbs./gallon}]/1000 \qquad \text{[Eqn. 1]}$$

The energy factor (EF) is a measure of the energy efficiency of a water heater. The higher the EF value the more efficient the water heater. A water heater that has an EF of 1.0 outputs all of the energy into the hot water supplied that is put into the water heater. Since standard electric resistance water heaters have heat losses through the tank walls their EF is less than 1.0. The National Appliance Energy Conservation Act (NAECA) has set the 2015 EF rating for electric resistance heaters at 0.95[2]. For this study the EF was calculated on a daily and weekly basis.

$$\text{EF} = \text{kBTUh} / \text{kWh} / 3.413 \text{ kBTUh/kWh} \qquad \text{[Eqn. 2]}$$

---

[2] EF=0.95 is a simplification of the regulations. Find the rules at: https://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/27

3. Results

The one-minute data was processed in spreadsheets for each site and condensed into hourly data. From there the data was analyzed across all the sites with usable data. Across all the sites there were 6,078 good hours of data. During the data validation and analysis, it was noticed that there were many days when there was no hot water use. These were assumed to be periods when the occupants were away from home. On average they were away from home 6.5% of the days per year, which is over 23 days per year.

3.1 Sample

At the time of sampling, SMUD was able to contact 71 customers who had installed HPWHs. These customers gave information about their household size and installation method of their HPWH. As shown in Table 1, this population is heavily skewed toward one- and two-person households.

Table 1: Population Distribution at the Time of Sampling

		Number of people in household						
		1	2	3	4	5	7	**Total**
Type of installation	Contractor	13	16	3	3	2	1	**38**
	Self	8	14	7	1	2	1	**33**
	Total	21	30	10	4	4	2	**71**
	Percent of total	**72%**		**20%**		**8%**		

As explained in section 2.3, the sample includes a higher representation of 3-4 and 5-7 person households than the program population, to ensure that a wide range of household sizes were studied. The sample design is shown in Table 2. The sample design shows that contractor installs were also oversampled; this is because the research team believed that contractor installs would likely be more prevalent going forward, if the program reaches higher volumes.

Table 2: Intended Sample for Long-term Monitoring

		Number of people in household			
		1-2	3-4	5-7	**Total**
Type of installation	Contractor	6	6	2	**14**
	Self	3	3	2	**8**
	Total	9	9	4	**22**
	Percent of total	**41%**	**41%**	**18%**	

The sample of 23 families metered ranged from 1 to 4 occupants in the home. Table 3 shows the distribution of occupants.

Table 3: Number of Occupants Per Home in Long-term Monitoring Sample

		Number of people in household				
		1	2	3	4	**Total**
Type of installation	Contractor	2	12	1	3	**18**
	Self	0	3	1	1	**5**
	Total	2	15	2	4	**23**
	Percent of total	**9%**	**65%**	**9%**	**17%**	

Although there were 22 HPWH units metered the analysis was conducted for 23 customers since one of the units was in a house that was sold several months after the metering equipment was installed. This house had a hot water circulation pump along with three other houses for a total of four houses with circulation pumps.

Three brands of HPWH participated in this metering study. By far the most common model was the GE GeoSpring™. The number of each type is shown in Table 4. The majority of units were 50 gallon capacity tanks. There were two with larger tanks.

Table 4: Types of HPWH Metered in Study

Quantity	**Manufacturer**	**Model**	**Gallons**
17	General Electric	GeoSpring™, GEH50DEEDSR	50
2	Rheem	EcoSense™, HB50ES	50
1	Rheem	Prestige Series™	50
1	Whirlpool	HPE2K80HD045	80
1	A.O.Smith	Voltex, PHPT 60 102	60

The first HPWH metering was installed on September 24, 2014, and the last one was removed on October 14, 2015. All but one of the houses metered had the same owners for the duration of the study. One house was metered for four months, the house was vacant for five months while being sold, and then occupied by a new owner for three months. Analysis was conducted separately for the two owners to account for different use patterns.

3.2 Energy Metering Results

The HPWH power use across all sites was averaged[3] to develop hourly load shape profiles for weekdays and weekends. The average annual data is charted in Figure 6 and a table of values is presented in Table 24 of the appendix. The average HPWH load peaks between 8:00 AM and 9:00 AM on weekdays at around 0.25 kW. The weekend peak is shifted a couple hours later. On summer[4] weekdays during the SMUD residential peak period of 4:00 PM to 7:00 PM, the average HPWH demand ranges from 0.07 to 0.08 kW, see Appendix chart Figure 31.

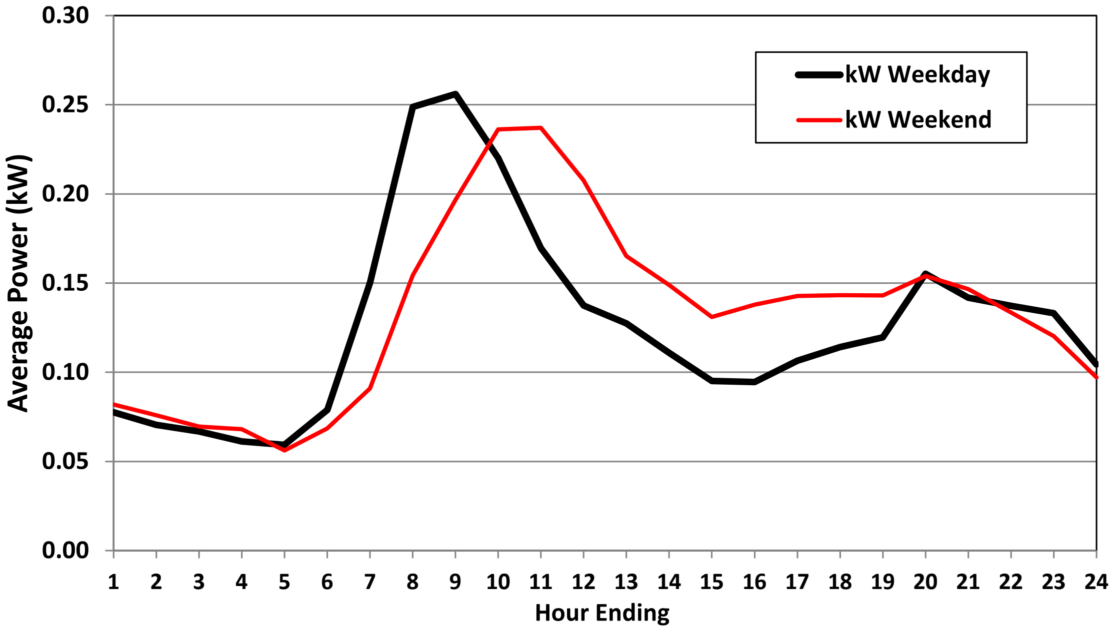


Figure 6: Average HPWH Electric Load Profile for Weekdays and Weekends

Peak period demand savings were estimated by first estimating the load profile of an average standard electric resistance water heater. The average savings during the 4:00 PM to 7:00 PM summer weekday peak period was 0.19 kW per HPWH.

Next, there is a comparison of the power profile of the HPWH to the power profile as defined by the Hourly Adjusted Recovery Load (HARL)[5] in Figure 7. Weekday and weekend profiles are provided in the chart and show the HPWH profile is lower, less peaky, and lags about an hour from the HARL profile. The hot water use profiles for both are very similar and will be shown next.

---

[3] This is a straight average across all 23 monitored households.

[4] Summer defined as June 1 to September 30.

[5] "Residential Water Heating Program – Facilitating the Market Transformation to Higher Efficiency Gas-Fired Water Heating – Appendices," December 2012, Report: CEC-500-2013-060-AP; Prepared for California Energy Commission, Prepared by Gas Technology Institute.

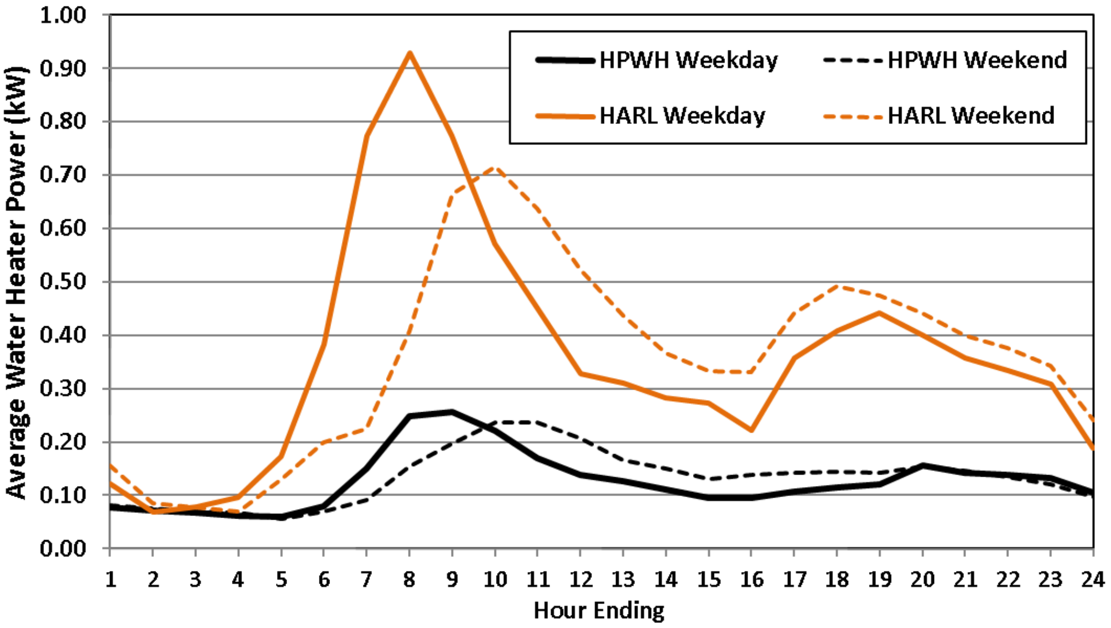


Figure 7: Average HPWH and HARL Power Profiles for Weekdays and Weekends

The household hot water use across all sites was averaged[6] to develop hourly use shape profiles for weekdays and weekends. The average annual household data is charted in Figure 8 and a table of values is presented in Table 24 of the appendix. The average hot water use peaks between 7:00 AM and 8:00 AM on weekdays at 3.6 gallons per hour (GPH). The weekend peak is shifted a couple hours later. The hot water use peaks approximately an hour earlier than the electric load demand. This is because the heat pump takes time to recover the temperature in the tank lost from hot water use. For the HPWHs there is about a one-hour lag in the electric load versus the hot water use. The recovery time is shorter for standard electric resistance water heaters. Figure 11 shows a comparison of the hot water use profile for the HPWHs in the study along with the HARL hot water use profile. The two profiles are very similar to each other.

---

[6] This is a straight average across all 23 monitored households.

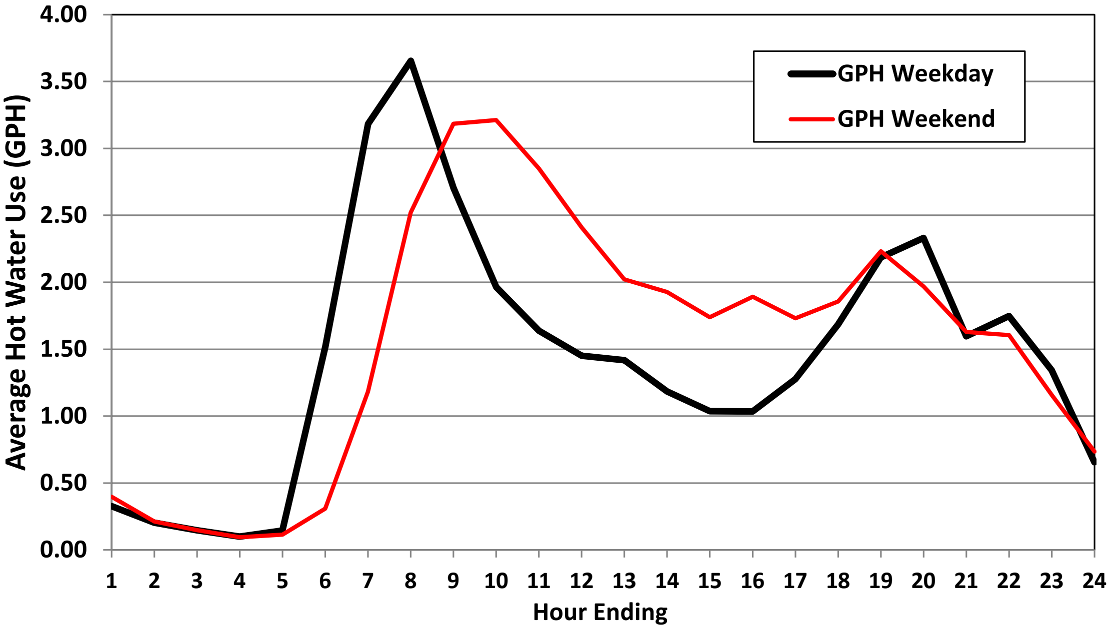


Figure 8: Average Household Hot Water Use Profile for Weekdays and Weekends

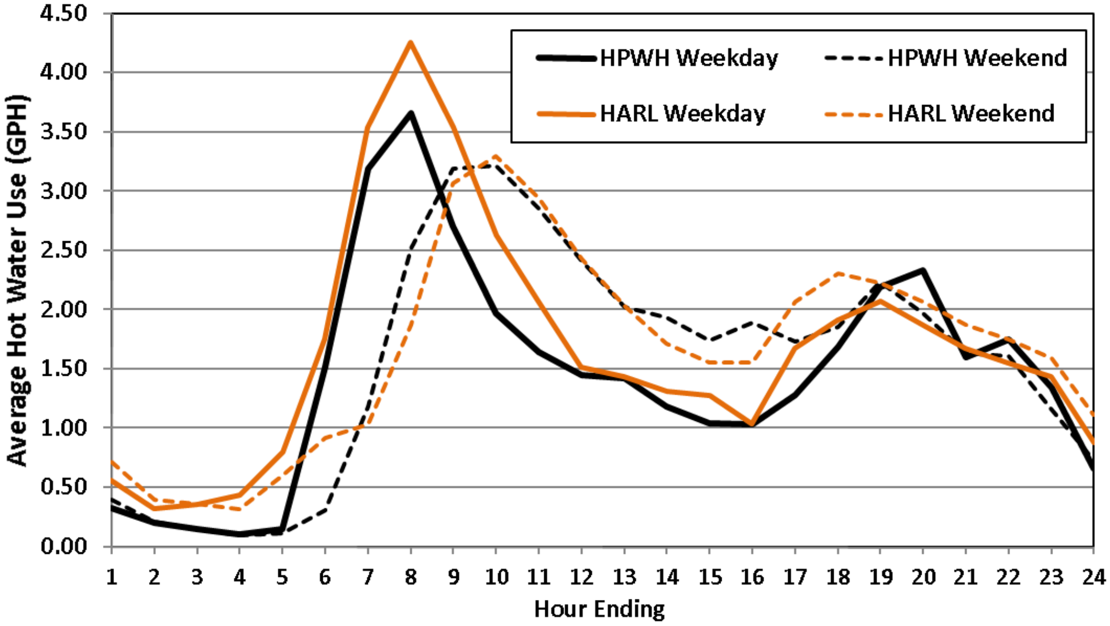


Figure 9: Average HPWH and HARL Household Hot Water Use Profiles

The distribution of daily energy use by the HPWH and daily hot water use by season and day type are presented in Table 5. The average daily hot water use is highest on non-summer weekend days and lowest on summer weekdays.

Table 5: Season and Day Type Average Energy and Hot Water Use

	Average Daily Energy Use, kWh		Average Daily Hot Water Use, Gallons	
	Weekday	**Weekend**	**Weekday**	**Weekend**
Summer Only	2.05	2.09	29.5	30.0
Non-Summer	3.53	3.76	37.0	40.7
Annual Average	3.04	3.21	34.5	37.1

The thermal energy output of the hot water was also averaged across all sites to develop hourly use shape profiles for weekdays and weekends. The data is charted in Figure 10, and a table of values is presented in Table 24 of the appendix. The data presented here is across all seasons per household. The thermal energy profiles are almost identical to the hot water use profiles; the subtle difference between them is due to cold water inlet temperature and hot water outlet temperature varying slightly over the course of a day.

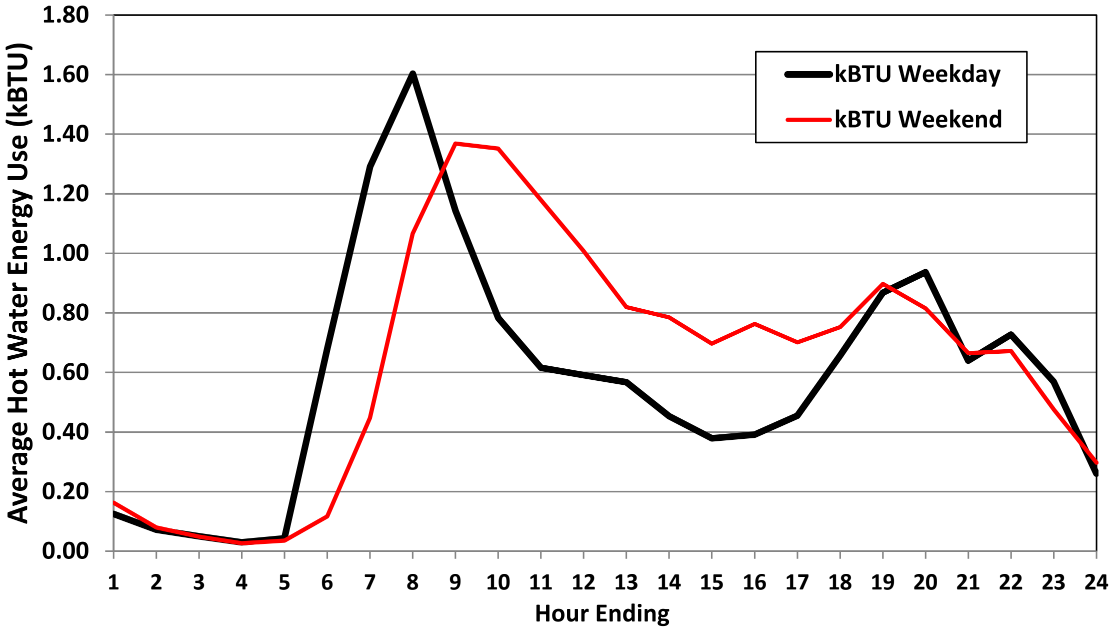


Figure 10: Average Household Hot Water Thermal Output Profile for Weekdays and Weekends

3.3 Temperature Metering Results

The hot water supply and cold water inlet temperatures averaged across all sites for the duration of the metering were 122.1 °F and 67.9 °F, respectively. These temperatures were a measure of the water temperatures only when there was sufficient water flow (defined as 0.4 GPM or greater) for the analysis; below this flow rate, cooling or heating of water as it passed slowly along the pipe would lead to inaccurate temperature readings.

The average temperature for each day for each site with water temperature data available for that day was averaged. The chart in Figure 11 shows the monthly average water temperature during the year. The number of houses with water temperature data available changes from day to day. The hot water temperature does not show any significant seasonal variation. Eighteen of the households did not change the hot water temperature set point as measured by the hot water sensor during the metering study. Four changed the temperature once, and one changed the temperature twice during the metering study. The cold water inlet temperature has a dramatic seasonal swing of over 20 ºF. The winter low occurred in January. The summer high had a longer duration and covered July and August. For comparison, Figure 9 also presents the inlet water temperature based on the HARL equation and a fixed hot water tank temperature of 124 ºF. The measured inlet water temperature averaged 10 degrees warmer than the HARL equation inlet water temperature.

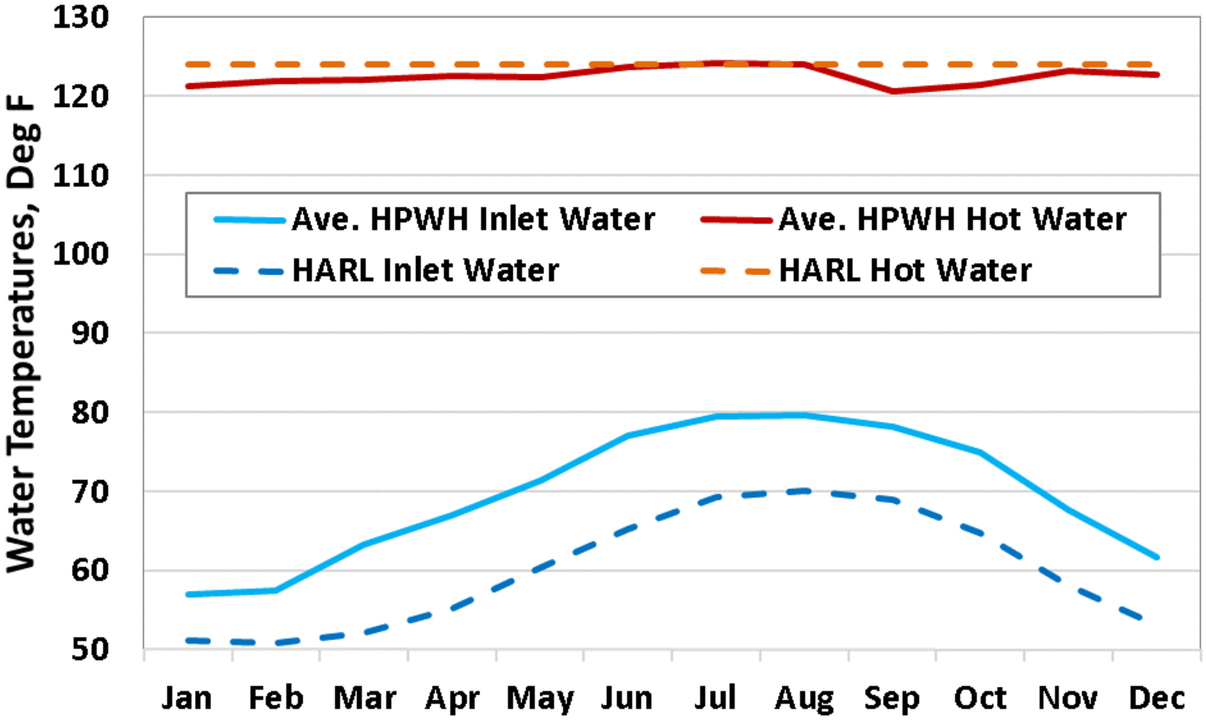


Figure 11: Average Hot Water Output and Cold Water Inlet Temperatures during the Year

The average hot water temperature as measured when there was hot water flowing was calculated. The values for each house are charted in ascending temperature order in Figure 12 to show the range and typical hot water set points. The lowest value shown in the chart is 107.5 ºF, and the actual setting on the HPWH for that house was 110 ºF.

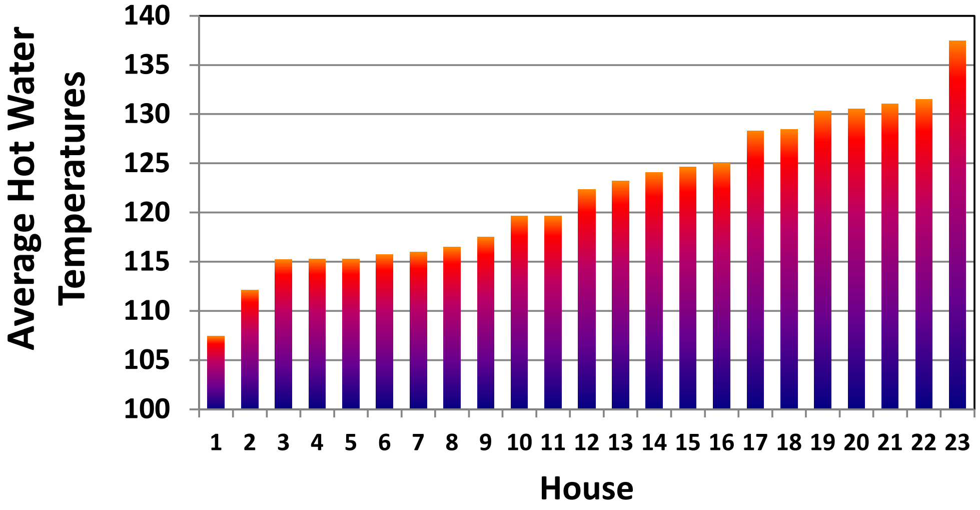


Figure 12: Average Measured Hot Water Outlet Temperatures for each House

The average cold water temperature as measured when there was water flowing was calculated. The values for each house are charted in ascending temperature order in Figure 13 to show the range and typical cold water inlet temperatures. The lowest value in the chart was for a house which only had data during the winter. The highest value in the chart was for a house which only had data during the summer.

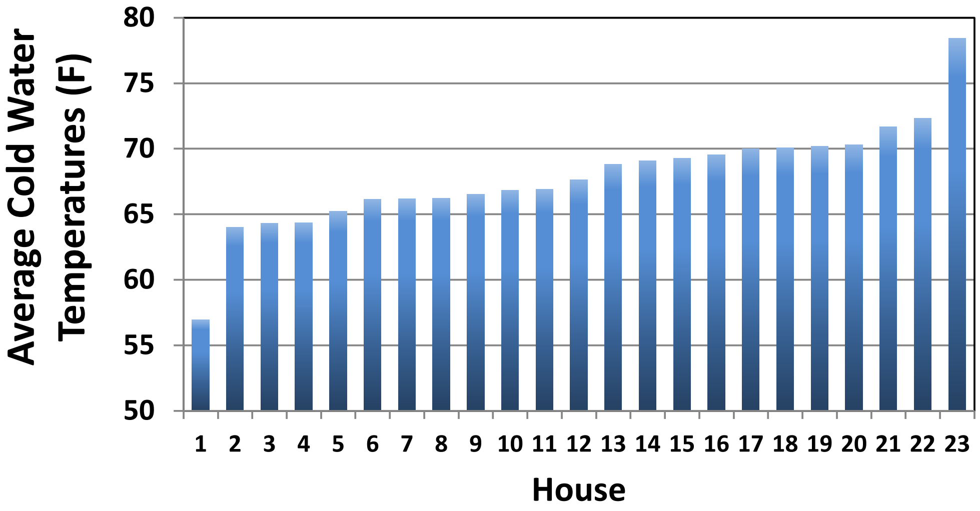


Figure 13: Average Measured Cold Water Inlet Temperatures for each House

In this study all of the HPWHs were located in garage spaces. To quantify the ambient air temperature during operation, air intake temperature for the evaporator fan was averaged only during compressor operation. The daily average from each site was averaged for each day data was available. A 365-day plot of ambient air temperature is shown in Figure 14. The seasonal temperature swing is over 30 °F.

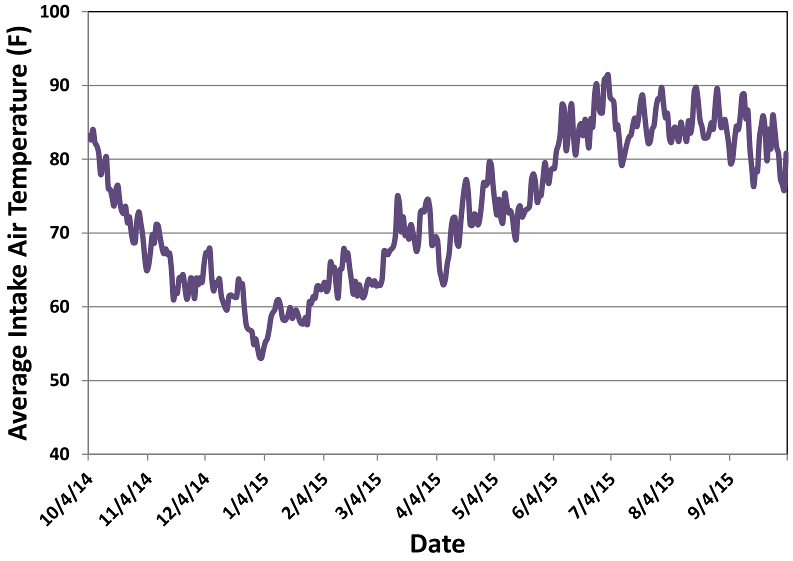


Figure 14: Average Ambient Air Intake Temperature during the Year

Another measure of ambient garage air temperature distribution is presented in Figure 15. This chart plots the average hourly temperatures when the HPWH compressor is not on. It shows a 3D surface representing hours of the day and by month. Using data from temperature sensors an estimate of the cooling the unit provided to the garage was made. By subtracting the average of the month by hour temperature when the HPWH compressor was off from the average of the month by hour temperature when the HPWH compressor was on provided a temperature difference of almost eight degrees. To get a true measure of the cooling to the garage, a baseline measurement of the garage temperature would need to be made when the HPWH was running in electric resistance mode only for an extended period of time.

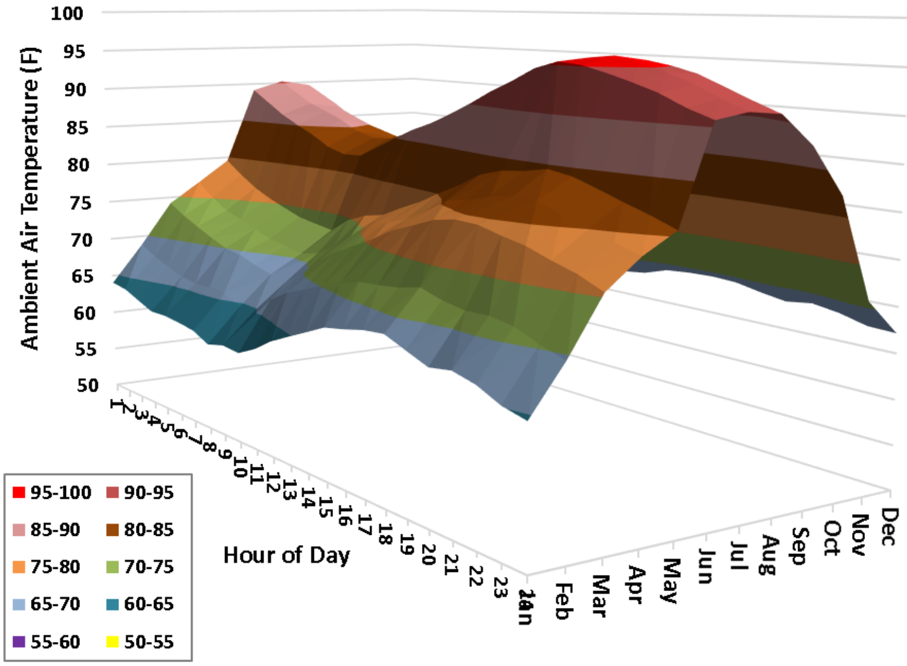


Figure 15: Average Ambient Garage Air Temperature by Month and Hour of the Day

3.4 Energy Factor Results

This study uses three metrics of the efficiency of the HPWH. For clarity, they are defined as follows:

- **Energy Factor**: This is the amount of heating provided by the heat pump system to the water in the house, per unit of electrical power supplied. This metric *does* include storage (tank) losses, so it must be measured over the course of a cycle during which the tank temperature returns to the same value it had at the beginning of the cycle. One day is a convenient cycle length to use in practice.
- **Department of Energy (DOE) Energy Factor**: This is defined in the same way as energy factor (above), but in the context of a specific DOE test that prescribes delivery and supply temperatures, supply volume, and test duration[7]. The supply volume (64 gallons) is much higher than the typical daily hot water use of a household, which leads to DOE EF values being higher than those achieved in practice. The DOE test is also designed so the backup heating element does not turn on.

---

[7] Test conditions include: 64 gallons/day, 135 °F tank temperature, 58 °F inlet water temperature, 67.5 °F ambient air temperature and 50% relative humidity.

- **Coefficient of Performance**: This is the amount of heating provided by the heat pump to the hot water tank, per unit of electrical power supplied. This metric *does not* include any storage (tank) losses, so must be measured only during heat pump operation.

The energy factor was calculated on a 24-hour daily basis. The EF was calculated for each day and a scatter plot of all the days is provided in Figure 16 versus hot water use per day. The four HPWHs with circulation pumps were also excluded from this chart and other further presentations except where explicitly stated.

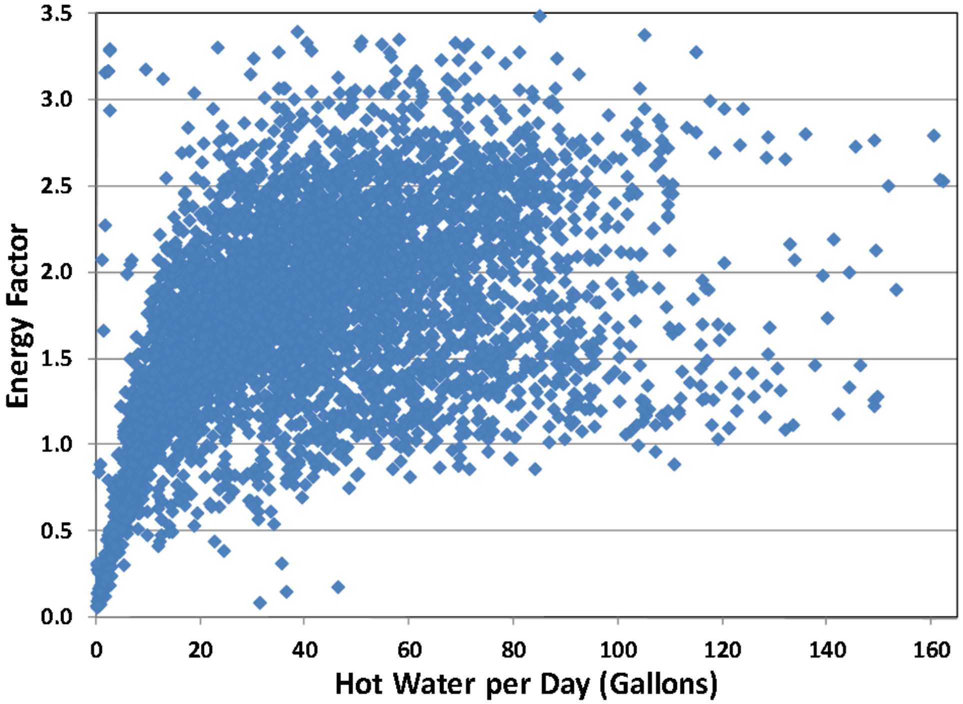


Figure 16: Energy Factor Versus Hot Water Use per Day for Sites without Circulation Pumps

The EF was calculated for various conditions. Descriptions of the various comparisons are provided here along with some of the results and will later be summarized in Table 6. The overall yearly average EF across all HPWH units without hot water circulation pumps was 1.77. This includes days when the resistive heating element was used and days when no one was home. If days when the resistive heating element was used are excluded the EF increased to 1.84. The EF of HPWH units with hot water circulation pumps was significantly lower. This is because the net or usable hot water delivery energy supplied was calculated for the kBTU thermal output. The effective EF for all HPWHs in the study was calculated and is also presented in the table. As expected it is lower than the EF for HPWH system without circulation pumps. Effective weekly EF values were calculated for the same conditions listed above. No significant difference was found between the daily and the weekly calculations of EF; therefore, no weekly values are reported.

A linear multi-variable regression of the data was created to determine the EF meeting the DOE testing standard conditions. The variables included in the regression were thermal output, gallons used, cold and hot water temperatures, and ambient air temperature. These variables were used to regress against the electrical energy used by the HPWH. The regression produced an R squared of 0.90, which is a good fit. Substituting the DOE test conditions into the equation provided an EF of 2.12. This compares to the GeoSpring™ Website EF rating listed as 2.4. This also compares to the NAECA 2015 standard of 0.95 EF for 50 gallon tanks and 1.99 EF for 60 gallon tank electric water heaters.

Some reports use coefficient of performance (COP) for reporting performance of HPWHs[8]. Coefficient of performance is a unit less quantity that historically has been used for air conditioning systems and represents the instantaneous efficiency. Conditions and thermal storage in the tank have allowed manufacturers to provide a COP which does not have a set of standard conditions defined for a HPWH. The linear regression model developed for determining the DOE EF was also used to calculate the average COP. The average COP during the study for HPWH without circulation pumps was 2.60.

Energy Factor and COP result summaries are provided in Table 6.

Table 6: Energy Factors and COP Results

Description of Values	All Days	Days with No Heating Element Use
Energy Factor for HPWHs without Circulation Pump	1.77	1.84
Energy Factor for All HPWH Sites	1.64	1.68
Energy Factor for HPWH Sites with Circulation Pump	0.77	0.77
DOE Energy Factor for HPWHs without Circulation Pump	NA	2.12
COP for HPWHs without Circulation Pump	NA	2.60

Displays showing how EF changes with other conditions are also provided. Averaging of the sites on a month to month basis produced a seasonal EF curve shown in Figure 17. There is the general seasonal trend expected which shows lower values during the winter and higher values in the summer. It would be expected to follow a similar trend to the average ambient air intake shown in Figure 14, and does with the exception of

---

[8] NEEA, October 22, 2013, Report #E13-266, NEEA Heat Pump Water Heater Field Study Report, Prepared by Fluid Market Strategies.

September which shows a higher EF. This may be due to the end of data collection at some sites in early September where the average was the result of fewer remaining units.

Figure 17: Average Energy Factor during the Year

The distribution of EF versus hot water used is presented in Figure 18. The difference between this chart and the chart in Figure 16 is this chart shows daily values when there was more than 30 gallons of hot water used per day and the daily values were averaged over a week to reduce the scatter. There is an upper cluster in this chart from four sites which happen to be the sites with the highest average daily hot water use and their tank temperatures are below average. This chart contains data for all manufacturers represented in this study. No significance can be identified between the brands since there were insufficient quantities for each brand except the GE GeoSpring™. However, similar data charts are presented in the appendix where the brands are separated.

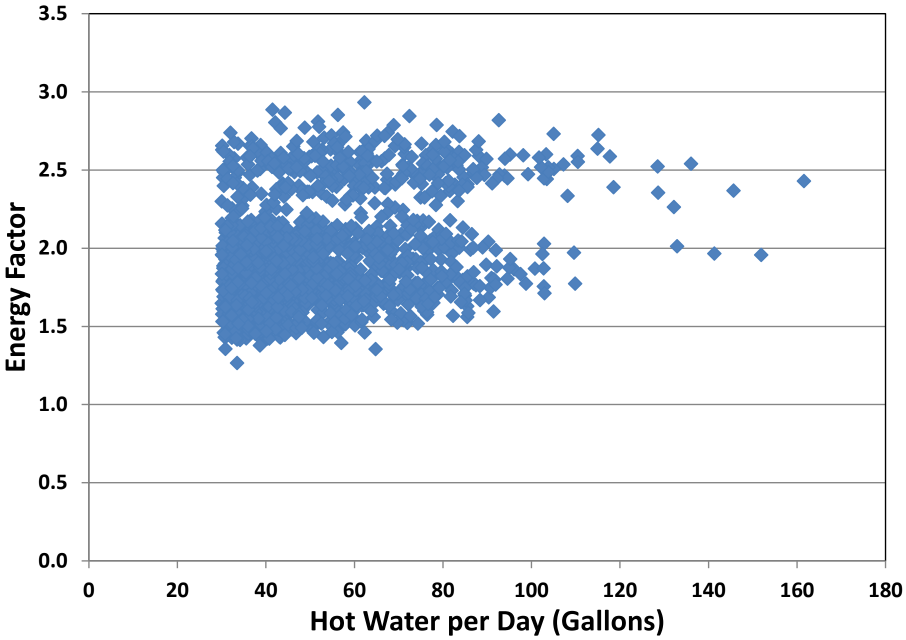


Figure 18: Daily Energy Factor for HPWH Versus Hot Water Use per Day

A similar chart showing the daily EF versus ambient air temperature is shown in Figure 19. An upward slope in the cluster of data points supports the theory that the efficiency of the HPWHs improve at higher ambient air temperatures. Again, the upper cluster of points is from four sites which happen to be the sites with the highest average daily hot water use.

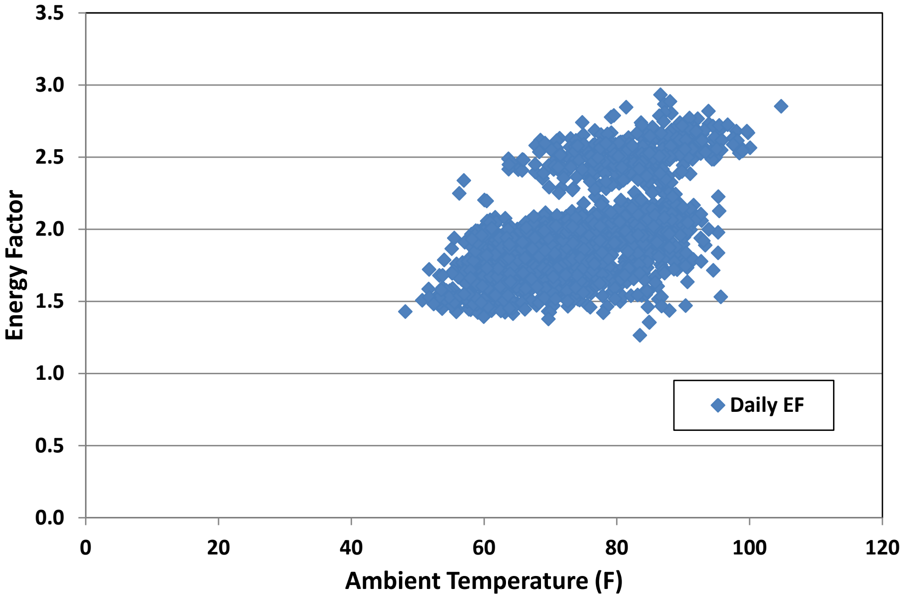


Figure 19: Daily Energy Factor for HPWH Versus Ambient Air Temperature

A general presentation of efficiency is energy use per unit output. The chart in Figure 20 shows the daily electric energy use versus gallons of hot water supplied. The steeper the slope of points the higher the efficiency of the HPWH. No houses with circulation pumps are included in this chart. Although this chart may not be directly relevant to the presentation of results, it provides readers another view of the data collected in this study.

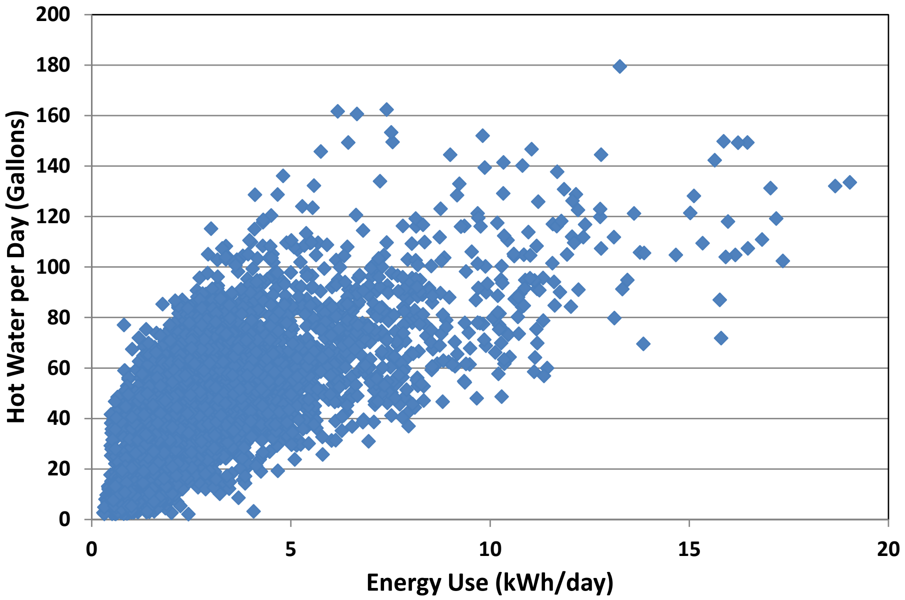


Figure 20: Daily Energy Use for HPWH Versus Hot Water Use per Day

3.5 Energy Saving Results

The average annual energy use of the HPWHs without circulation pumps was 966 kWh per year. To determine savings, we need to estimate the annual energy use that standard electric resistance water heaters would use for these houses. The average annual thermal output from the water heaters was calculated to be 5,640,400 kBTU based on the metered data. The 2015 rating for electric resistance water heaters is an energy factor rating of 0.95. This value is based on lab testing of 64 gallons of hot water use per day. The amount of energy used to heat the delivered hot water is proportional to the amount of hot water used. The energy loss of the tank to the surrounding environment in the garage is similar day to day and is a somewhat constant load. The calculation of EF is the result of both the tank losses and the energy to heat the water used. On days with very little hot water use the EF is lower than on days with high hot water consumption. The 0.95 EF rating for electric resistance heaters was adjusted down based on the field data EF values for the HPWH to represent the diversity of hot water use on days when there was significant water use versus the average EF over all days. The equation used to develop the effective EF for electric resistance water heaters (ERWH) is as follows:

$$EF_{effective\ ERWH} = EF_{rated\ ERWH} \times \frac{EF_{HPWH,\ all\ days}}{EF_{HPWH,\ DOE\ test\ conditions}} \qquad \text{[Eqn. 3]}$$

That ratio is 0.868[9] which was multiplied by 0.95 to give an effective EF of 0.825 for an electric resistance water heater in the study houses. The electric resistance water heaters would have used 2,004 kWh per year. This provides a savings of 1,038 kWh or 52 percent. The energy use and savings is charted in Figure 21.

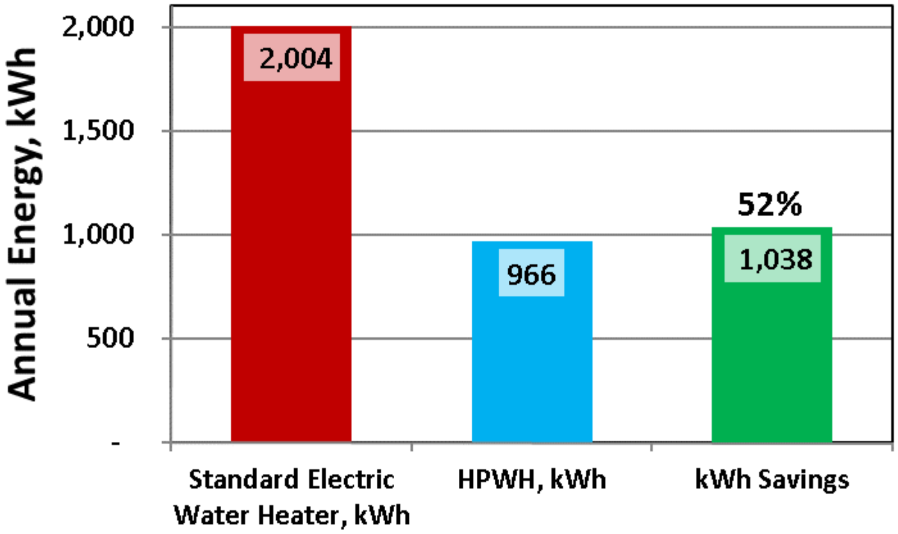


Figure 21: Water Heater Annual Energy Use and Savings

The average annual energy use of the HPWHs with circulation pumps was 1,702 kWh per year. This is significantly higher due to energy loses in the piping by maintaining the hot water in the pipes. A standard electric water heater would have also used significantly more energy. The thermal energy output could not be directly calculated based on the metering configuration. Using the same percentage savings as the other group the houses with circulation pumps would have used 3,530 kWh per year if they had standard electric water heaters. This would have amounted to a savings of 1,828 kWh per year.

3.6 Program Energy Savings

An estimate of the program savings is provided in this subsection. Hot water use and therefore energy savings generally increases with the number of people in the house. The data from the monitored HPWHs is used here to develop an energy savings versus number of occupants regression. The regression was developed for the HPWH without recirculation pumps and Figure 22 shows the distribution of energy savings versus number of occupants.

---

[9] 0.868 = 1.84/2.12 where the EF for the HPWH did not include units with circulation pumps.

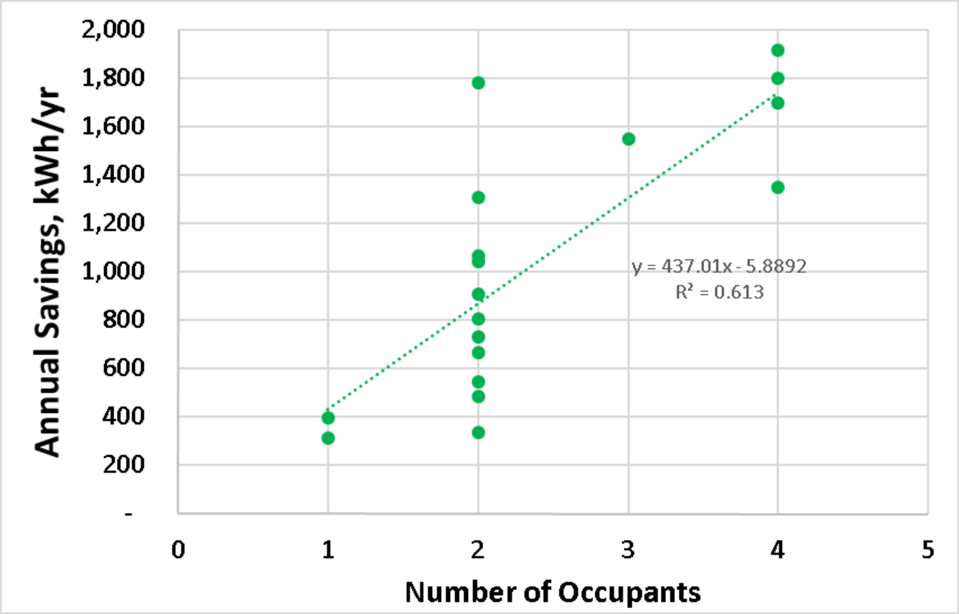


Figure 22: HPWH Annual Energy Savings Versus Number of Occupants

The savings for the program was then allocated by the number of occupants in each house receiving the HPWH as presented previously in Table 1. Table 7 shows the savings by household size and accumulatively for the program. Note that the savings per home for five and seven occupants is based on an extrapolation. The total program estimated savings is 69,940 kWh per year.

Table 7: Estimated Program Savings

	Number of Occupants						
	1	**2**	**3**	**4**	**5**	**7**	**Total**
# of Homes	21	30	10	4	4	2	71
Savings per Home, kWh/yr	431	868	1305	1742	2179	3053	na
Program Savings, kWh/yr	9,054	26,044	13,051	6,969	8,717	6,106	69,940

3.7 Hot Water Delivery Results

There are other characteristics of performance that may have different evaluations applied. One concern for HPWHs is how quickly they can supply heat when there are significant draws of hot water. This is of concern because the recovery time for an HPWH is longer than for electric resistance water heaters; GE quotes the first hour rating at 67 gallons, compared with 80-90 gallons for a 50-gallon gas storage water heater. An attempt to quantify the delivery of warm water rather than hot water is presented here. A warm water draw was defined as a minute of data when there was water flow and the water temperature was more than 10 ºF less than the average hot water temperature for that house. The amount of time was tabulated for each house and ranged from 1 minute to 615 minutes per year and is presented in Figure 23. The data was translated into percentage of time the water was being delivered at less than optimal water temperature and is presented in Figure 24. The percentage ranged from 0.0% to 8.4% of time the water was being delivered as warm rather than hot.

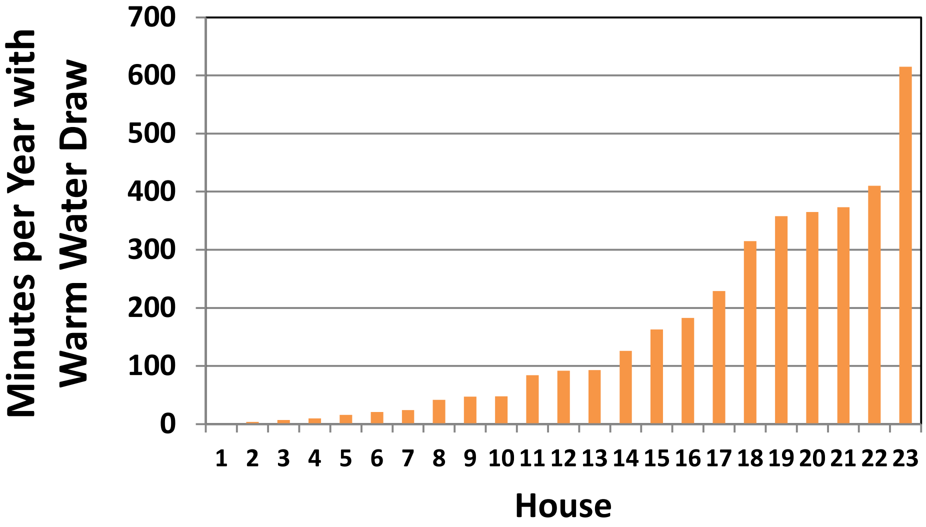


Figure 23: Minutes per Year with Warm Water Draws for each House

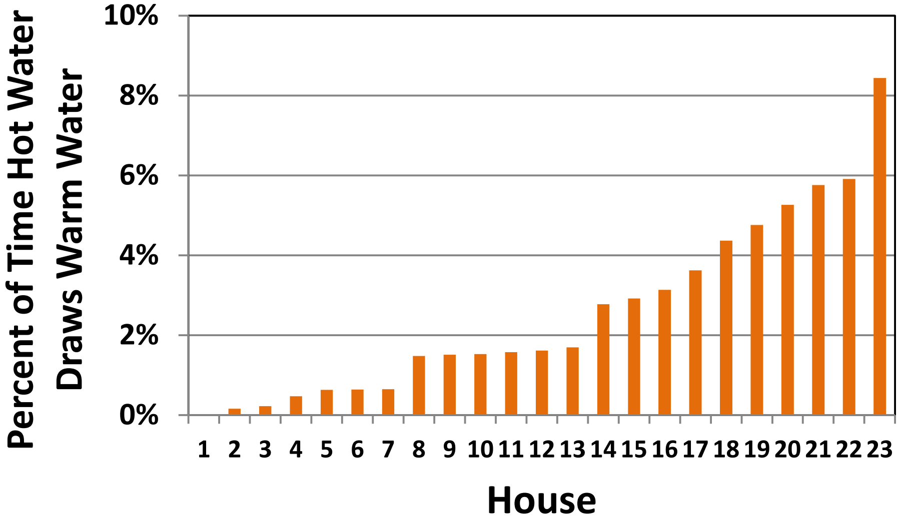


Figure 24: Percent of Time Hot Water Pipe Draws Warm Water for each House

3.8 Use of the Backup Electric Resistance Heating Element

There were five houses that did not use the backup electric resistance element in the HPWH. This was because they operated the unit in the heat pump only mode, thus forcing the electric element not to turn on. Of the 966 kWh used annually by the HPWH on average 198 kWh was used by the electric resistance heater. This amounts to 20.5% of the annual electric energy use operating the less efficient heating source. Mode of operation was not directly recorded during this monitoring study; however, review of the electric load data indicates only one site operated the HPWH in electric heat only mode, and that site only operated the water heater in that mode for the last month of the study.

Peak period demand savings were estimated by first estimating the load profile of an average standard electric resistance water heater. The average savings during the 4:00 PM to 7:00PM weekday peak period was 0.16 kW per HPWH.

3.9 Economics

Installation Cost

Based on the first year of data from SMUD's program, the installation cost for HPWHs averaged $1,265 for 38 contractor installations, but varied very widely. Customers taking part in the program provided SMUD with itemized invoices for the cost of installing the water heater (including labor and parts but excluding the water heater itself). It was evident that invoices broke down into three types:

- "Itemized," where individual part costs are recorded, and time is charged hourly;
- "Parts and Labor" invoices, where individual part costs are recorded but labor is charged as a lump sum agreed in advance; and
- "Total cost," where a lump sum cost is agreed in advance and individual parts and labor are not itemized.

Because "parts and labor" and "total cost" invoices were less numerous, and were similar in total cost, they were analyzed together vs. "itemized" invoices. Figure 25 shows all invoices ordered by increasing cost. It shows that for "itemized" invoices (the majority of contractor installations) the average price was $800, whereas for the other invoice types the average was $1,800. Without understanding more about the work involved or the reasons for choosing these different forms of billing, it's impossible to draw a firm conclusion about the reason for this large difference, but it may be due to some plumbers having limited experience with HPWHs, and therefore charging customers a premium to cover any unknown risks, either during the installation work itself or afterward due to callbacks.

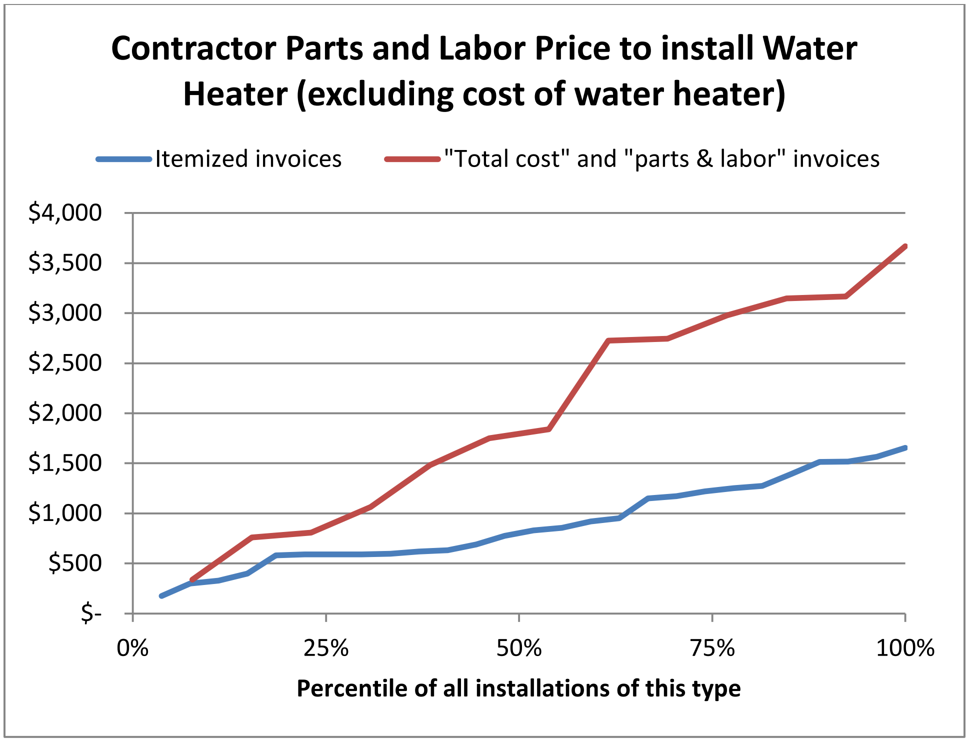


Figure 25: Contractor Parts and Labor Price to install Water Heaters

Incremental Cost

According to the Website homewyse.com, the typical installed cost of a standard electric water heater is $901, with the water heater cost at $491, and labor and ancillary supplies cost at $410.

In SMUD's HPWH program, the average cost of the water heater was $1,118 (of which SMUD paid $1,000 as an incentive), and the average installation cost was $1,265 as detailed above.

In SMUD's program, most of the water heaters were replaced before failure; only 5 were replaced on failure, with 86 being replaced before failure, and 15 unknown. This means that customers were spending money to replace a water heater that potentially may not have needed to be replaced for another few years. This would represent an addition to the incremental cost. In SMUD's program documentation, customers were asked to estimate the age of the water heater being replaced. The average value given was 17.4 years. This is substantially longer than the water heater lifetime assumed by CPUC (12 years), or guaranteed by manufacturers (6 to 12 years depending on water heater quality). It is therefore impossible to estimate what additional life the water heaters may have had, so the incremental cost of early retirement is ignored in the cost-effectiveness calculations.

Lifetime Savings

During the year in which the HPWHs were monitored, SMUD residential customers were almost all on tiered volumetric rates. The average price of a kWh of electricity sold to a residential customer in 2014 was 12.92 cents per kWh[10]. An annual savings of 1,038 kWh is therefore worth $134. Over a 15-year useful life, the total value of energy savings in 2014 dollars at a 6% discount rate is $1,380.

Cost Effectiveness

From the perspective of a program participant, the HPWH program is extremely cost-effective. Averaged across all program participants (38 contractor installations and 33 self-installations) the net present value of program participation is $1,132, with a simple payback period of 10 weeks, and an initial outlay of just $24 compared to the cost of replacing the existing electric resistance water heater. Examples of incremental cost, payback and net present value for various participant classes are shown in Table 8. Note that the net present value is derived from the on-site data collection sample, not weighted for the program population. Therefore, Table 8 represents the likely payback for future participants that are more demographically average than the current program population.

Table 8: Simple Payback and Net Present Value to SMUD HPWH Program Participants

	Incremental cost of water heater	**Incremental cost of labor**	**Total incremental cost**	**Simple payback (years)**	**Net present value ($)**
Self-install	-$373	$0	$-373	0	$1,753
Contractor install at $1,265	-$373	$855	$482	3.60	$898
Contractor install at $800	-$373	$390	$17	0.13	$1,363
Average across program	-$373	$397	$24	0.18	$1,356

3.10 Customer Surveys

To complement the on-site data, SMUD administered two online surveys to customers who had participated in the HPWH program. The online surveys were sent to all program participants, not just to those who were participating in the on-site monitoring.

---

[10] SMUD annual report 2014, page 21.

Because HPWH performance is seasonal, the survey was administered twice. The first survey was sent out at the end of the winter (late February 2015) to capture customers' opinions of winter performance, and a second survey was sent out in early September 2015 to capture summer performance. Both surveys were identical except for a few questions where answers would not change.

Invitations for both surveys were sent out via email (email addresses were obtained from program application forms). Both were administered via the SMUD Power Voice Website. Participants were paid an incentive of $20 for each survey, in addition to any incentive they received for participation in the on-site monitoring.

Functions and Modes

The first question in the survey asked customers about their use of the various "modes" the water heater can be set to. All of the HPWH models in the SMUD program can be set to different modes, but because the names of the modes vary between different manufacturers, the survey used generic names for the modes.

Table 9 shows the results only from the first (winter) survey, to allow a comparison (in Table 24) between the first and second survey to see whether customers had become more familiar with the mode options during the six-month period between the two surveys. The first table shows that almost all users had used the "energy efficient" mode, and had used the ability to set a desired water temperature. Users were familiar with the "high demand" and "vacation" modes, but had not necessarily used them yet.

Table 9: Familiarity with HPWH Mode Settings

	Energy Efficient Mode	**High Demand Mode**	**Vacation Mode**	**Programming Desired Water Temperature**
I have used this function before	29	11	18	31
I have not used, but know how it works	2	20	15	3
I know this function, but unable to use	0	0	0	0
I did not know about this function	3	3	1	0
Total	34	34	34	34

Table 10 shows that there was a slight increase in both the awareness and use of the HPWH modes during the six months between the two surveys. The increase in awareness may be attributable in part to the survey itself.

Table 10: Changes in Familiarity with HPWH Modes over the Six Months between the Two Surveys

	Energy Efficient Mode	High Demand Mode	Vacation Mode	Programming Desired Water Temperature
I have used this function before	0	-1	1	1
I have not used, but know how it works	2	1	0	-1
I know this function, but unable to use	0	1	0	0
I did not know about this function	-2	-1	-1	0

The second question in the survey asked which of the available “modes” the water heater was currently set to. Table 11 shows that the water heaters were split almost evenly between the two most efficient modes (“heat pump” and “hybrid”). Only one water heater was set to the least efficient mode (“high demand”). “Heat pump” is a mode in which the heater is restricted to only use the heat pump, i.e., the electric resistance backup heating element is never switched on. “Hybrid” is a mode in which the electric resistance element comes on under certain circumstances when the water heater is experiencing hot water draw and low tank temperatures. The algorithm for switching on the resistance element is set by the manufacturer and likely differs between models.

The rightmost column of Table 11 also shows that, between winter and summer, a few users changed the mode of the water heater. The rightmost column includes those respondents who gave an answer to this question in both winter and summer, so the total number of respondents for that column is only 25 compared to 34 for the leftmost column. The number of users who changed mode is small, so these results do not show a clear net migration from one mode to another over time.

Table 11: Current Mode Setting of HPWH

	Number of respondents (winter)	Percent of total (winter)	Change from Winter to Summer (n=25)
Heat pump	14	41%	-2
Hybrid	18	53%	1
High demand	1	3%	-1
Electric	0	0%	1
Vacation	0	0%	0
Don't know	1	3%	1
Total	34		

Table 12 shows a categorization of responses to the question “Why did you choose this mode for the water heater?” The table includes responses from both the winter and summer surveys. The response to this question was free text, but the responses have been categorized into types (only one category per response). In some cases, the response could not be categorized unambiguously, so it was assigned the category of "other." Almost half of customers said they had chosen the water heater mode to optimize efficiency, while another 17% said they had chosen a mode to "balance" the water heater between efficiency and the ability to respond to high demand. The fact that so many users gave such a specific response shows a high level of understanding of the function of the water heater. In a few cases (7%), the user had simply left the water heater in whichever mode was set by the installer. One interesting result from this question is that at least five responses (8%) showed a misperception about the efficiency of the water heater—users believed that the electric resistance element was more efficient than the heat pump in the winter, and so they manually changed the mode to reduce the use of the heat pump. In reality, the heat pump is more efficient than the electric resistance element at all the ambient temperatures experienced during the study, although the rate at which it produces hot water reduces in cold weather. However, in "hybrid" mode the water heaters switch automatically to the resistance element when the heat pump can't keep up with demand. So there is no reason to manually change modes seasonally.

For those users who had this misperception, we tested the hypothesis that one of the installation contractors may have been the common source for this information. Of the five users who were clearly identified as having this misperception, two had used the same installer, one had used a different installer, and two had installed the units themselves. So we concluded that this erroneous information may be coming from different sources.

Table 12: Reasons Why Users Chose the Mode for Their Water Heater

	Number of Respondents
Balance	10
Most efficient	25
Lowest cost operation	2
Set by installer	4
Insufficient hot water in heat pump only mode	1
Misperception (seasonality)	5
Other	12
Total	59

Table 13 shows how often users reported changing the mode of their water heater. Most users either had never changed mode, or had changed mode only once (which may have included the first time they set the mode).

Table 13: Frequency of Changing Water Heater Mode

	Number of Respondents
Never	11
Only once	11
Several times	4
Don't know	2
Total	28

Table 14 shows responses to the question "What caused you to change the water heater mode?" The table shows responses to both the winter and summer surveys, so some respondents may have given two separate answers. Consistent with the responses to Table 12, it shows that several users were changing the mode of the water heater based on a misperception that the heat pump was less efficient than the electric resistance element in the winter. The most common reason for changing mode was the presence of visitors. The high number of users who had changed mode due to visitors, in conjunction with the minimal overall change in mode settings shown in Table 11, suggests that many users are motivated to change back to a more efficient setting once their visitors have left.

Table 14: Reason for Changing Water Heater Mode

	Number of Respondents
Misperception (seasonality)	8
Visitors	9
Vacation	2
Higher efficiency	4
Ran out of hot water	1
Other	6
Total	30

Figure 26 shows what customers reported their setpoint temperatures to be. The graph was generated by putting the responses for each season in rank order, and then assigning each response a percentile based on the total number of responses received for that season. It shows that customers chose a wide range of setpoints (from 110 °F to 140 ºF), and that they did not change their setpoints seasonally (winter average was 125.8 ºF (n=33), summer average was 125.5 ºF (n=28)).

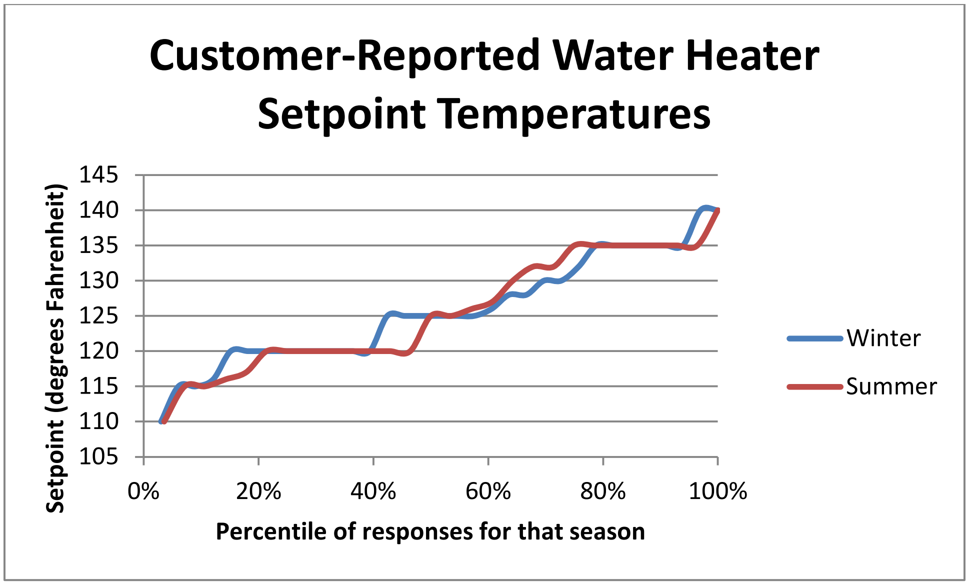


Figure 26: Customer-Reported Water Heater Setpoint Temperatures

Satisfaction with Performance

After being asked several detailed questions about the performance of the water heater, customers were asked “All things considered, please rate your overall satisfaction with the performance of your heat pump water heater.” Responses to this question are shown in Table 15. To capture the widest possible time period, all responses to the second (summer) survey are included, and responses to the first (winter) survey are included if that respondent did not give an answer in the summer survey. The answers show very high levels of overall satisfaction—there were no customers who were not either “extremely satisfied” or “satisfied.” Because the performance of the water heater was not entirely flawless, this may indicate that this particular group of early-adopter customers is predisposed to be supportive of the technology.

Table 15: Overall Satisfaction with the Performance of the Water Heater

	Number of Respondents
Extremely Satisfied	22
Satisfied	15
Neutral	0
Dissatisfied	0
Extremely dissatisfied	0
Don't know	0

Table 16 shows responses to the question "Have you experienced any of the following major mechanical or functional issues with your heat pump water heater?" Respondents were able to give more than one answer, but only one had experienced more than one of these problems. All responses to the second (summer) survey are included, and responses to the first (winter) survey are included if that respondent did not give an answer in the summer survey. The four "other" responses included two reports of alarms going off, one noisy fan that was replaced, and one heat pump that would not run until reset.

Table 16: Mechanical or Functional Failures

	Number of Respondents
Water or moisture on the floor	1
Excessive noise or vibration	2
Complete Failure	0
Excessive increase of cold air near unit	1
Running out of hot water	1
Water heater takes too long to heat water	1
Other	4
No functional problems	28
Total	37

Table 17 shows responses to the question "Which of the following statements best describes your heat pump water heater?" The responses show that most customers never ran out of hot water, but in the winter 26% reported "sometimes" running out of hot water; this percentage dropped to 14% in summer, which would be consistent with the heat pump's heating capacity reducing in the winter due to colder ambient air temperatures and lower incoming water temperatures. It is arguable that the HPWH's algorithm should take account of that effect when deciding whether to engage the resistive heating element. Because the survey was not conducted while customers had their old electric resistance water heaters, we don't know whether they were running out of water less or more frequently than before the HPWH was installed.

Table 17: Availability of Hot Water

	Winter		Summer	
	Number of Responses	**Percentage of Responses**	**Number of Responses**	**Percentage of Responses**
I frequently run out of hot water	0	0%	0	0%
I sometimes run out of hot water	9	26%	4	14%
I never run out of hot water	25	74%	23	82%
I don't know	0	0%	1	4%
Total	34		28	

Table 18 shows responses to the question "Please rate the level of noise and vibration caused by the heat pump water heater, as experienced from the living space of your house (living room, bedrooms, kitchen etc.)." Across both seasons, 71% of customers noticed neither noise nor vibration in the household. Of those who did notice either noise or vibration, none found it annoying. Both noise and vibration were slightly more noticeable in winter, which would be consistent with longer run-times for the heat pump due to both lower ambient air temperature and lower incoming water temperature.

Table 18: Noise and Vibration Levels

	Winter		Summer	
	Noise Level in the Household	**Vibration Level in the Household**	**Noise Level in the Household**	**Vibration Level in the Household**
Annoying	0	0	0	0
Noticeable but not annoying	11	3	7	2
Not noticeable	23	31	21	26
Don't know	0	0	0	0
Total	34		28	

Satisfaction with Installers

Table 19 shows answers to the question "Please rate your satisfaction with each of the following." This question was asked only in the first (Winter) survey; 34 responses were received. The bottom row shows that, across all categories, customers were either "satisfied" or "extremely satisfied" in 91% of cases. In the context of this high level of satisfaction, the areas with the most potential for improvement were the communication between the customer and the installer; installers could provide customers with more information about what to expect prior to the installation, and could provide better explanations of how to operate the water heater.

Table 19: Satisfaction with Installers

	Extremely Satisfied	Satisfied	Neutral	Dissatisfied	Extremely Dissatisfied	Total
Amount of information provided by the installer prior to installation	4	14	3	1	0	22
Ease of scheduling an installation appointment	8	14	1	0	0	23
Length of installation process	6	17	3	0	0	26
Cleanup of installation	12	12	0	0	0	24
Courtesy of installer	14	10	0	0	0	24
Explanation of equipment operation and controls	6	13	5	0	0	24
Total	35%	56%	8%	1%	0%	

Effect on Garage Ambient Air Temperature

The surveys asked about the effect of the HPWH on the ambient air temperature in the garage (all heaters were installed in the customer's garage). The questions did not "prime" the respondents by telling them the HPWHs expel cold, dehumidified air, but nevertheless around half of respondents said that they had noticed a slight cooling effect, as shown in Table 20. The perception of the cooling effect did not vary very much between winter and summer.

Table 20: Perception of Change in Garage Temperature Due to HPWH

	Winter	Summer
A lot warmer	0	0
A little warmer	1	0
Stayed the same	16	13
A little cooler	15	15
A lot cooler	2	0
Total	34	28

If the respondent said that they perceived a change in temperature, the survey then asked whether this change in temperature was perceived as a benefit or a drawback. As shown in Table 21, the temperature change was never perceived as a drawback (even in winter), and was perceived as a benefit more than half the time.

Table 21: Perception of Temperature Change as a Benefit or Drawback

Winter				
	It was a benefit	**It was a drawback**	**Sometimes a benefit and sometimes a drawback**	**It had no effect on me**
A lot warmer				
A little warmer				1
Stayed the same				
A little cooler	8		4	3
A lot cooler	2			

Summer				
	It was a benefit	**It was a drawback**	**Sometimes a benefit and sometimes a drawback**	**It had no effect on me**
A lot warmer				
A little warmer				
Stayed the same				
A little cooler	10		1	4
A lot cooler				

Table 22 shows customers' responses to the question "In which of the following ways do you, or members of your family, use your garage?" Each respondent could give more than one answer. Overall, 48% of the 62 respondents said that they either "sometimes" or "frequently" spend long periods in their garage ("for instance as a workshop or additional living space"). The table shows that the longer people spend in their garage, the more likely they are to consider the cool air produced by the HPWH as a benefit. For instance, of those people who "frequently" spend long periods in their garage, 71% said they consider the cool air a benefit; this is higher than the percentage of all respondents who considered the cool air a benefit (61%). This suggests that program marketing could be targeted at people who make frequent use of their garages.

Table 22: Frequency of Use of Garage vs. Perception of Temperature Change

Frequency of use	Winter	Summer	Total	Percent of these respondents who found the cool air "a benefit"	Percent of all respondents who found the cool air "a benefit"
I almost never enter my garage	0	0	0	N/A	61%
I enter my garage several times a week	23	22	45	59%	
I sometimes spend long periods in my garage	9	10	19	64%	
I frequently spend long periods in my garage	10	2	12	71%	
My pets spend long periods in the garage	1	1	2	50%	
Other	0	0	0	N/A	

Table 23 shows a similar breakdown, but for the type of use to which people put their garages. Among the 62 respondents, almost all used their garage for one or more of the uses shown in the table. Among those who used their garage as a workshop, 68% said that the cool air was a benefit (vs. 61% for all respondents). As for the previous table, this suggests that program marketing could be targeted at people who use their garage as a workshop.

Table 23: Type of Use of Garage, vs. Perception of Temperature Change

Type of use	Winter	Summer	Total	Percent of these respondents who found the cool air "a benefit"	Percent of all respondents who found the cool air "a benefit"
Car	27	23	50	65%	61%
Storage	29	22	51	57%	
Workshop	23	15	38	68%	
Other	7	4	11	60%	

4. Discussion

4.1 Findings from the Customer Surveys

- The customers who were surveyed had a high level of awareness of how to operate their HPWH, i.e., that it could be set to different modes, and that the temperature setpoint could be changed.
- Almost all HPWHs were set to one of the two most efficient modes ("heat pump" or "hybrid") even after many months of use.
- Among this group of early adopters, energy efficiency was the most common reason for choosing which mode to set the HPWH to.
- Most users had changed the "mode" of the water heater only once, or not at all; only four users out of 28 had changed it more than once. The main reasons for changing mode were the change in seasons and the presence of visitors.
- Approximately five respondents had a specific misperception about the heat pump—that it was less efficient than the electric resistance element during the winter. This erroneous information did not seem to originate from a specific installation contractor, so it may come from multiple sources.

User satisfaction with the performance of the HPWHs was very high. All 37 people who gave a response described themselves as "satisfied" or "extremely satisfied."

- Most users never ran out of hot water. 82% of people in the summer, and 74% in the winter said that they never ran out. Of the remainder, all said that they "sometimes" run out of water; none said that they "frequently" run out. Only one person had had to change the mode of their water heater because they were running out of hot water too frequently.
- Most users (71%) did not notice any noise or vibration due to the HPWH. Of the remainder, all said that the noise or vibration was "noticeable but not annoying"; none called it "annoying."
- There were no significant technical or functional problems that caused people to remove or replace their HPWHs.
- Customers were pleased with the work done by the installation contractors; 91% were either "satisfied" or "extremely satisfied." The main area for improvement was the explanation in advance of what work would be done, and the explanation of how the water heater operates.
- Around half of respondents had noticed a slight drop in temperature in their garage due to the water heater. This was overwhelmingly perceived as a benefit, both in the winter and summer surveys. This effect was especially pronounced among people who reported spending long periods in their garage, and among people who used their garage as a workshop.

4.2 Other Information Resulting from this Study

On average occupants were away from home 23 days per year. Labor statistics indicate the typical worker gets approximately 20 days (vacation and holidays) off per year. This statistic does not mean they leave home all of those days. We suggest that the sample families included in this study are away from home more than average.

How could the days away from home influence the results? The average amount of hot water use would be less. This would also translate to a lower average electrical energy use profile for the water heaters. The overall effective EF could be lower since during periods of none use the tank loses heat while maintaining water temperature. One design feature that could be implemented is an auto vacation mode. This could be accomplished by lowering the hot water setpoint if there was no water flow within the previous 24 hours. It could then reset the temperature to the original setting after flow was detected.

A worthwhile follow up to this study would be the evaluation of energy used by hot water circulation systems. They add significantly to the cost of providing hot water. Customers should be informed how inefficient it is to circulate hot water. If they were given the economics of operating them some may choose to turn them off. Customers that are installing HPWH are doing so either for the economics or for the installing more energy efficient equipment. If they knew there was a switch they could turn off and save a large percent of their water heating bill they would try it.

The HPWHs have a control board much like an air conditioning system whereas a standard electric water heater does not. The controller runs continuously and adds almost 1% to the annual energy use per Watt of power they consume.

The GE GeoSpring™ model has a communication port. GE has suggested it can be used to collect and record some operating parameters. Details of the interface to collect the information have not been worked out; however, they suggest the use of a Raspberry Pi and Green Bean could be used for the purpose. Software and programming would be specific to the model. It may allow for collection of information about the modes of operation which were not intrinsically captured during this metering study. The list of data point that could be collected is not known, but it is unlikely that all necessary data could be collected through this system. This would mean additional data would need to be collected by other dedicated loggers.

If the Raspberry Pi and Green Bean option can be successfully deployed on the GeoSpring™ HPWH they may be able to be used to control the units for Demand Response. Keep in mind that the demand savings associated with an HPWH is less than a standard resistance water heater.

5. Conclusion

The average annual energy use of the HPWHs without circulation pumps was 966 kWh per year. The electric resistance water heaters would have used 1,887 kWh per year. This provides a savings of 1,038 kWh per year or 52 percent. For houses with hot water circulation pumps the energy savings increases to 1,828 kWh per year. The measured EF for HPWHs without circulation pumps at standard test condition was 2.12. The COP for HPWHs without circulation pumps at standard test condition was 2.60.

5.1 Recommendations

Incentives for installation of HPWHs are necessary in the SMUD territory to encourage the use of this technology. Continuation at the current incentive level is suggested until a market study that may suggest another incentive level may be accepted.

Regarding electrification, the SMUD Home Performance Program already has the HPWH as a component of the program. More education is recommended for the program implementers to promote the switching from gas water heaters to electric HPWHs.

A marketing champagne is suggested to educate customers on the energy costs associated with hot water circulation pumps. This could be conducted through SMUD's Website to specifically focus on electric water heater customers.

6. References

Heat Pump Water Heater Technology presentation, Dr. Carl C. Hiller, P.E., Applied Energy Technology, Davis, CA.
http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ns/b9_heat_pump.pdf

Home Power Magazine Article Figure. Tom Gocze, Published In: Issue #156, August / September 2013. Website: http://www.homepower.com/articles/solar-water-heating/domestic-hot-water/heat-pump-water-heaters/page/0/1

NEEA Heat Pump Water Heater Field Study Report, Report #E13-266, October 22, 2013 Prepared by: Fluid Market Strategies for Northwest Energy Efficiency Alliance.

NEEA Laboratory Assessment of GE GEH50DFEJSRA Heat Pump Water Heater Report, Report #E15-013, April 09, 2015, Prepared by: Ben Larson and Nicholas Kvaltine, Ecotope, Inc.

Residential Water Heating Program – Facilitating the Market Transformation to Higher Efficiency Gas-Fired Water Heating – Appendices; Prepared for California Energy Commission, Prepared by Gas Technology Institute, December 2012, Report: CEC-500-2013-060-AP,

7. Appendix

7.1 Monitoring Equipment Specifications

Electric Energy: The electric energy of the HPWH will be monitored using a pulse producing WattNode (model: WNB-3D-240-P). The accuracy of the WattNode is ±0.5%. Two 20-Amp current transducers (CTs) (model: Accu ACT-0750-20) were wired to the WattNode. The CTs have an accuracy of ±0.75 % from 1% to 120% of full scale. This combination provides approximately 18 pulses per minute for a typical HPWH in the HP mode, and approximately 150 pulses per minute when the electric resistance heater is on. The pulse output of the WattNode was recorded on a HOBO® State/Pulse Logger (model: UX90-001M). The pulse logger was set to record pulses during one-minute intervals. All of this equipment was placed inside the main electrical breaker panel. This facilitated the electrical monitoring of the HPWH without the need to add boxes for the monitoring equipment or break into the existing electrical connections.

Water Flow: The cold water to the HPWH was monitored with a ¾" inline water flow meter (model: FTB 4607). The accuracy is ±1.5% from 2 to 20 gpm and ±2.0% from 0.22 to 2 gpm. The sensor outputs 75.7 pulses per gallon. It requires a voltage source of 6 to 16 Vdc, which was provided by installing a plug-in transformer to a wall outlet. The pulse output of the flow meter was recorded on an HOBO® State/Pulse Logger (model: UX90-001M). The pulse logger was set to record pulses during one-minute intervals. Hot water flows out of the water heater at the same rate as cold water flows into the water heater with the exception of houses that are installed with a recirculation pump that keeps the water hot in the pipes. These systems feed the returning water back into the tank through the drain valve. To install the flow meter we shut off the incoming old water and opened hot water faucets inside the house to drain the water from the hot water pipes. The flex connection inlet to the water heater was disconnected and any excess water was drained into a bucket. Suitable brass pipe fittings were used to adapt from the connections to the flow meter and to the water heater. After the flow meter was installed the cold inlet water was turned back on and air flushed out of the hot water line pipes in the house.

Hot & Cold Water Temperature: The inlet (cold) and outlet (hot) water temperatures were measured using Type T thermocouples sensors input to a HOBO® (model: UX120-014M) four-channel thermocouple logger. The logger was setup to average temperature readings every 15 seconds into one-minute recording intervals for all the channels on this logger. The Type T thermocouple has an accuracy of ±1.08 ºF and a resolution of 0.03 ºF. The thermocouple sensors are very small junctions of wire which were strapped so they were in direct contact with the metal piping near the inlet and outlet of the water heater. Heat conducting paste was liberally applied to insure good thermal contact between the temperature sensor and the pipe. In addition, insulation was added over the temperature sensor to shield it from the surrounding environment.

HPWH Fan Air Exhaust Temperature: The air output from the HP fan was measured using a Type T thermocouples sensor input to the third channel of a HOBO® (model: UX120-014M) 4-channel thermocouple logger. The logger was setup to average temperature readings every 15 seconds into one-minute recording intervals for all the channels. The Type T thermocouple has an accuracy of ±1.08 ºF and a resolution of 0.03 ºF. The sensor probe was strapped to the air outlet grill of the HPWH.

Ambient Air to HPWH Fan: The air inlet to the HPWH evaporator was measured using a HOBO® (model: Ux100-023) temperature and relative humidity logger. This logger uses a set of sensors mounted on the end of a wire cable. The temperature sensor has a range of -4 ºF to 158 ºF and an accuracy of ±0.38 ºF in the expected range of operation. The response time in air moving at two mph is six minutes. The humidity sensor has a range of 1% to 95% RH and an accuracy of ±2.5% RH in the expected range of operation. The response time in air moving at two mph is five minutes. The sensor probe was strapped to the air inlet grill in a manner to allow the owner to clean the filter as needed.

7.2 Monitoring Challenges

Some challenges arose during the metering of the HPWHs. One was that not all sensors were recorded with one logger so the data needed to be synchronized for the thermal BTU calculation. The HOBO® logger clocks drift up to one minute per month and the loggers collected data for six months before being resynchronized. The data was post processed to correct for the clock drift since each logger had its own drift rate.

The water flowmeters require an external power supply of 6 to 16 Volts dc. Plug-in power supplies rated for 12 Volts dc were initially installed at some houses. After the first few weeks of data collection it was found that the water flow meter data either showed no water use or very erratic use. Troubleshooting identified that the very lightly loaded power supplies were outputting 17+ Volts dc. The power supplies where changed to 9 Volt dc nominal ratings which fixed the problem.

In a few other sites small water flow events were occurring on a continual basis at all hours. The diagnosis was that the bladders attached to the cold water lines were allowing water to “slosh” back and forth in the pipe (and flow meter) as pressure in the line changed. As a solution check valves were installed in those installations to only allow water to flow in the forward direction.

There were several (four) sites that had circulation pumps to provide hot water to the house all the time, or at least when the timer turned on the pump. Initially. these were just considered to be loads on the end use side of the water heater. After the first six months of data was processed it was identified that the electrical energy use and water use were being correctly recorded. However, the thermal outflow was not because the return loop the circulation pump was on did not feed through the water flow meter, but rather entered the tank through the drain valve. The effective EF of the system was calculated, but the EF of just the HPWH could not be calculated. These sites are not included in the EF reporting of this report; however, they are included in the water use and energy profiles.

7.3 Quantity of Good Data

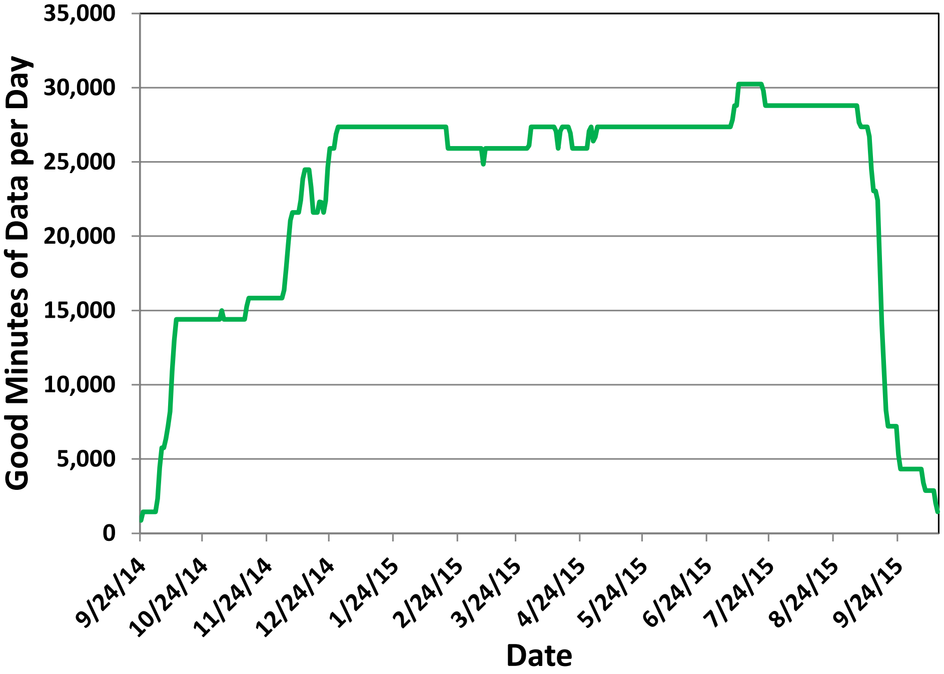


Figure 27 Chart of the Number of Good Minutes of Data from each Day of the Study

7.4 Good Data and Resident Occupancy

The values used to chart Figure 6, Figure 8, and Figure 10 in the report are presented in Table 24. These values represent averages of all the good data across all seasons and include periods when the residents were away from home for extended periods.

Table 24: Hourly Average Electric Load, Hot Water Use, and Thermal Output (kBTU) per HPWH

	kW	kW	GPH	GPH	kBTU	kBTU
Hour	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
1	0.078	0.082	0.327	0.398	0.125	0.162
2	0.070	0.076	0.204	0.212	0.072	0.080
3	0.067	0.070	0.146	0.147	0.050	0.049
4	0.061	0.068	0.099	0.094	0.029	0.026
5	0.059	0.056	0.145	0.114	0.043	0.035
6	0.079	0.069	1.519	0.308	0.681	0.117
7	0.150	0.091	3.184	1.182	1.292	0.448
8	0.249	0.154	3.655	2.520	1.603	1.066
9	0.256	0.197	2.704	3.185	1.143	1.369
10	0.220	0.236	1.964	3.213	0.783	1.352
11	0.169	0.237	1.638	2.850	0.616	1.180
12	0.137	0.208	1.450	2.411	0.591	1.008
13	0.127	0.165	1.417	2.021	0.567	0.820
14	0.111	0.149	1.183	1.928	0.453	0.785
15	0.095	0.131	1.035	1.739	0.379	0.697
16	0.094	0.138	1.034	1.892	0.391	0.763
17	0.106	0.143	1.275	1.731	0.455	0.701
18	0.114	0.143	1.684	1.856	0.656	0.752
19	0.120	0.143	2.186	2.231	0.868	0.897
20	0.155	0.154	2.331	1.969	0.937	0.815
21	0.142	0.147	1.596	1.628	0.639	0.665
22	0.137	0.133	1.747	1.604	0.727	0.672
23	0.133	0.120	1.342	1.158	0.569	0.475
24	0.104	0.097	0.656	0.734	0.261	0.297

The data was processed in a similar manner to show the use patterns when the residents were at home. Charts in Figure 28 to Figure 30 and the values presented in Table 25 represent averages of all the good data across all seasons only when the residents were at home.

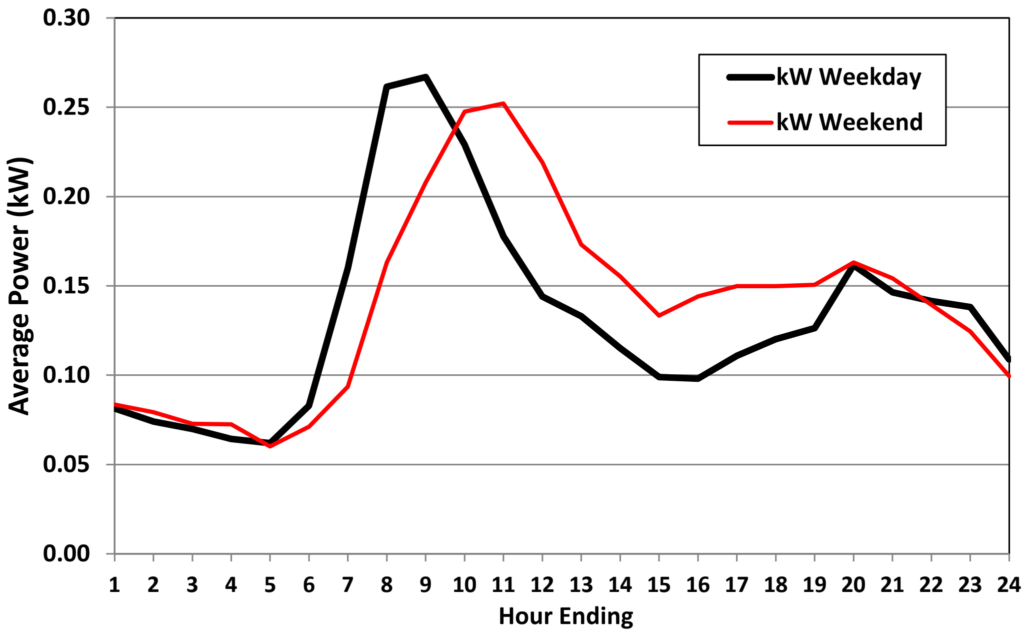


Figure 28: Average HPWH Electric Load Profile for Weekdays and Weekends when Residents Home

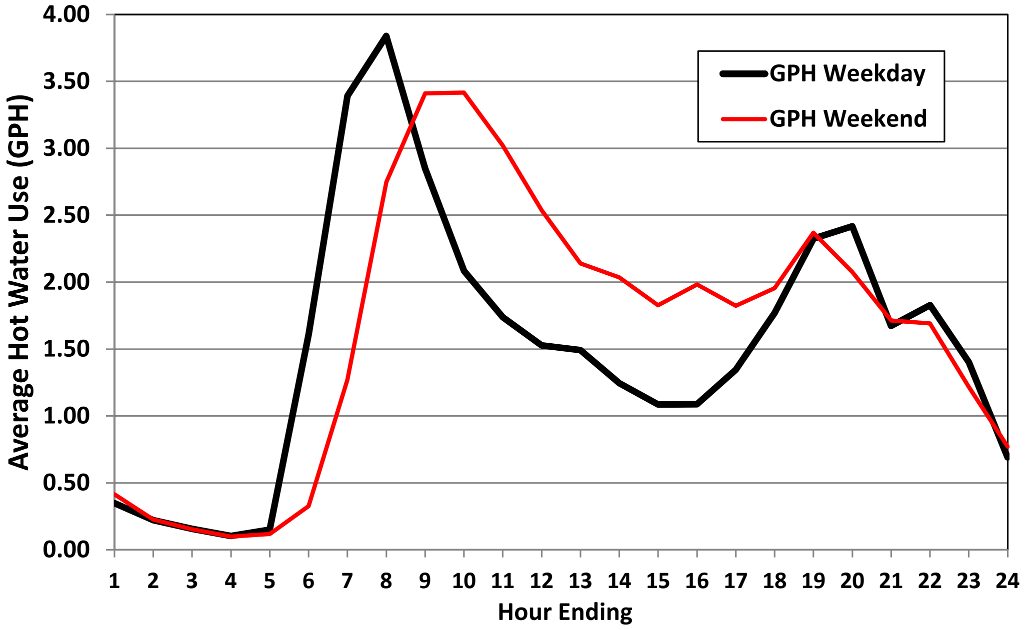


Figure 29: Average Household Hot Water Use Profile for Weekdays and Weekends when Residents Home

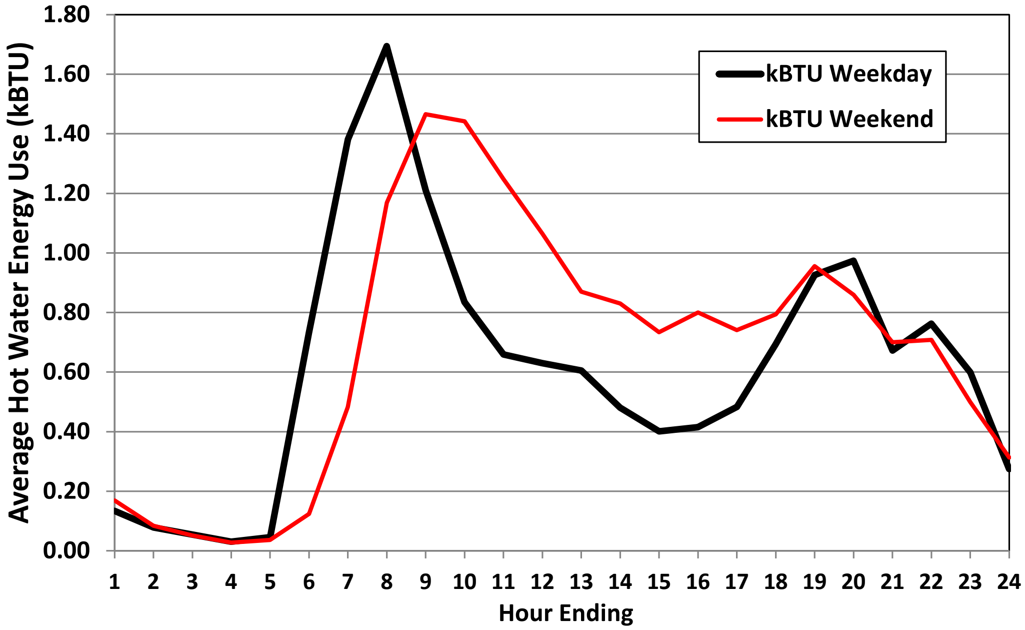


Figure 30: Average Household Hot Water Thermal Output Profile for Weekdays and Weekends when Residents Home

Table 25: Hourly Average Electric Load, Hot Water Use, and Thermal Output (kBTU) per HPWH when Residents Home

	kW	kW	GPH	GPH	kBTU	kBTU
Hour	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
1	0.081	0.084	0.349	0.415	0.134	0.169
2	0.074	0.079	0.221	0.225	0.078	0.084
3	0.070	0.073	0.156	0.154	0.054	0.052
4	0.064	0.073	0.104	0.099	0.031	0.028
5	0.062	0.060	0.150	0.118	0.045	0.036
6	0.083	0.071	1.611	0.326	0.732	0.124
7	0.160	0.094	3.392	1.268	1.381	0.483
8	0.261	0.163	3.839	2.747	1.694	1.168
9	0.267	0.208	2.851	3.411	1.210	1.465
10	0.229	0.247	2.083	3.416	0.835	1.442
11	0.178	0.252	1.737	3.021	0.659	1.248
12	0.144	0.219	1.528	2.537	0.630	1.064
13	0.133	0.173	1.492	2.140	0.605	0.870
14	0.115	0.155	1.245	2.035	0.481	0.830
15	0.099	0.133	1.086	1.827	0.401	0.734
16	0.098	0.144	1.088	1.983	0.415	0.801
17	0.111	0.150	1.345	1.823	0.483	0.741
18	0.120	0.150	1.770	1.955	0.694	0.794
19	0.126	0.151	2.326	2.369	0.926	0.956
20	0.162	0.163	2.417	2.075	0.974	0.860
21	0.146	0.154	1.673	1.714	0.672	0.700
22	0.142	0.139	1.828	1.692	0.763	0.708
23	0.138	0.125	1.402	1.218	0.599	0.500
24	0.109	0.099	0.690	0.771	0.274	0.313

7.5 Summer Data

The values used to chart Figure 31 are presented in Table 24. These values represent averages during the summer period (June 1 to September 30.) The residential peak period of 4:00 PM to 7:00 PM is represented by the hours 17-19.

Table 26: Hourly Average Electric Load, Hot Water Use, and Thermal Output (kBTU) per HPWH during Summer

	kW	kW	GPH	GPH	kBTU	kBTU
Hour	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
1	0.050	0.053	0.227	0.225	0.069	0.071
2	0.048	0.046	0.201	0.141	0.059	0.035
3	0.049	0.049	0.156	0.149	0.045	0.043
4	0.038	0.051	0.102	0.112	0.020	0.025
5	0.037	0.043	0.138	0.134	0.031	0.035
6	0.057	0.047	1.532	0.257	0.613	0.081
7	0.132	0.065	2.809	1.194	1.058	0.443
8	0.184	0.106	2.860	2.583	1.098	0.996
9	0.176	0.157	2.218	2.679	0.846	1.030
10	0.130	0.164	1.505	2.405	0.536	0.889
11	0.089	0.137	1.489	1.760	0.503	0.641
12	0.080	0.118	1.265	2.188	0.451	0.806
13	0.082	0.099	1.358	1.507	0.502	0.559
14	0.081	0.091	1.094	1.560	0.376	0.592
15	0.067	0.091	0.964	1.225	0.329	0.456
16	0.070	0.081	0.957	1.315	0.332	0.466
17	0.072	0.082	1.039	1.317	0.342	0.486
18	0.076	0.079	1.406	1.330	0.505	0.480
19	0.080	0.087	1.760	1.904	0.635	0.676
20	0.086	0.095	2.000	1.694	0.723	0.618
21	0.088	0.099	1.431	1.528	0.525	0.574
22	0.100	0.097	1.460	1.448	0.544	0.539
23	0.094	0.094	1.015	0.855	0.371	0.306
24	0.079	0.062	0.509	0.458	0.177	0.147

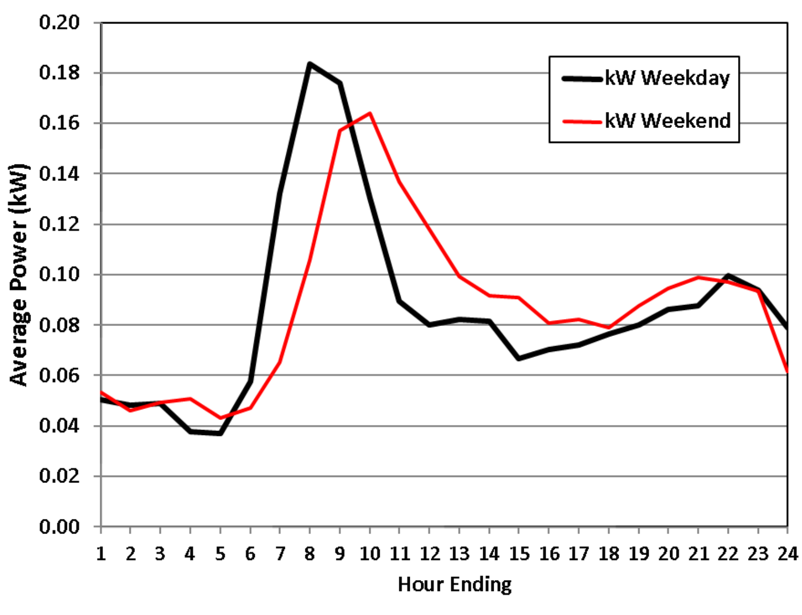


Figure 31: Average HPWH Electric Load Profile for Weekdays and Weekends during Summer

7.6 Energy Factor by Brand

Charts only display days with 30 or more gallons of hot water use.

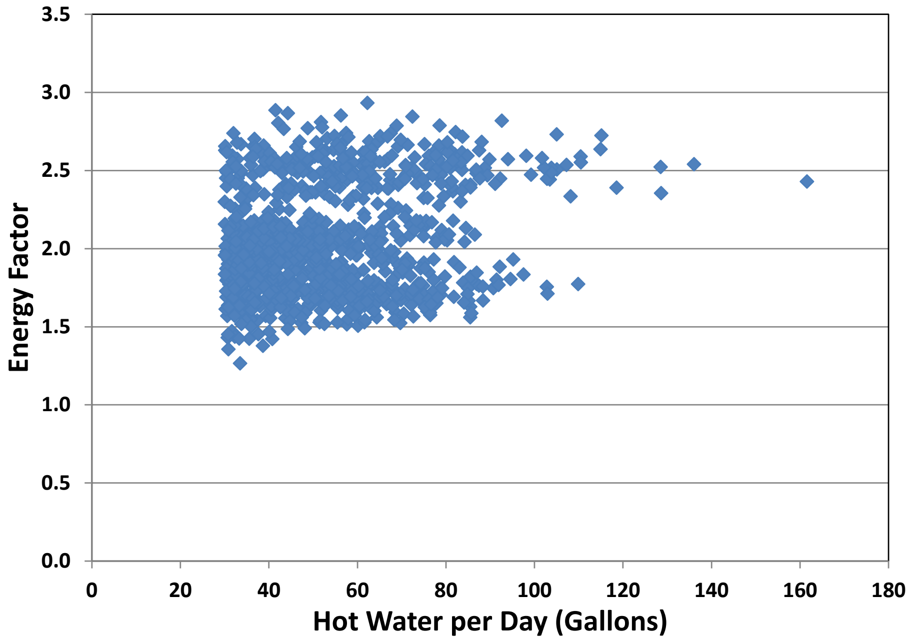


Figure 32: Daily Energy Factor for HPWH Versus Hot Water Use per Day - GeoSpring™

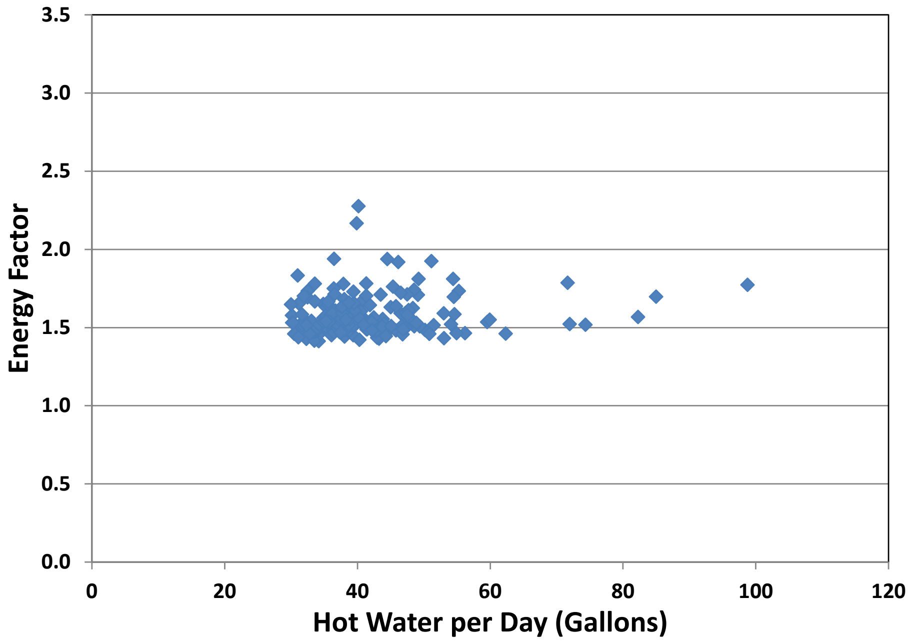


Figure 33: Daily Energy Factor for HPWH Versus Hot Water Use per Day – Rheem (One Unit)

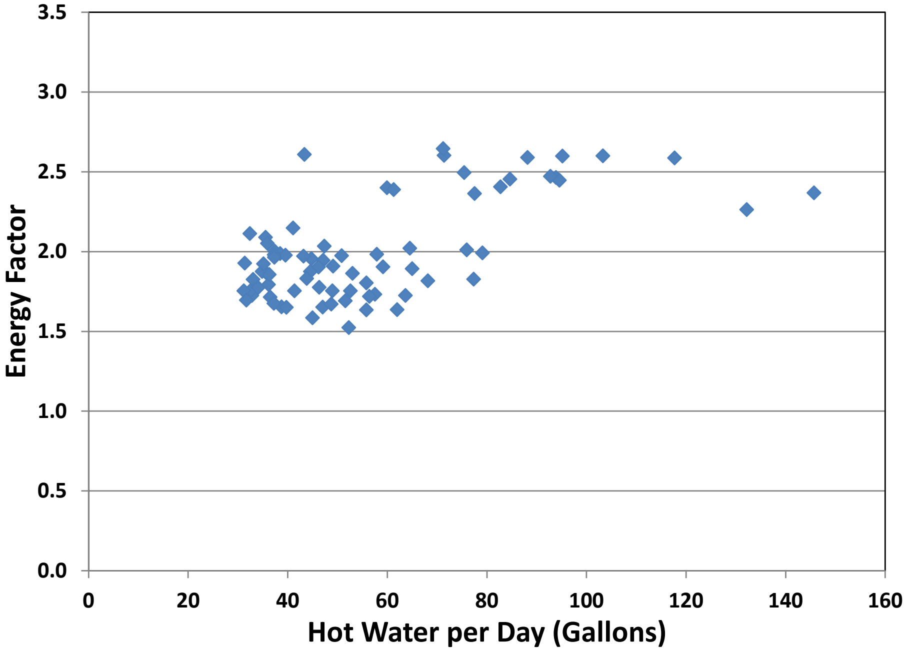


Figure 34: Daily Energy Factor for HPWH Versus Hot Water Use per Day – Whirlpool (One Unit)

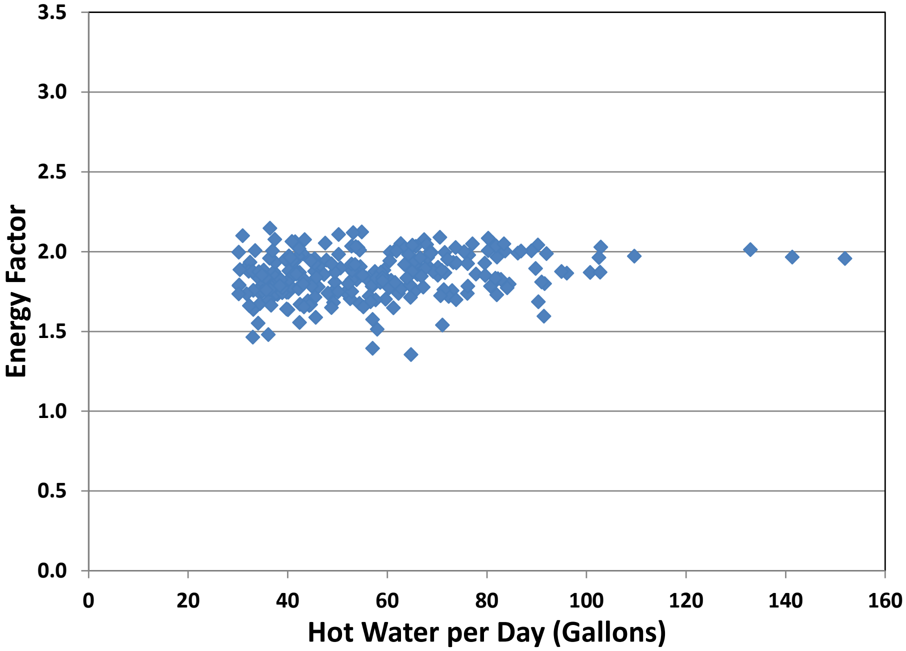


Figure 35: Daily Energy Factor for HPWH Versus Hot Water Use per Day – A.O.Smith (One Unit)