Heat Pump Water Heaters: Field Evaluation of New Residential Products

Ammi Amarnath, Electric Power Research Institute
John Bush, Electric Power Research Institute

ABSTRACT

Heat pump water heaters (HPWHs) are significantly more energy efficient than standard electric water heaters, and can result in lower annual water heating bills for the consumer, as well as reductions in greenhouse gas emissions. HPWHs use the vapor compression cycle to transfer heat from the air into stored water. In the U.S. about 8 million residential storage water heaters are sold annually according to AHRI data [1], but for the past two decades, less than 0.1% of these have been heat pump water heaters. In recent years, several major U. S. water heater manufacturers (and some overseas companies) have introduced new HPWH products as energy-efficient alternatives to standard water heaters. With improved product designs and promises of 3-6 year payback periods, new heat pump water heaters have the potential to make significant penetration in the residential water heating market. Starting late-2009, the most extensive field study in the USA was put in place to demonstrate the efficiency, reliability and performance of major modern HPWH models. Over 145 HPWHs and 27 baseline electric resistance water heaters were instrumented in residences in different climates across the country. Measurement data including system power and energy, entering and exiting water temperature and flow rate were recorded. In addition, to capture customer satisfaction, customer surveys were gathered before, during and at the end of the study. Results of this study will be presented to provide insights on real-world efficiency, reliability and customer satisfaction for HPWHs.

Introduction

Background

Although they have been around since the 1980s, heat pump water heaters (HPWHs) are just now receiving attention from the electric utility industry because of involvement by major manufacturers, exciting efficiency claims from manufacturers, and approval by the DOE of an ENERGY STAR labeling program for water heaters. Robust research reveals that it is simply more efficient to transfer heat from the air and into a water tank (via a heat pump) than it is to heat water with an electrical heating element. The efficiencies are expected to be higher in Southern and Western portions of the United States, especially in areas where ambient temperatures are relatively high.

According to manufacturers' literature, efficiencies of HPWHs may double the efficiencies of traditional electric water heaters. Whereas traditional electric water heaters have an energy factor (EF, or annual efficiency) of less than 1.0, the EF of available HPWHs is typically higher than 2.0, resulting in an annual savings of $250 or more for a typical household, according to the DOE.

The EF of an HPWH depends upon usage patterns, climate, and location of installation (for example, basements, garages, conditioned rooms, etc). Manufacturers claim that such water heaters have the potential to operate efficiently in the southern and western climatic regions; their operability in northern and northwestern regions is unknown. The EPRI Energy Efficiency Demonstration is designed to test the efficiency and reliability of HPWHs in most climatic conditions in the U.S., for a period of two years.

Study Overview

Because heat pump water heaters have been deployed only in small numbers, the technology still needs to be proven. While the technology itself is fairly well understood, the actual performance of HPWH systems has not been quantified in sufficient numbers. This demonstration aims to provide that quantification. The variation of system efficiency with climate, water usage, and installation location are being examined. Using this information, insights can be made regarding the viability of HPWHs for larger-scale deployment as an energy-efficiency measure. The research objectives of the field portion of the HPWH Demonstration are efficiency, reliability and customer satisfaction. The efficiency is determined by observing the load-shape impacts and performance of these units in real-world settings. Doing so enables utilities to design customer programs that create utility and customer value.

Typically, the field comparison requires the development of a baseline, from which the efficient units can be compared. Utilities are most interested in three components: 1) Reliability of this new technology; 2) the impact on energy consumption as measured by the difference in the average load shapes and 3) the coincident demand impact by assessing the impacts at the time of their system peak. The second component reduces the customer electric bills and utility cost savings, which ultimately are passed back to customers. The third reduces peak demand or coincident demand, which may result in deferring future power plant construction. These deferred costs are also passed back to customers.

To determine the effects of climate, ambient temperature, and temperature of the incoming water, the demonstration is monitoring the temperatures of the incoming and outgoing water flow and the air surrounding the HPWHs. The results of this monitoring will help to quantify the impact of climate and point towards conclusions on which climate zones are best suited for HPWH installations.

Previous laboratory work performed by EPRI has examined HPWH system performance in a laboratory setting. In 2009, EPRI conducted laboratory tests of several heat pump water heaters to assess their performance and energy efficiency. Among the U.S. heat pump water heaters tested were new products from A. O. Smith, General Electric (GE), and Rheem. These units are designed to be integral, drop-in replacements for standard electric water heaters. Additionally, EPRI tested the Japanese-based Eco-cute heat pump water heater from Daikin, which is a split unit with an outdoor heat pump utilizing CO_2 as the refrigerant and an indoor hot-water tank. The results of this work can be found in EPRI's 2010 ACEEE paper [2]. The Demonstration seeks to affirm the findings from the laboratory testing across a spectrum of conditions in the field, accounting for conditions that cannot be captured in laboratory testing.

In addition to performance goals, the Demonstration aims to develop an understanding of the reliability and customer satisfaction with these products. Because the active deployment of HPWHs is very low nationally, the Demonstration will be among the first to see how HPWHs operate over an extended period and receive feedback from users on their experiences.

Research Methodology

The research methodology consists of the following sub-tasks:

- Design, test, and assemble instrumentation packages for treatment and control units.
- Conduct site-selection surveys to identify appropriate locations for treatment and control sites.
- Install HPWHs and instruments in the field.
- Collect and analyze data.
- Conduct customer-satisfaction surveys.

Design and Assemble Instrumentation Packages

The HPWH systems installed in the field are instrumented to measure the quantity of hot water provided and the power/energy used in operation, among other significant variables. The "full" instrumentation package at each site includes: A power meter to measure the consumption of electricity by both the whole house and the water heater electricity (includes two CTs for the whole house and one for the water heater); a water-flow totalizer with sufficient resolution to capture small and large draws; two immersion thermistor probes for water inlet and outlet temperature; an ambient temperature/humidity sensor for the air conditions surrounding the water heater; a data-acquisition device with wireless transmitter (WiFi) that plugs into the home router.

Conduct Site-Selection Surveys

Collaborating utilities selected potential sites for installation of HPWHs. Surveys were sent to the consumers at these sites. A site was approved if it satisfied several requirements. It was required that installation of both the water heater and the data-acquisition system could be performed without requiring additional engineering or parts. Requirements included having sufficient space for the water heater to be installed, having convenient access to power for the data acquisition, and having access to the customer's internet connection for data transmission. Also, a site was rejected if it had any unusual loading or configurations, such as households with only one resident or where an instantaneous water heater was in use to boost temperature at one or more taps.

Install HPWHs and Instruments in the Field

Water heaters and instruments were installed by local contractors, who were selected by the host utility. The process was outlined in instructions provided by EPRI. After installation, the installer was instructed to contact EPRI to confirm proper installation and data transmission.

In addition to the treatment HPWH systems, a number of baseline electric resistance water heaters were instrumented. These systems were existing in the customer houses, varying greatly in age, size, and manufacturer. It was decided that a random sample is preferable to approach a representation of what is in the field. As of September 2011, there were 151 HPWH and 30 control units in the field.

Collect and Analyze Data

Data is sent to EPRI approximately every 8 hours, automatically, by the Acquisuite data-acquisition system. While the number of sites is too large for continuous site-by-site analysis, a checking methodology was added to monitor selected information from each site in order to catch errors or anomalies.

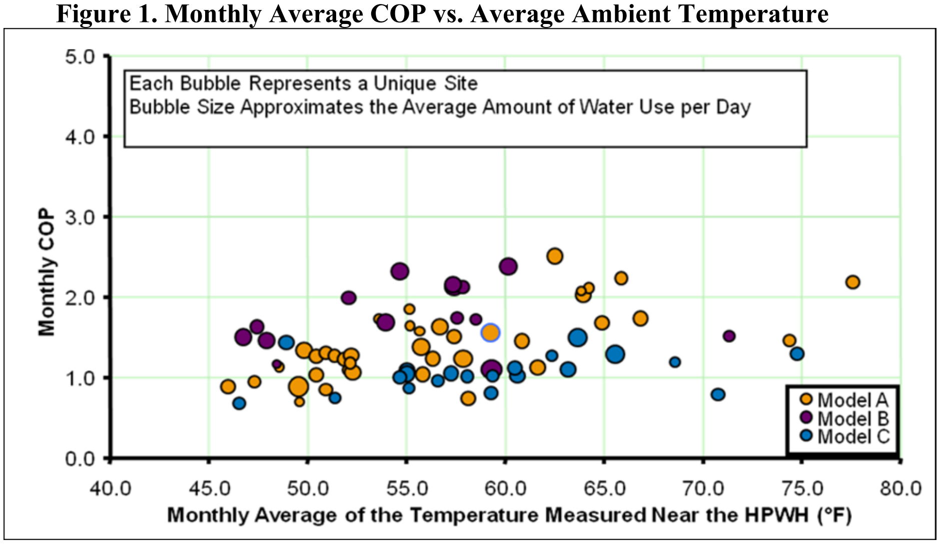
Conduct Customer-Satisfaction Surveys

The purpose of the HPWH customer surveys is to gauge customer satisfaction levels with the installation and operation of the equipment, as well as opinions regarding equipment appearance, noise levels, the existence of condensate leakage, and others.

Preliminary Results

Data from January through March 2011 indicate that most heat pump water heaters operated reliably, with no major issues even during cold ambient air conditions. However, some models operated better than others in the field. Figure 1 illustrates these units' relative operational efficiency.

Figure 1. Monthly Average COP vs. Average Ambient Temperature



Impact Analysis

The impact analysis for heat pump water heaters includes data analysis for the months of January through March 2011 for three host utilities. The utilities discussed herein are Bonneville Power Authority (BPA), in the Pacific Northwest; Tennessee Valley Authority (TVA) in Tennessee and the surrounding states; and Southern Company, in the southeastern states. The number of sites included in the analysis—both control and treatment sites—was reduced from the number of originally selected sites by the following three criteria (a site that did not meet one or more of the criteria was excluded from data analysis):

- The site must have started generating *good* (or error-free) data on or before the first day of the analysis month to count for that month.
- 95% or more of the hourly energy-consumption values for each site must be recorded (or not be missing) for the month, and the recorded values must be within the acceptable power rating of the water heater.
- Sites must have 1) 5% or less of their data for the variables being collected “out of range” and 2) 5% or less of other anomalous hourly energy-consumption (kWh) data points within a month.

For the period examined in depth (January-March, 2011), the number of sites was as follows: 69 HPWH and 16 control sites in January, 80 HPWH and 20 control sites in February, and 97 HPWH sites and 23 control sites in March.

Table illustrates the average weekday, weekend day, and peak day impacts for the three host utilities for the month of January 2011. The average energy savings for week days ranged from about 21% to 28% per weekday. The average energy savings for weekend days was slightly higher, ranging from about 23% to 32% per weekend day. The average weekday demand savings was 7.64 % and 7.10 % per peak hour of weekday in the case of BPA and Southern Company and 14.5 % in the case of TVA. Coincident demand reduction on the January winter system peak day is relatively low, ranging from 48 watts to 264 watts per peak hour.

January 2011 was the winter system peak month for TVA and Southern. It is interesting to note that the energy savings for the month are significant, while the peak demand savings are small and statistically insignificant.

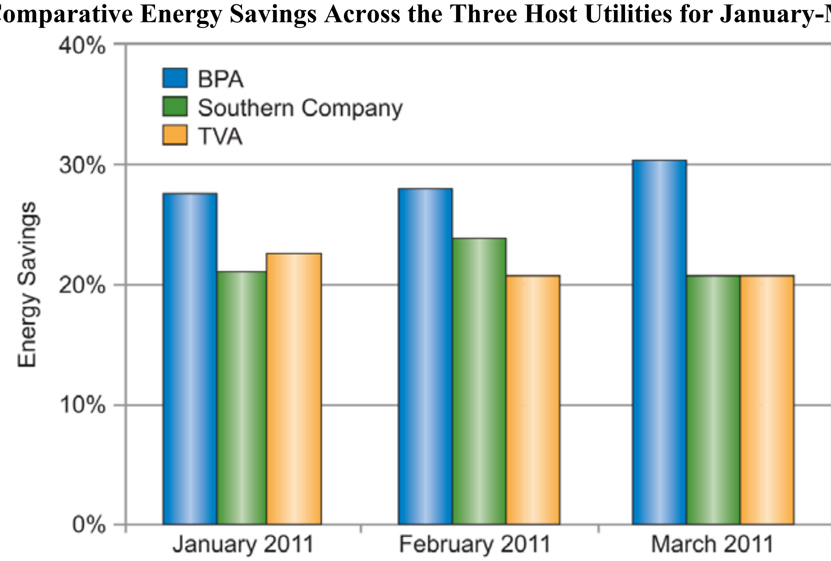
Statistical non-parametric tests conducted at a 95% confidence level showed a significant difference in energy consumption between the averages of the control water heaters and the treatment water heaters for both weekdays and weekend days. For the system peak day, no significant difference in energy consumption at 90% confidence level was observed between the mean of the control units and the mean of the treatment units for the peak hours between 7:00 AM and the end of 10:00 AM. Statistically, the lack of significant difference between the control group and treatment group for peak demand reduction means that the reduction may be due to chance.

Table 1. January 2011 Impact Analysis of Heat Pump Water Heaters

January 2011					
Utility	Average Weekday		Average Weekend Day	Average Peak Day	
	Energy Savings (kWh per Weekday)	Demand Savings (Peak kW per Weekday)	Energy Savings (kWh per Weekend Day)	Coincident Demand Reduction (kW)	January System Peak Date
BPA	3.0 * (27.8 %)	0.27 * (7.6 %)	3.7 * (32.2 %)	0.06 ** (1.6 %)	01/03/2011 (Monday)
Southern Company	1.7 * (21.25 %)	0.15 * (7.1 %)	1.9 * (22.76 %)	0.05 ** (1.9 %)	01/14/2011 (Friday)
TVA	1.6 * (22.8 %)	0.45 * (14.5 %)	2.2 * (23.8 %)	0.26 ** (7.1 %)	01/14/2011 (Friday)

* Means of control and treatment groups are significantly different at the 95% confidence level.
** Means of control and treatment groups are not significantly different at the 90% confidence level.
Average weekday demand savings (kW/weekday) and coincident demand reduction (kW) were calculated over the four-hour period beginning at 7:00 AM and ending at end of 10:00 AM.

Figure 2. Comparative Energy Savings Across the Three Host Utilities for January-March, 2011



Load Shapes

The field sites in this HPWH research do not constitute a random sample. However, we can simply test whether the means of the load shapes at certain times are statistically different from one another. We provide these results for both energy and coincident demand reductions. The load shapes reflect what is shown in Table . As an example, **Error! Reference source not found.** and **Error! Reference source not found.** show the load shape for the TVA HPWH units for an average weekday and for the system peak day— specifically, the hours from 7:00 AM to the end of 10:00 AM (three control sites and 20 treatment sites). Average weekday load shapes show significant energy reduction, as illustrated by the gap between the two lines. It also shows the lack of a gap during the utility's peak days (about 7%, or 264 watts, of peak reduction). This is likely the result of colder ambient temperatures where the units operate. Colder temperatures may result in the back-up resistance elements running to the exclusion of the heat pump. The result is a similar load shape during those few cold hours. The load shape shown in **Error! Reference source not found.** shows an average energy savings of 1.6 kWh (22.8%) and an average demand savings of 452 W (14.5%).

Figure 2. Average Weekday Load Shape for the Month of January 2011 for Units Installed by TVA

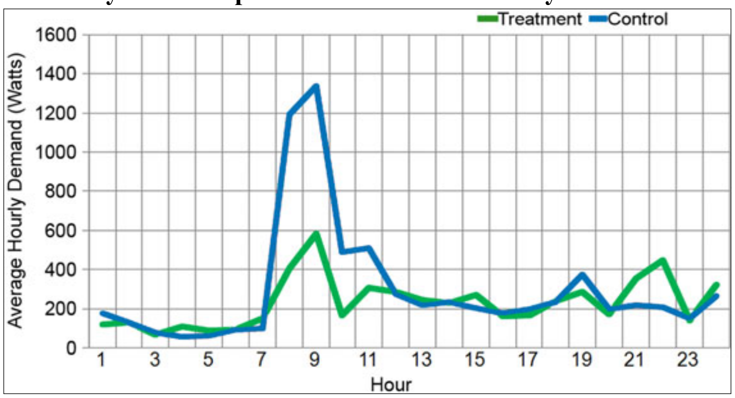
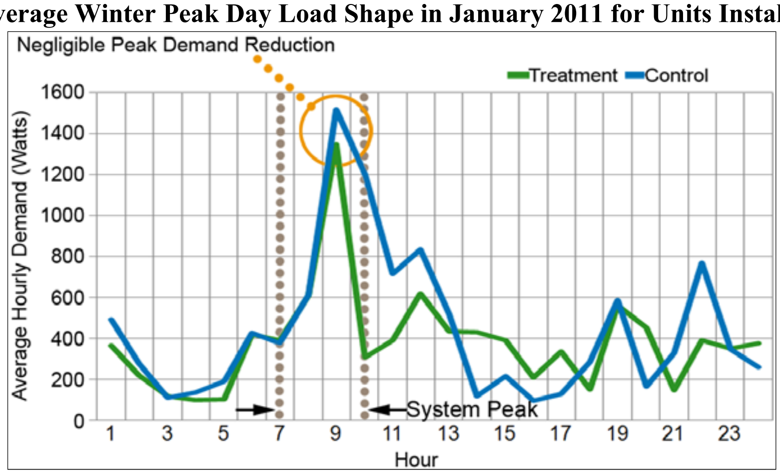


Figure 4. Average Winter Peak Day Load Shape in January 2011 for Units Installed by TVA



Monthly Average COP

The efficiency of heat pumps is measured by calculating a coefficient of performance (COP), which is a ratio of useful output (hot water, in this case) to the amount of work or energy input (electrical power). The COP values presented here were calculated as the ratio of heat provided (the mass flow of water, times specific heat, times temperature difference) divided by energy input.

At the time of this interim report, three full months of data were available across three utilities. Table summarizes the monthly average COP for treatment HPWHs by month and collaborating utility. The data in the table is weighted by water consumed. Water consumption is an influential variable for efficiency; this the effect of normalizing the effect of flow which provides an appropriate comparison of data sets from different utilities and months. For all utilities and all months, the average monthly COP was 1.5; this average includes the models that performed poorly on a consistent basis. The monthly COP for units installed in TVA's service territory was best, with a monthly average COP of 1.8 over all three months.

Table 2 Summary of Monthly Average COP for HPWH Units*

Utility	January 2011 Average COP	February 2011 Average COP	March 2011 Average COP	Average by Utility
BPA	1.3	1.1	1.3	**1.2**
Southern Company	1.4	1.4	1.6	**1.5**
TVA	1.7	1.8	1.9	**1.8**
Average by Month	**1.5**	**1.4**	**1.6**	**1.5**

Average COP is the weighted COP for all sites installed by a specific host utility for a month, weighted by the monthly hot water usage (gallons) for each site.

* Includes models that performed poorly on a consistent basis

The Effects of Inlet and Outlet Temperature

Three one-minute temperature values are being recorded for the inlet and outlet water, namely the minimum, maximum, and average temperatures (based on two-second measurement intervals). Over time, researchers have noted that calculations of average COP can result in different values for the same HPWH in seemingly identical circumstances. At least two factors have been observed to cause significant variation in the calculated values of COP:

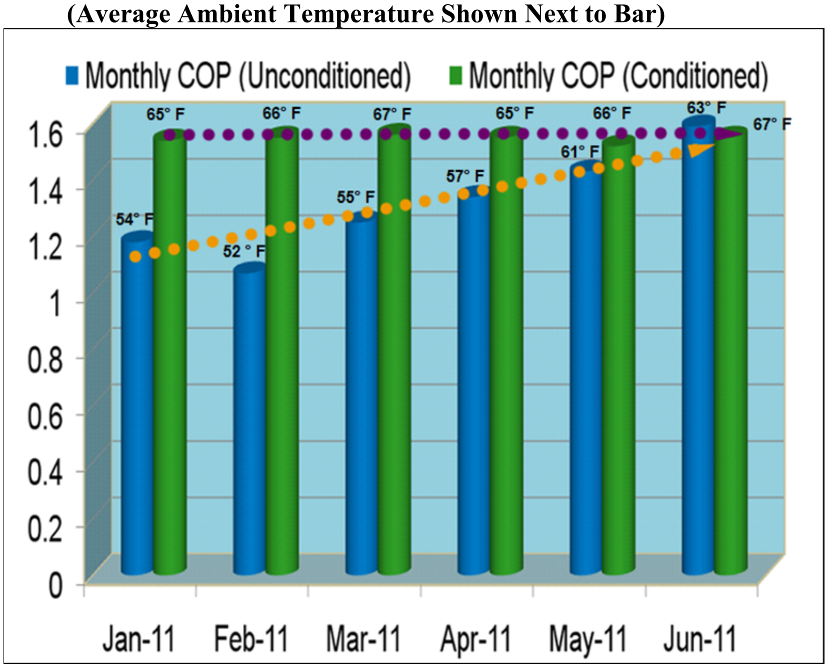
- COP interval: The interval over which COP is calculated (such as over a 15-minute period or a 24-hour period).
- Temperature difference: Difference in the average inlet cold water and outlet hot water temperatures.

COP calculated over a long duration, such as a day or a week, reflects the true performance of the unit. Fifteen-minute COP values can be inaccurate and misleading because within a 15-minute period, there may be a very small draw of hot water or no draw at all. A review of the data on the outlet water temperature measured for sites installed as part of the Demonstration reveals that within a given 15-minute period, smaller draws of hot water (less than 0.5 gallons per draw) on the average have a higher measured inlet temperature than the average temperature of a few large draws (two gallons or more) during the 15-minute duration. Closer inspection reveals that this is a result of sensor location.

Because the inlet and outlet temperature sensors are installed on piping outside of the tank, the temperature detected during periods of no draw changes over time as the water in the pipes approaches the ambient temperature. This occurs even while the tank is fully charged to the set-point temperature. When a very small draw occurs, for example someone turning the faucet to "warm" water to briefly rinse something, a small amount of hot water is drawn from the tank, and a flow registers. However, because there is water in the outlet pipe, which has already cooled, the temperature at the sensor may or may not change. While superficial analysis might suggest that this is an issue with the heater (water was drawn, it was not hot), this in fact happens in all houses, with all water heaters. A true draw of hot water at the faucet entails a lag while water leaves the tank and reaches the faucet.

The losses of hot water from the pipes are reflected in the energy-consumption results gathered here (though the total amount lost to pipe losses is unknown since measurements are near the tank and pipe length varies by house). However, the effect of pipe thermal losses on the calculated COP makes it more difficult to evaluate the impact of incoming (e.g. municipal or city) water temperature on COP performance. Although small water draws certainly impact the calculated COP of the water heater, their usefulness in determining efficiency and regional/climate impacts is minimal. The inlet water temperature to the tanks varied greatly by region and season, and even within regions. In the cold regions of the northwest, minimum monthly inlet temperatures at each site (reflective of water that likely has not been warmed by prolonged exposure to the indoors) ranged from 43°F to 51°F during the months evaluated here. The inlet water temperatures were higher in the other regions, with hot-humid climates ranging from approximately 50°F to 65°F.

Figure 5. Unconditioned Spaces Expose HPWHs to Seasonal Temperature Variations (Average Ambient Temperature Shown Next to Bar)



The Effects of Installation Location

The colder air exiting the HPWH may alter the temperature of the room in which it is installed. This effect may be negligible when the unit is installed in an unconditioned space. However, in conditioned spaces—especially in the cooler months—the effect may be appreciable and undesirable. In such a condition, ductwork may need to be installed to avoid "robbing" the conditioned space of its energy content.

The efficiency of an HPWH is seasonal if the unit is installed in an unconditioned space, with the cold months dampening efficiencies and the warm months improving them. **Error! Reference source not found.** shows how seasonal temperature variation directly and positively affects the efficiency of an HPWH installed in an unconditioned space, whereas installations in conditioned spaces result in a season-independent efficiency.

Differences between Manufacturers/Models

Most HPWHs are hybrids, containing a heat pump and two electrical immersion heaters. The design of the heat pump and that of the resistance elements are different from manufacturer to manufacturer. For example, GE and AO Smith's heat pump condenser coil surrounds the tank, and heat is transferred to the water via conduction through the tank metal. On the other hand, the Rheem units tested call for potable water to be pumped from the tank to the heat pump's condenser for gaining heat. Also, the size of the resistance elements varies by each manufacturer. The tank sizes are also different; AO Smith offers units with tank sizes of 60 and 80 gallons, and GE and Rheem are 50 gallons. Finally, the operating strategy for each HPWH, as designed by the manufacturer, is different. What is common is that all HPWHs have passed the EnergyStar labeling tests, under the DOE test conditions.

Consumer Surveys

In total, the analytics plan for the heat pump water heaters entails the administration of four surveys: one pre-installation survey and three post-installation surveys administered after the equipment has been installed for approximately one, six, and twelve months. These are being administered to both treatment and control households.

This section focuses on the results of the first post-installation survey that was administered approximately one month after the installation of the water heaters. These surveys were administered via two participating member utilities: BPA and Southern Company. In both cases, the surveys were administered through their respective distribution companies. There were 37 BPA respondents and 28 Southern Company respondents. Utility and contractor representatives followed up with customers on an on-going basis to address some of the issues emerging from the survey responses. These responses should be reflected in the results of the second post-installation survey, which is being fielded approximately six months after the heater installations. It will ask many identical questions so that any differences that have occurred over time will be able to be assessed, as well as the water heater performance over the winter months.

The summary results of the one-month post-installation survey are given below.

General Satisfaction

Although running out of hot water during the winter months was a common theme, the majority of BPA and Southern Company customers who responded to the survey were satisfied with their water heaters after they had been installed for about one month (86%, N=65). A direct comparison of satisfaction between BPA and Southern Company customers is not possible because the question on general satisfaction was worded slightly differently. In the case of Southern Company, one customer out of 28 expressed dissatisfaction and said the water did not get hot enough or last long enough. In the case of BPA, six customers out of 37 expressed some element of dissatisfaction (again, this number cannot be directly compared to the Southern Company result). These complaints referred mainly to the temperature of the water, running out of hot water more quickly—or a "slow recovery" of the heater, meaning it took longer to have hot water again after it had initially run out— and in some cases, the water pressure and time it took to reach various household faucets.

When asked whether customers noticed a difference in their hot water with the new heaters, slightly more than half of the BPA customers did—about two thirds of those who noticed a difference cited unfavorable reasons (such as not hot enough, running out faster, slower recovery, lower pressure, and slightly longer to reach the tap). The other third cited what could be construed as favorable reasons (such as more hot water and higher water temperatures). In the case of Southern Company, slightly less than half of the respondents noticed a difference in their hot water—half favorable and half unfavorable. A few people noticed "problems with water running onto the floor from the condensation vent tube." Three BPA customers (8%) noticed moisture or water on the floor around the heater; no Southern Company customers noticed this. The sound of an operating heat pump atop a water tank is noticeable, according to survey respondents. "It is loud when it comes on" was a common theme in the survey results. When asked directly about any noticeable difference in noise level, most respondents said yes, they did indeed detect a difference between their old water heaters and their newly installed HPWHs. However, most of the respondents who detected a difference indicated that the new noise was not bothersome. Of those who noticed it, four BPA customers (approximately one quarter) and two Southern customers (10%) stated they found it bothersome.

HPWHs expel cool air during normal operation of the heat pump. Some respondents considered this cool air beneficial, but the benefit depends upon the climate. A common theme was that during the winter, the cool air was a nuisance. One respondent installed his HPWH in the basement, which he used as a workshop. In the winter, he had to "change the setting to activate the heating elements to cut out the cool air produced by the heat pump." One respondent desired a way to "position [the heat pump] to direct the fan blowing in a specific direction." Another solved the problem by turning on his electric space heater when he was working in his garage, potentially cancelling energy savings accomplished by the HPWH.

Electronics enable users to control settings to compensate for cold days, such as switching from an economy mode to a mode that provides faster recovery: "We were able to switch to the Hybrid setting on the very low temp days and it maintained hot water for all of our needs," said one respondent. Users were able to adjust the temperature, set the vacation mode, change the mode of operation, and turn off the heat pump when the noise proved to be disruptive.

When asked about whether they detected a difference in their electricity bill after their HPWHs were installed, a few respondents indicated that they had realized “obvious” savings. However, most used terms like “seems,” “hard to quantify,” “too early to tell,” and “comparative costs are not obvious.” Numerous respondents did not “notice” any difference in their electricity bills at all. Some expressed confusion about the contribution of their HPWHs because of simultaneous energy-efficiency measures, such as installation of high-efficiency appliances, lighting, or heating and cooling systems—which complicated a reasonable inference about savings attributable to the HPWH. Because other factors complicated this question, it was asked to assess customer perceptions only

Two additional questions that were added to the one month post-installation survey for Southern, and these have since been added to subsequent follow-up surveys for the other utilities as well. When asked if they would consider purchasing this type of water heater in the future, 20 people (77%) said yes, four people (15%) said maybe, and 2 people (8%) said no (N=26). When asked if they would recommend the unit to a friend or family member, 22 people (85%) said yes, 3 people (12%) said maybe, and 1 person (4%) said no (N=26).

Conclusions

Heat pump water heaters can save significant amounts of energy over conventional water heaters, with savings of 20 to 30% found in the winter of 2011; these savings are expected to be higher in the summer. However, peak reduction was less than expected; the systems generally used their resistance heat elements during the highest utility loads, and this occurred around the same time of day for heat pump and conventional systems. The peak kW reduction is on the order of 2 to 7%.

Because HPWHs gather heat from ambient air and move it to water, there is a space-cooling effect provided along with water heating. This cooling effect can be desirable, such as in a hot, humid region like the southeastern United States. It can also be detrimental if the HPWH is not properly installed to account for the cool air, such as when a unit is located in a conditioned space in the colder climates of the northern Midwest. The degree of benefit or detriment is not fully known and will vary with installation location. In addition to the cooling effect, systems will require longer run times in cooler ambient conditions. Because efficiency and total energy consumption, as well as cooling to the space, are all tied together, the best installation location of the HPWH will likely vary by climate. This important consideration merits further evaluation, and more insights can be drawn after data has been gathered for all seasons in each climate.

The temperature of the incoming tap water may also be a variable that can affect efficiency. Generally speaking, with lower water temperature, the heat pump transfers heat more efficiently to the water, but the duration of operation is longer. Changing incoming water temperature also changes the ratio of operating time of the heat pump and resistance elements. Therefore, it is likely that incoming water temperature plays a part in HPWH efficiency. The significance of water temperature will be further examined and reported in the next technical update.

Customer feedback is generally good, although some customers complain about running out of hot water, and the cooling effect of the systems can be undesirable. Some of these problems were remedied by contacting customers and instructing them on how to adjust the settings of their water heaters. The consumer experience gleaned from this first post-installation survey can potentially be used to create educational materials for future deployments to educate customers about what to expect regarding the water temperature and quantities, noise levels, and cooler temperatures around the heaters. In terms of future questions to address with the survey results, although the sample of treatment customers was not randomly chosen and sample sizes are relatively small, it may be interesting to analyze results through the lens of variables such as the type of water heater that was installed, temperature set points, and how old tank sizes compared with new ones.

Finally, most of the HPWHs operated very reliably during the course of winter. However, it is important to capture the reliability aspects over a longer period of time; it will be updated in the next report.

Some important implications of this work are that heat pump water heaters can be a valuable tool for energy reduction, but they must be sized and located properly. Customer satisfaction can be substantially improved if customers are made aware of how to operate and control their water heaters.

References

[1] "Residential Storage Water Heaters Historical Data". *AHRI* Web. 16 May 2012 http://www.ahrinet.org/residential+storage+water+heaters+historical+data.aspx

[2] Amarnath, A., Trueblood, C. "Heat Pump Water Heaters: Laboratory and Field Evaluation of New Residential Products" *ACEEE Summer Study* (2010)