ELECTRIC POWER RESEARCH INSTITUTE

# Commercial Heat Pump Water Heaters

## Evaluation of Field Performance for San Diego Gas & Electric (SDG&E)

2015 TECHNICAL REPORT

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*Evaluation of Field Performance for San Diego Gas & Electric (SDG&E)*

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**THE ELECTRIC POWER RESEARCH INSTITUTE (EPRI) PREPARED THIS REPORT.**

**NOTE**

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# Abstract

A heat pump water heater (HPWH) offers a considerable opportunity for energy and demand savings over a conventional electric water heater. This report examines HPWHs for commercial applications by evaluating the performance of a HPWH installed in a condominium building at a time-share resort outside of San Diego, California. The HPWH was installed and monitored for 12 months at the site, and its performance, energy efficiency, and cost-effectiveness were compared to a baseline electric resistance water heater (ERWH) installed previously at the facility. Results of this analysis show 52% energy savings over baseline ERWH technology, with payback of 3.2 to 4.4 years under the San Diego Gas & Electric (SDG&E) existing commercial rate structure. Commercial HPWH technology is estimated to provide potential savings in lodging, restaurants, and healthcare facilities of 41.5 GWh in California and 6 GWh in the SDG&E territory. Findings from this work provide the basis for consideration of commercial HPWH technology in utility rebate and incentive programs to target these reductions in end-use energy.

**Keywords**

Heat pump water heater (HPWH)
Electric resistance water heater (ERWH)
Water heating
Energy efficiency
Energy savings
Commercial buildings

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# Section 1: Introduction

Water heating represents the second-largest load in residential buildings in the United States, and a considerable load in many commercial buildings [1]. However, electric water heating in particular has remained relatively unchanged for many decades, relying on an electric resistance element to heat water. Such a water heater is referred to as electric resistance water heater (ERWH) in this study. In the 1980s heat pump technology, the same basic technology used in refrigerators and air conditioners, was applied to water heating in an effort to improve efficiency. However, early models were wrought with performance and reliability issues, as well as high costs, and the technology remained niche. In the last five to ten years, several manufacturers have revisited heat pump water heaters and launched a new wave of products aimed to satisfy continuing demand for energy efficient technologies. EPRI continues to study these products and technologies both residential and commercial, and one such commercial Heat Pump Water Heater (HPWH) field study is discussed in this report.

Heat pump water heaters offer a considerable opportunity for energy and demand savings over conventional electric water heaters. The electric resistance heating element applied in most electric water heaters today is a simple and effective device. In the ideal scenario, 100% of the electricity is converted from electricity to heat. Heat pump water heaters can improve upon this efficiency. Heat pumps use electrical energy to drive a mechanical system which moves heat from the cooler ambient to heat water. A heat pump can move several units of heat for each unit of electricity supplied.

This report examines the application of commercial HPWH through evaluation of a field demonstration at a site near Escondido, CA. The performance of this system is examined for energy efficiency and peak load savings to help further the understanding of the HPWH class of products.

## Background

Heat pump water heaters operate using the same vapor compression cycle that is seen in refrigerators, air conditioners and heat pumps. Represented in Figure 1-1, the vapor compression cycle requires input to the system to compress a gaseous refrigerant. Compression increases the temperature as well as the pressure of the gas, and the mechanical inefficiency of compression adds some additional heat. The refrigerant, at high temperature and pressure, condenses to a liquid in the condensing coil on the high temperature side, releasing heat. The liquid refrigerant is metered through a valve, reducing the pressure, and boils to the gas phase in the evaporator on the cold side, absorbing heat. The low pressure gas then returns to the compressor. The net effect of this cycle is that, for a relatively small energy input to the compressor, a large amount of heat can be transferred from the cold side to the hot side by refrigerant.

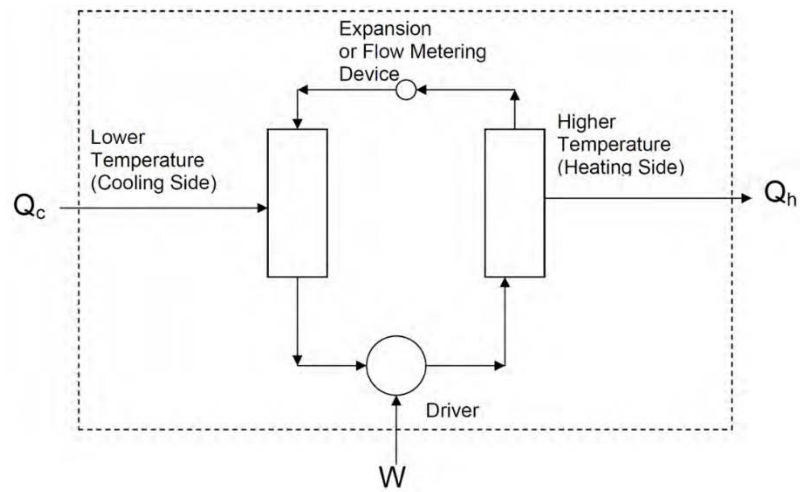


*Figure 1-1*
*Simple Schematic of Vapor Compression Cycle*

Viewed with either heating, $Q_h$ or cooling $Q_c$ as the output and electrical energy W as the input, the apparent efficiency can be significantly higher than 100%. For this reason, the term COP is used: COP is the ratio of useful heating or cooling output divided by energy or power input, in like units.

Heat pump water heaters use the above cycle with the condensing side transferring heat to water. While the evaporator side fluid can be water or other fluids, this report focuses on air-to-water heat pumps. The most common refrigerant in the United States for this process is R-134a, which has the desirable properties for water heating of relatively high operating temperatures. Other systems use R-410a, a common refrigerant often seen in air-to-air heat pumps and air conditioners. Still other heat pumps use a modified version of the same refrigerant cycle, and utilize CO2 as a refrigerant.

Unlike traditional electric water heaters or gas water heaters, heat pump water heater performance depends upon ambient air and entering water conditions. The compressor power is driven by air and water temperature. With higher temperatures, the operating pressure of the refrigerant is higher. When the compressor's operating pressure increases, its operating power also increases. For heat pump water heaters, the increase of ambient air temperature drives up compressor power. It also drives an increase in system capacity because higher available heat in the air allows more refrigerant to evaporate, increasing the rate of heat transfer. For a fixed water temperature, the increase in capacity as air temperature increases is generally greater than the increase in compressor power, leading to higher efficiency. Increasing water temperature also drives up compressor power. The high-side refrigerant temperature and pressure are driven upwards by higher water temperatures. High compressor discharge pressures require high power input. Also, heat transfer rates decrease as the temperature difference between the condensing refrigerant and the water decreases. For a fixed air temperature, increasing water temperature results in a decrease in capacity and increase in power, resulting in lower COP.

An important distinction to be made is that higher efficiency does not inherently mean a better installation. The COP of HPWHs is higher when water on the condensing side is cold, but the amount of heat required to bring water to the desired temperature is higher. Therefore, while a HPWH with 45˚F entering water temperature may operate with a higher COP than the same HPWH with 65˚F entering water temperature, the 65˚F case requires less total energy input to arrive at the set-point temperature.

## Residential Heat Pump Water Heater Systems

Heat pump water heaters for residential applications have taken on a consistent form in recent years. Typical residential HPWHs have a storage tank with the heat pump components mounted on top in a semi-enclosed 'head.' Most systems have featured a condensing coil which wraps around the outside of the storage tank, all of which is then enclosed in insulation and an outer shell. At least one system has used a water pump to bring water from the bottom of the tank to a separate condensing heat exchanger, then back into the top of the tank; this strategy is largely being abandoned as it tends to mix residential-sized tanks. The compressor, expansion valve, evaporator, fan and other components are housed in the head area which is vented and/or ducted for evaporator airflow. These systems are sometimes referred to as "integrated HPWHs." The systems currently offered in the United States all include electric resistance heat elements for backup heat. The elements are up to 4.5 kW each and, in units with two elements, operate one at a time.

An additional, separate class of residential heat pump water heaters is seen internationally. HPWHs using CO2 as a refrigerant have been available in Japan and elsewhere since at least 2001. The most common configuration was developed by a collaboration including the Tokyo Electric Power Company (TEPCO), Central Research Institute of the Electric Power Industry (CREIPI) and the Japanese manufacturer Denso. This configuration is referred to under the umbrella name EcoCute. EcoCute HPWHs are made by a number of manufacturers and have been sold in the millions in Japan, Australia and Europe. The systems are sold in a split-type configuration: the tank and controls sit inside the home, while the heat pump components are all housed outdoors. Water circulates to the heat pump, in a single pass heating to the storage temperature and returning to the tank. Stratification is maintained in the tank. EcoCute systems typically heat water to a temperature much higher than the intended delivery temperature, and use a mixing valve to deliver water at the desired outlet temperature. The devices common to Japan feature "smart" controllers which allow for time-of-use heating, and have variable speed compressors to allow high-efficiency, low output heating at some conditions, and higher output heating at other conditions. They also have extra features such as a bath water temperature maintenance system, which circulates bath water to a plate heat exchanger, drawing heat out of the storage tank to maintain the temperature of a bath tub. As many of these features are unlikely to sell in the United States, particularly given the high associated cost, manufacturers such as Sanden are also investigating using the core technology of the EcoCute to develop a simpler product operating with the same principles. Among the obstacles to adoption of $CO_2$ HPWHs in the US is the high operation temperature and pressure of the heat pump cycle: the critical point of $CO_2$ is 1079 psia and 87.8°F and $CO_2$ heat pump water heaters routinely operate at temperatures and pressures well above this condition. However, manufacturers are pursuing Underwriter's Laboratory (UL) and other certifications, which would increase confidence in the safety of $CO_2$ HPWH systems. EPRI previously reviewed one such system, manufactured by Daikin, in the 2008 report *Performance Assessment of an Eco-Cute Heat Pump Water Heater*. EPRI, Palo Alto, CA. 2008. 1016074 [2].

## Commercial Heat Pump Water Heaters

In some commercial water heating applications, the same unit that is sold for residential applications may function just as well for a commercial one. For example, office buildings which are served by a small residential-type water heater may be served by an integrated HPWH. However, commercial buildings vary tremendously in their hot water needs and available heat sources; as such, the HPWH product lines developed for commercial buildings are modular and generally should be engineered on a site-by-site basis. A commercial HPWH typically has a single packaged heat pump system, which houses all of the heat pump components and a water pump to bring water to a condensing heat exchanger. The HPWH is then paired with one or more separate storage tanks. The design of a commercial heat pump water heater system entails selecting a heat pump component, a storage tank or tanks, and a backup or auxiliary heat source if desired. From the electric utility perspective, the most attractive installations may feature large storage tanks, relatively small heat pumps, and no backup heat, providing large storage and minimal load peaks. However, these systems may have higher initial costs than those with smaller tanks and backup heat elements.

The available commercial HPWHs have one of two control strategies:

- Single pass: Water is drawn from the bottom of the storage tank. The flow rate is modulated such that the outlet temperature is the desired system storage temperature. The water returns to the tank, where it is fed into the top of the tank. This leads to top-down heating of the tank with a high level of stratification.
- Multi-pass: Water is drawn from the bottom of the storage tank at a fixed flow rate. The water is heated approximately 10-20°F and returned to the tank approximately one third of the way from the bottom. This strategy has the effect of heating the whole tank at once.

These two strategies are discussed in depth in EPRI's report, *Heat Pump Water Heaters for Commercial Buildings.* EPRI, Palo Alto, CA. 2011. 1021970 [3]. The commercial HPWH tested in this work uses a multi-pass strategy.

The water heating site design may include additional heat sources. Some commercial applications call for water at temperatures higher than HPWHs typically deliver, such as chemical-free sanitation applications which may require 180°F water. In other cases, the ambient air temperature available may not be consistently high enough for the HPWH to always operate. Or, the HPWH may be added as a retrofit and the tank not necessarily be optimized to the HPWH capacity, or for budget reasons the tank or HPWH size selection may be limited. For any of these reasons among others, auxiliary heat sources such as electric resistance or natural gas can be used. The heat sources may be applied in the same tank, in an instantaneous heater configuration, or in a separate storage tank.

As evidenced by the many possibilities discussed above, system sizing and design is usually best done on a site-by-site basis.

The system discussed in this report is an air-to-water heat pump. Not discussed here but of equal significance are water-to-water systems. In these systems, both the evaporator and condenser are water-to-water heat exchangers, and heat is moved from a liquid heat source to a liquid heat sink. These systems are most attractive when a waste stream of hot liquid is available and/or a chilled liquid supply is needed.

## Continuing Research Areas

As heat pump water heaters expand their presence in the residential and commercial markets, ongoing research will be essential in allowing consumers, architects, engineers, contractors and business owners to make informed decisions, and in helping the technology grow and improve in efficiency, reliability and capability. Some of the areas already being focused on by EPRI and others, or in need of research attention include:

- Verifying the savings of systems in the field. HPWH systems, and particularly commercial HPWH systems which have been deployed in very small numbers to date, offer promise of savings; however, confidence in the technology depends upon third party verification of the claimed benefits. Manufacturer claims and laboratory findings must be supported by real-world results. EPRI has studied residential HPWHs extensively in the field through the Energy Efficiency Demonstration, and seeks to extend this effort to commercial systems in the Energy Efficiency Demonstration 2.0. Field tests of residential and commercial systems in many climates will continue, to help map the viability and performance of these devices.
- Examining technologies that address some concerns about HPWH, such as cold ambient conditions and whole-house impacts of HPWH in the conditioned space or adjacent spaces. As part of a Technology Innovation project, EPRI seeks to quantify whole-building effects initial through building modeling.

- Examining emerging technologies, including those using alternative refrigerants and radical redesigns compared with the conventional HPWH. EPRI's research in $CO_2$ HPWHs, discussed in this report, addresses one alternative. EPRI also intends to test $CO_2$ systems for commercial applications in 2013. Further testing in the laboratory and field on these systems as well as other concepts that emerge is essential to the progress of the technology.
- Quantifying and progressing the capability of water heaters for grid connectivity, demand response and other utility-facing functionality. Since HPWHs and other water heaters store energy, they offer the potential to be used as a resource to influence load shapes. Manufacturers presently engage with utilities and EPRI to attempt to provide some of these functions; however, a clear path forward has yet to emerge.

EPRI, through a Technology Innovation project co-funded by the Bonneville Power Administration, is examining the heat pump water heater thoroughly to identify and lead the "next generation" of the technology. This project will aim to, among other things, improve efficiency, reduce or eliminate load "peaks" associated with electric resistance heating, provide electric utilities with a load resource, and provide customers with a "smart" appliance that meets their demands.

# Section 2: Site Description

The site selected for demonstration of HPWH technology is a condominium building at a time-share resorts in Escondido, California. The selected site is in California climate zone 10 (CZ 10). This two level building has a total of 8 apartment units that are rented as time-share units, four on each level. Each unit has two showers and a kitchen. Figure 2-1 shows bird's-eye view of the selected site.

*Figure 2-1*
*Selected Site (from Google Earth)*

### California Climate Zone 10

California CZ 10 encompasses the interior hills and valleys of Southern California. This inland region is not affected by the ocean as much as some other zones like CZ 7. As such, this hilly region experiences greater seasonal temperature extremes and can get cold in winter months with temperatures reaching freezing or below in some areas. Most of the cities in CZ 10 have equal cooling and heating requirements over the course of the year. However, in the case of water heating, the number of heating and cooling degree days are not directly related to energy use.

# Section 3: Heat Pump Water Heating System

The existing water heating system on site consisted of two electric resistance water heaters connected in series. In this arrangement, one 80-gallon, 4.5 kW (single-phase) ERWH was coupled with a 119.9-gallon, 12kW (three phase) water heater as shown in Figure 3-1. The setup is housed in an unconditioned mechanical room separate from any of the living units. The building is equipped with a hot water loop so that end units can get hot water as soon as possible. The loop was not in working condition and wasn't fixed for this project as it was determined to be out of scope for the current project objectives.


*Figure 3-1*
*Existing Water Heating Setup*

The heat pump water heater confiuration employed the larger 119.9 gallon water heater and added another 119 gallon storage tank (without heating elements) to the system in place of the 80 gallon electric water heater. This increased total storage capacity by 40 gallons in order to prevent user disatisfaction from insufficient hot water. Figure 3-2 shows the schematic of plumbing, electrical and instrumentation for the proposed system.

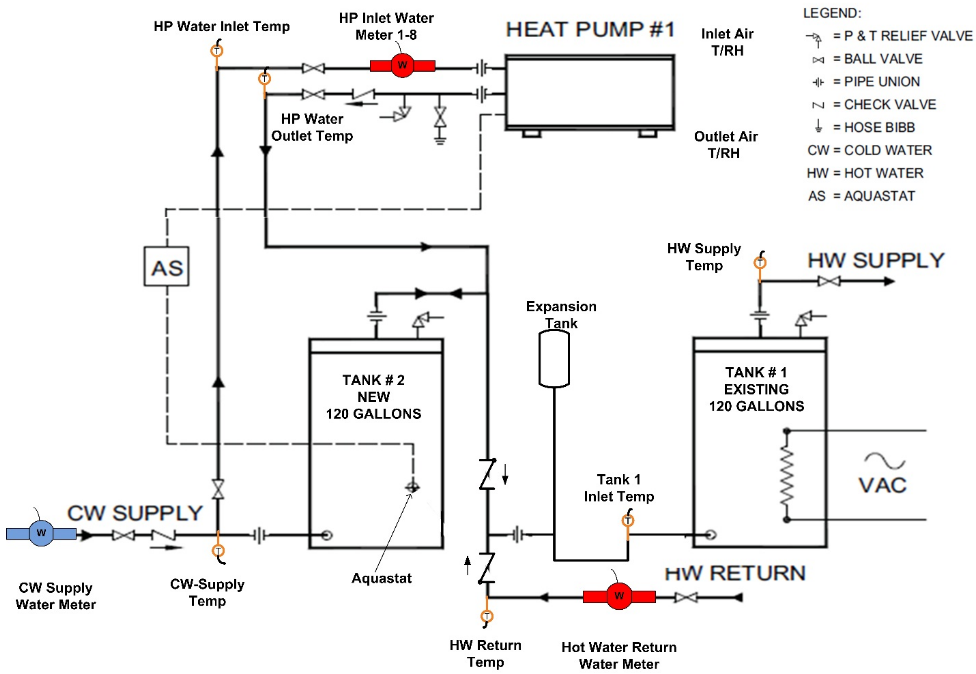


*Figure 3-2*
*Instrumentation Plan for HPWH Setup*

## Specifications of Heat Pump Water Heater

The commercial HPWH chosen for this demonstration is the Colmac HPA4. This unit is capable of providing 66.1 MBH at 27.6 A (approximately 10 kW) with an integrated (both heating and cooling effects are used) COP of 8.7. Table 3-1 shows the specifications of this unit. The HPA4 is a single-pass water heater, signifying that output temperature is maintained by modulating flow rate based on inlet temperature.

*Table 3-1*
*Specification of Colmac HPA4 Water Heater*

| | |
|---|---|
| Full Load Amperage | 27.6 A |
| Heating Capacity | 66.1 MBH |
| Cooling Capacity | 52.6 MBH |
| Integrated COP | 8.7 |
| Refrigerant | R134a |

## Water Heating System Operation

Figure 3-2 depicts the configuration of the water heaters, with water flow directed from left to right. Cold water enters from the CW supply through the blue cold water flow meter. This flow meter measures the total cold water coming into the water heating system and hence the hot water supplied to the entire building. The incoming water follows two different paths depending on the situation encountered:

### *No Water Draw*

When no water is drawn from the building, the HPWH draws water from tank 2 (the new tank), heating the water and returning hot water to the top of the new tank. Thermal stratification keeps the hot water on top while cold water stays at the bottom. This cycle continues until the aquastat (temperature sensor) reaches its set temperature. The tank one on initial startup gets heated by the heating elements and the heating elements also make up for stand-by losses.

### *Water Draw*

When hot water is drawn (water is used by someone in the building), the water is taken from top of the downstream tank (old 119.9 gallon tank) and cold water enters the upstream tank from the bottom. This cold water eventually reaches the level where aquastat is located and triggers the heat pump to start heating water. When heat pump is heating water the hot water from the heat pump, rather than going to the top of the upstream tank goes straight to the downstream tank. This arrangement ensures that downstream tank is the one that gets replenished first.

## Instrumentation

The instrumentation plan involves monitoring three important characteristics of the water heating system – electrical, thermal and water flow. Electrical measurements include monitoring the following parameters for the HPWH and the backup resistance water heater:

1. Power draw (kW)
2. Energy (kWh)
3. Current (A)
4. Power factor

Thermal measurements include temperature measurements at various points in the system as shown in Figure 3-2. Temperature and relative humidity are measured at the air-side inlet and outlet of the HPWH. Three water flow meters measure system water flow, water flow through the heat pump and through the recirculating loop. The recirculating loop water flow meter was added to cover the possibility of the loop being repaired at a later date by the building owner.

### Data Monitoring

Data monitoring is accomplished by using the following sensors –

*Table 3-2*
*Monitoring Equipment Used*

| Measurement | Device / Instrument | Accuracy |
|---|---|---|
| Power | Elkor WattsOn | Within 0.2% @ 25°C |
| Energy | | |
| Power Factor | | |
| Current | Accu-CT | ±0.75% |
| Water Temperature | Veris TI Series | ±0.1°F |
| Air Temperature | Dwyer RHT-R016 Temperature | ±2% @ 10-90%RH |
| Air Relative Humidity | Dwyer RHT-R016 RH | ±2% @ 10-90% |
| Water Flow Rate | Badger Meter Recordall Disc Meter | 95% for low flow and ±1.5% for normal flow rates |

For transferring the data back to EPRI server, communications products from Obvius (Obvius Holdings, LLC) were used.

- AcquiSuite – data acquisition server
- FlexIO – universal input / output module
- ModHopper – wireless Modbus transceiver
- Cell Modem – Airlink 3G

# Section 4: Data Analysis

The water heating system was monitored for a period of one full year, from January 2014 to December 2014. Data analysis for this period is presented in this section.

## Energy Use and Efficiency

The energy use by the heat pump water heater (HPWH) and the electric resistance water heater (ERWH) is shown in Figure 4-1.

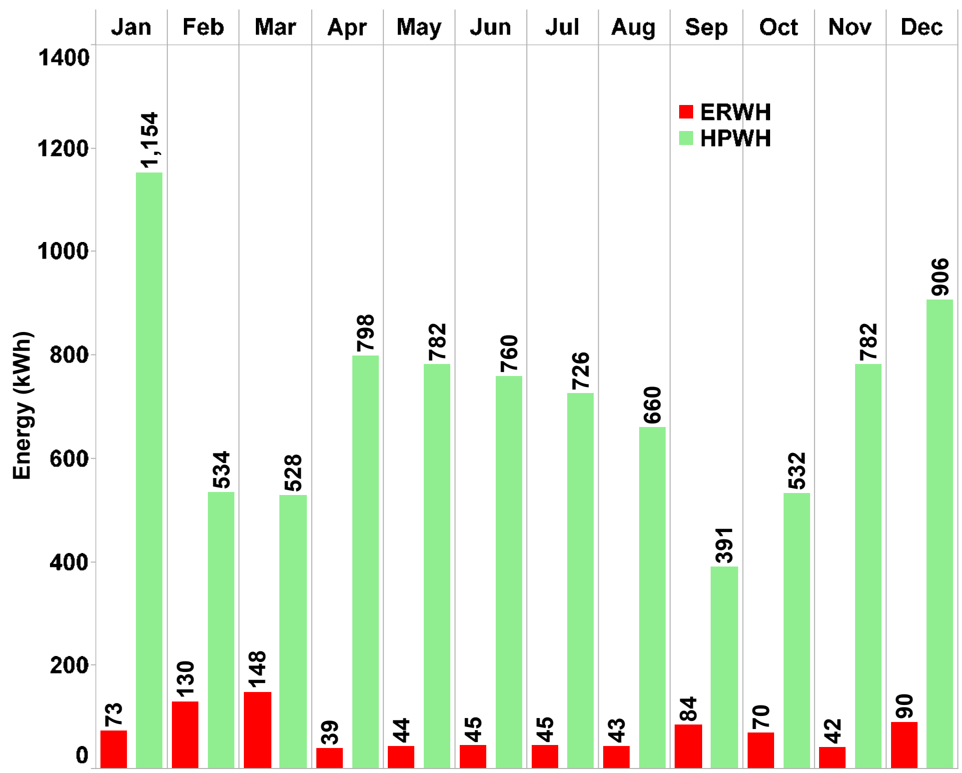


*Figure 4-1*
*Energy Use by Month*

Energy usage for the HPWH is much higher than the ERWH, as was the intent of the system design. Since the HPWH is more efficient than the ERWH, most (and if possible, all) water should be heated using the HPWH. The ERWH in this case provides for the standby losses from the downstream tank. The building was unoccupied during 02/23/2014 to 03/13/2014 for remodeling and which is reflected in the overall energy usage during the months of February and March. As the system was not in use, the standby losses were higher which is also seen by higher input from the ERWH.

Performance of the HPWH is dependent on the ambient temperature. Lower ambient temperature causes the heat pump to work harder to extract heat from the surroundings to be transferred into water. The coefficient of performance of a HPWH is defined as the ratio of energy output (heat transferred to water) to energy input (electrical energy). The heat transferred by the heat pump to water can be calculated from inlet water temperature, outlet water temperature and the mass flow rate of water. All these data points are available through the EPRI instrumentation. With this information the COP of the HPWH can be calculated. Figure 4-2 shows the COP of the HPWH for different temperature bins.

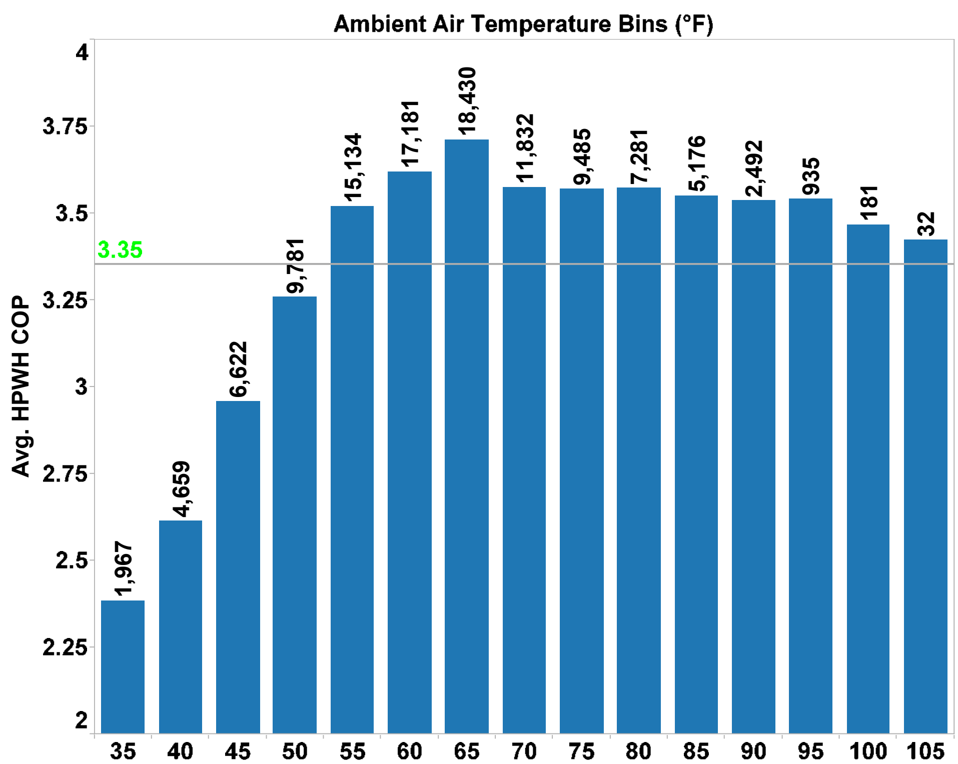


*Figure 4-2*
*COP of HPWH for Different Temperature Bins*

The temperature bins are for 5˚F with the displayed number being the center of the bin. For example temperature bin of 40˚F includes data between 37.5˚F and 42.5˚F. The numbers on the bar graph indicated the number of minutes the HPWH was operating in that temperature bin during the entire year. As expected, colder ambient temperatures result in lower COPs. However, the performance at lower temperatures is at least double that of an ERWH alone. With maximum COP of 1, an ERWH would use at least double the amount of energy as the HPWH, whose minimum COP was 2.3. It must be noted that this is the COP of the HPWH itself and not the COP of the entire system. The COP of the entire system is reduced due to heat losses and the low efficiency of ERWH. Figure 4-3 shows comparison between HPWH COP and the entire system COP.

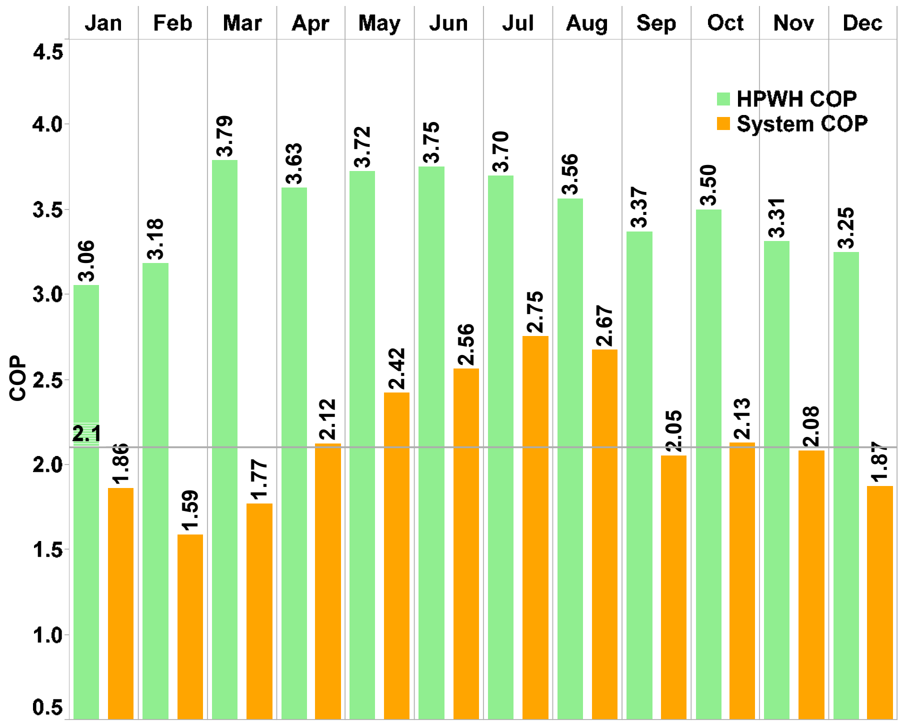


*Figure 4-3*
*Monthly HPWH and Entire System COP*

Over the course of the year, the average COP of the system was found to be 2.1. The COP is slightly degraded during months of February and March due to building shut down for remodeling.

If there were no HPWH system, the entire water heating load would have been handled by the ERWH. The total energy used by the ERWH to satisfy the same water heating load is given by

$$Energy_{ERWH} = Total\ Water\ Usage\ (lbs) * \Delta T_{water}(°F) * C_{p,water}\left(\frac{BTU}{lb\ °F}\right) + Losses\ (BTU)$$

*Eq. 4-1*

where

Energy is total energy used in given time to heat given amount of water

ΔT is the temperature difference between the incoming water (cold water) and the hot water supplied to the building

$C_p$ is specific heat of water at constant pressure (1 BTU/lb °F)

Losses are the standby losses from the tank which are calculated based on the actual standby losses observed during this test. All the ERWH energy input for the year has been to make up for standby losses. The ERWH did not run for more than a few minutes at a given time and mostly ran when there was no water usage. This is typical behavior of an ERWH making up for standby losses. Figure 4-4 shows this behavior for three days in the month of September. It can be clearly seen that the ERWH power draw (red lines) coincide with the flat periods on the blue line which indicate no water draw. In these periods there is no water draw and the small amount of energy added is only to compensate for the heat loss during the stand-by period.

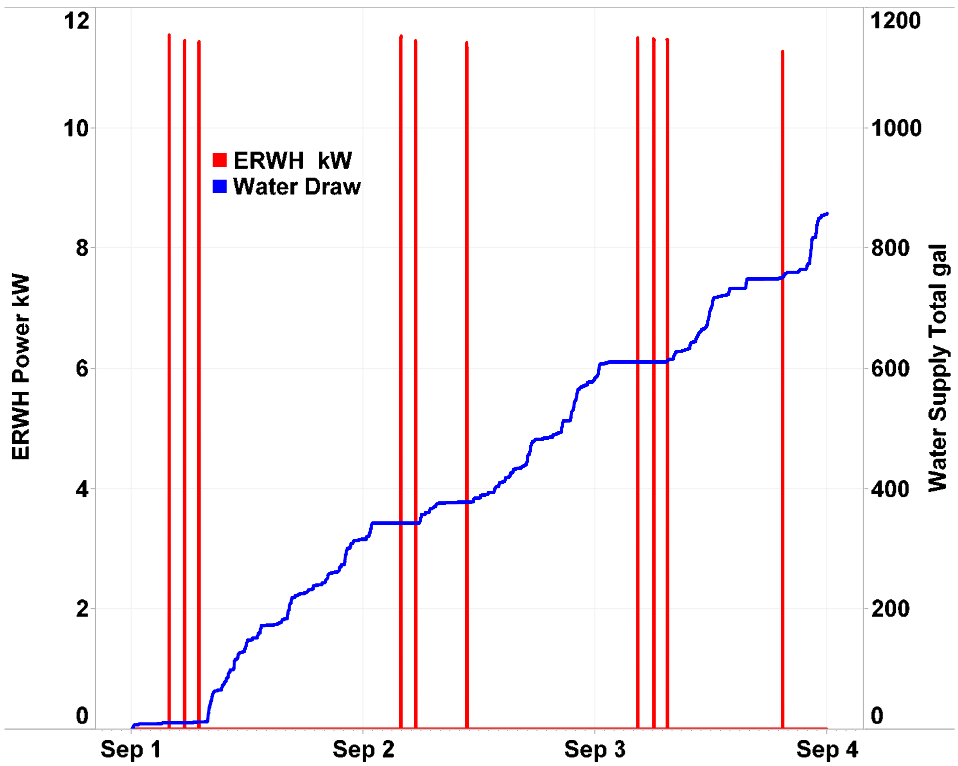


*Figure 4-4*
*Water Draw and Power Draw from 3 Days in September 2014*

For the entire year, the energy lost per hour as a standby losses from the ERWH was 350 BTU. This loss is taken as a constant hourly loss from the system. The new installed tank will also have losses but are not considered since there is no instrumentation to determine the loss. The loss could be estimated but for this analysis, those losses are ignored.

## Billing Data

Billing data for the building was provided to confirm the measured energy use data, shown in Table 4-1.

The water heating system and some ancillary building loads (lights and sprinkler system) are on one common meter for which billing data was made available. The exact billing dates were not available (bill date indicates when the customer was billed and not the period of service).

*Table 4-1*
*Comparison between Billing Data and EPRI Measured Data*

| Bill Date | SDG&E Billed Usage 2013 (kWh) | SDG&E Billed Usage 2014 (kWh) | EPRI Measured Data (kWh) |
|---|---|---|---|
| January | 2,029 | 1,267 | 1,226 |
| February | 1,569 | 778 | 663 |
| March | 2,240 | 992 | 676 |
| April | 2,434 | 1,033 | 837 |
| May | 2,164 | 951 | 826 |
| June | 2,719 | 957 | 805 |
| July | 2,171 | 978 | 771 |
| August | 1,860 | 873 | 703 |
| September | 1,704 | 648 | 474 |
| October | 1,996 | 818 | 602 |
| November | 2,169 | 1,032 | 824 |
| December | 2,147 | N/A | 996 |

The data lines up very well with what is measured by the utility meter. The EPRI monitoring data is well in line with the SDG&E meter for year 2014. With no other loads being modified, the energy use in 2014 has gone significantly down as compared to 2013.

## Energy Comparison

Table 4-2 shows the monthly electricity consumption of each component of the water heating system measured during this field study. The first row ERWH is the electrical energy (in kWh) used by the electric resistance water heater as measured by EPRI's equipment. HPWH is the energy used (in kWh) by the heat pump, and Total Energy (kWh) is the sum of ERWH and HPWH energy use measured in this study. Baseline energy consumption is estimated using the water draw measured in this study.

*Table 4-2*
*Energy Use by Month*

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ERWH (kWh) | 73 | 130 | 148 | 39 | 44 | 45 | 45 | 43 | 84 | 70 | 42 | 90 | 850 |
| HPWH (kWh) | 1,154 | 534 | 528 | 798 | 782 | 760 | 726 | 660 | 391 | 532 | 782 | 906 | 8,552 |
| Total Energy (kWh) | 1,226 | 663 | 676 | 837 | 826 | 805 | 771 | 703 | 474 | 602 | 824 | 996 | 9,402 |
| Baseline (kWh) | 2,207 | 880 | 1,038 | 1,696 | 1,930 | 2,044 | 2,078 | 1,878 | 966 | 1,279 | 1,649 | 1,767 | 19,411 |
| Savings (kWh) | 981 | 217 | 362 | 859 | 1,104 | 1,239 | 1,307 | 1,175 | 491 | 677 | 825 | 771 | 10,009 |
| Savings ($) | $201 | $44 | $74 | $176 | $301 | $338 | $357 | $321 | $134 | $185 | $169 | $158 | $2,459 |

This analysis shows estimated annual energy savings of 10,009 kWh from the use of HPWH over ERWH alone. This signifies energy savings of 52%. Using SDG&E's Schedule A rates for general service customers, these savings amount to $2,459 annually.

### Water Usage Profile

Water usage profile is an important aspect of the study, although it does not directly correlate with the power draw or energy consumption. The importance of understanding water draw is that the demand (kW) from water heating system tends to follow the water draw pattern in case of the ERWH. Figure 4-5 shows the hourly water draw profile for the entire year. The water draw profile indicates high water draw in the times when the system demand is highest as well. As such the ERWH becomes a coincident load and any reduction in either the actual power draw or the time of energy use is of benefit to the utility.

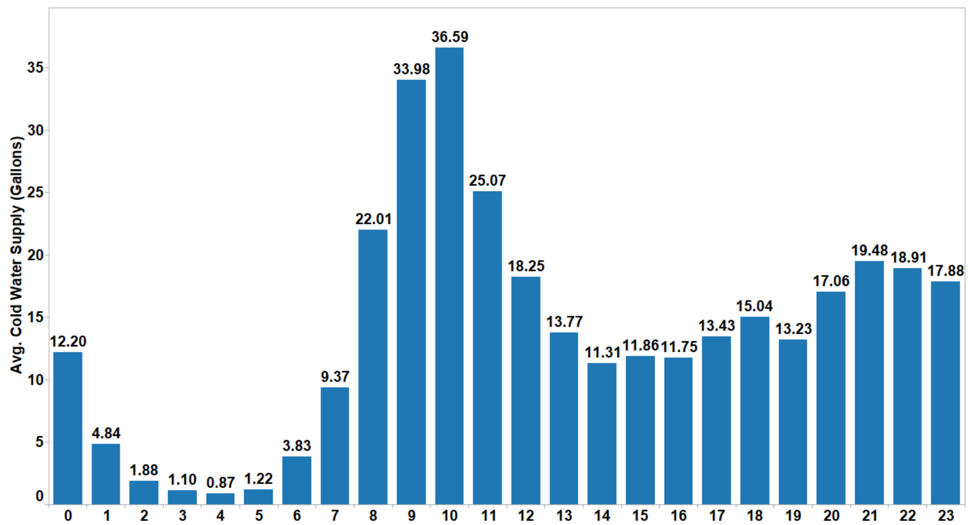


*Figure 4-5*
*Average Hourly Hot Water Demand*

The water draw is also beneficial in understanding and sizing similar water heating systems on the property (approximately 60 additional systems). The availability of this data will help guide the design of the systems. Figure 4-6 shows the total water draw for each month of the study. Again, it should be noted that the building was vacant 02/23/2014 to 03/13/2014, causing water draw to be reduced for February and March.

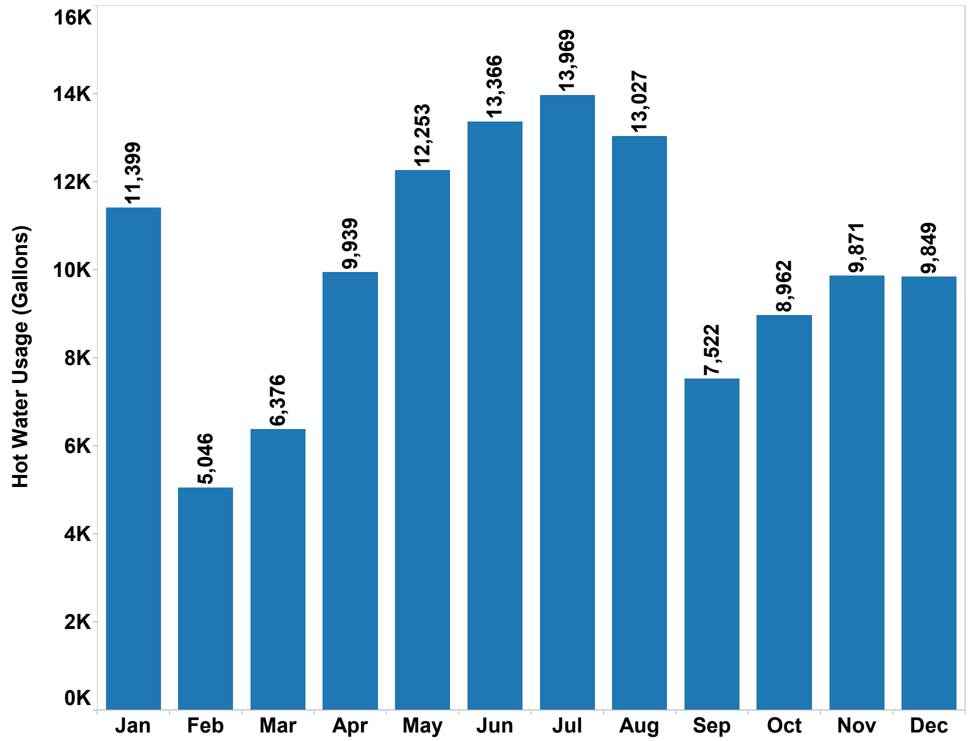


*Figure 4-6*
*Monthly Hot Water Usage*

# Section 5: Utility Implications

The energy savings demonstrated in this study can be achieved at other similar commercial installations in SDG&E's territory, especially in places where ERWH is currently used for water heating. The resort at which this study was performed has numerous other buildings on the property which would be great candidates for the commercial HPWH technology.

## Cost Considerations

The cost of such a system is undeniably higher than a simple ERWH. The total cost of this installation was approximately $24,000 which was a fixed price that included all equipment and labor. The cost is slightly higher than typical due to the installing contractor's unfamiliarity with the technology and the added complexity of installing all the monitoring equipment and replacing the existing hot water storage tank. As contractors become familiar with this technology, installation costs should decrease. The equipment cost was not itemized on the original quote received by EPRI. Based on others' quotes and previous work done by EPRI, the total installed cost (equipment and labor) of a similar system is in the $8,000 to $11,000 range. Given the $2,459 annual savings estimated in Chapter 4, simple payback of the added cost of the HPWH is roughly 3.2 to 4.4 years.

## Commercial HPWH Potential in California

The state-wide energy consumption data reported by the California Energy Commission in its 2006 report "California Commercial End-Use Survey (CEUS)" [3] is used to determine potential energy savings from commercial HPWHs.

The total electrical energy used to heat water in commercial buildings in California is 611 GWh [3]. Table 5-1 (Table 8-2 from [3]) shows the 12 commercial building types defined by the CEUS, with their corresponding water heating energy use. The table values show that the 'Miscellaneous' building type uses more electrical energy for water heating than any other building. However, the nature of this classification makes it difficult to target a 'miscellaneous building' category for promoting HPWHs through utility programs. The application studied in this project is classified as a lodging, which as a category has an energy usage of 9 GWh for the entire state. Other building types like restaurant and health can also be targeted. A significant advantage with restaurants is that the commercial HPWH can be used to also cool commercial kitchens which in general need some sort of mechanical cooling equipment. Considering these additional building types the potential exists to target 83 GWh of energy use annually.

*Table 5-1*
*Water Heating Energy Usage in California (Commercial buildings)*

| Building Type | Water Heating Energy Use (GWh) |
|---|---|
| Small Office (<30,000 $ft^2$) | 90 |
| Large Office (>30,000 $ft^2$) | 80 |
| Restaurant | 56 |
| Retail | 96 |
| Food Store | 20 |
| Refrigerated Warehouse | 3 |
| Unrefrigerated Waterhouse | 26 |
| School | 43 |
| College | 25 |
| Health | 18 |
| Lodging | 9 |
| Miscellaneous | 145 |

Electric energy use for water heating in commercial buildings in SDG&E territory is estimated to be 93.6 GWh. The potential exists to address the entire segment, but if only the lodging, restaurant and health building types are considered a total of 12 GWh can be addressed. If conservatively energy savings of 50% is assumed, the total potential just in SDG&E's territory is about 6 GWh.

## Additional Research Needs

For both residential and commercial HPWH systems, research continues to verify the energy efficiency and demand reduction numbers discussed above and elsewhere. Readers of this report may find results of interest in the following areas:

- Demonstration of energy efficiency for commercial HPWH systems. Commercial HPWHs can significantly reduce energy consumption compared with electric resistance units, and may also offer comparable performance to gas. The field testing performed here provides real-world results to augment laboratory findings.
- Evaluation of residential HPWH systems which provide better performance in cold ambient conditions. Demand reduction in the winter is generally minimal when ambient conditions are cold, because many systems disable

heat pump operation below certain temperatures, resulting in electric resistance heating.

- Evaluation of advanced systems using $CO_2$ refrigerant, which may represent a next-generation product in the US. If HPWHs continue to grow in market share, these systems may emerge as viable products in the US. With high storage temperatures and no electric resistance backup heat, these systems look very different from conventional US devices. Their energy efficiency savings and demand reduction potential are high, and they offer “smart” controls which can control time-of-use, providing a valuable additional utility benefit. Test results for these systems can help advise utilities looking for longer-term input to what may emerge in the HPWH market.

# Section 6: References


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6. *Performance Testing Residential Heat Pump Water Heaters under South- and Central-Florida Climate Conditions: Hot, Humid Climate and Warm Ground Water Pose Unusual Operating Environment for Heat Pump Water Heaters*. EPRI, Palo Alto, CA: 2013. 3002001998.
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***Program:***

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