U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM

Measure Guideline: Heat Pump Water Heaters in New and Existing Homes

C. Shapiro, S. Puttagunta, and D. Owens
Consortium for Advanced Residential Buildings (CARB)

February 2012

Building America
U.S. Department of Energy

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Measure Guideline: Heat Pump Water Heaters in New and Existing Homes

Prepared for:

Building America

Building Technologies Program

Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

Prepared by:
Carl Shapiro, Srikanth Puttagunta, and Douglas Owens

Steven Winter Associates, Inc.

of the

Consortium for Advanced Residential Buildings (CARB)

50 Washington Street

Norwalk, CT 06854

NREL Technical Monitor: Cheryn Engebrecht

Prepared under Subcontract No. KNDJ-0-40342-02

February 2012

[This page left blank]

Contents

List of Figures

Unless otherwise noted, all figures were created by the CARB team.

List of Tables

Unless otherwise noted, all tables were created by the CARB team.

Definitions

CARB	Consortium for Advanced Residential Buildings
COP	Coefficient of Performance
DHW	Domestic Hot Water
EF	Energy Factor
ERWH	Electric Resistance Water Heater
GE	General Electric
IECC	International Energy Conservation Code
NREL	National Renewable Energy Laboratory
ROI	Return On Investment
SPB	Simple Payback Period

Foreword

Heat pump water heaters (HPWHs) promise to significantly reduce energy consumption for domestic hot water (DHW) over standard electric resistance water heaters (ERWHs). While ERWHs perform with energy factors (EFs) around 0.9, new HPWHs boast EFs upwards of 2.0. High energy factors in HPWHs are achieved by combining a vapor compression system, which extracts heat from the surrounding air at high efficiencies, with electric resistance element(s), which are better suited to meet large hot water demands. Swapping ERWHs with HPWHs could result in roughly 50% reduction in water heating energy consumption for 35.6% of all U.S. households.

This Building America Measure Guideline is intended for builders, contractors, homeowners, and policy-makers. While HPWHs promise to significantly reduce energy use for DHW, proper installation, selection, and maintenance of HPWHs is required to ensure high operating efficiency and reliability. This document is intended to explore the issues surrounding HPWHs to ensure that homeowners and contractors have the tools needed to appropriately and efficiently install HPWHs.

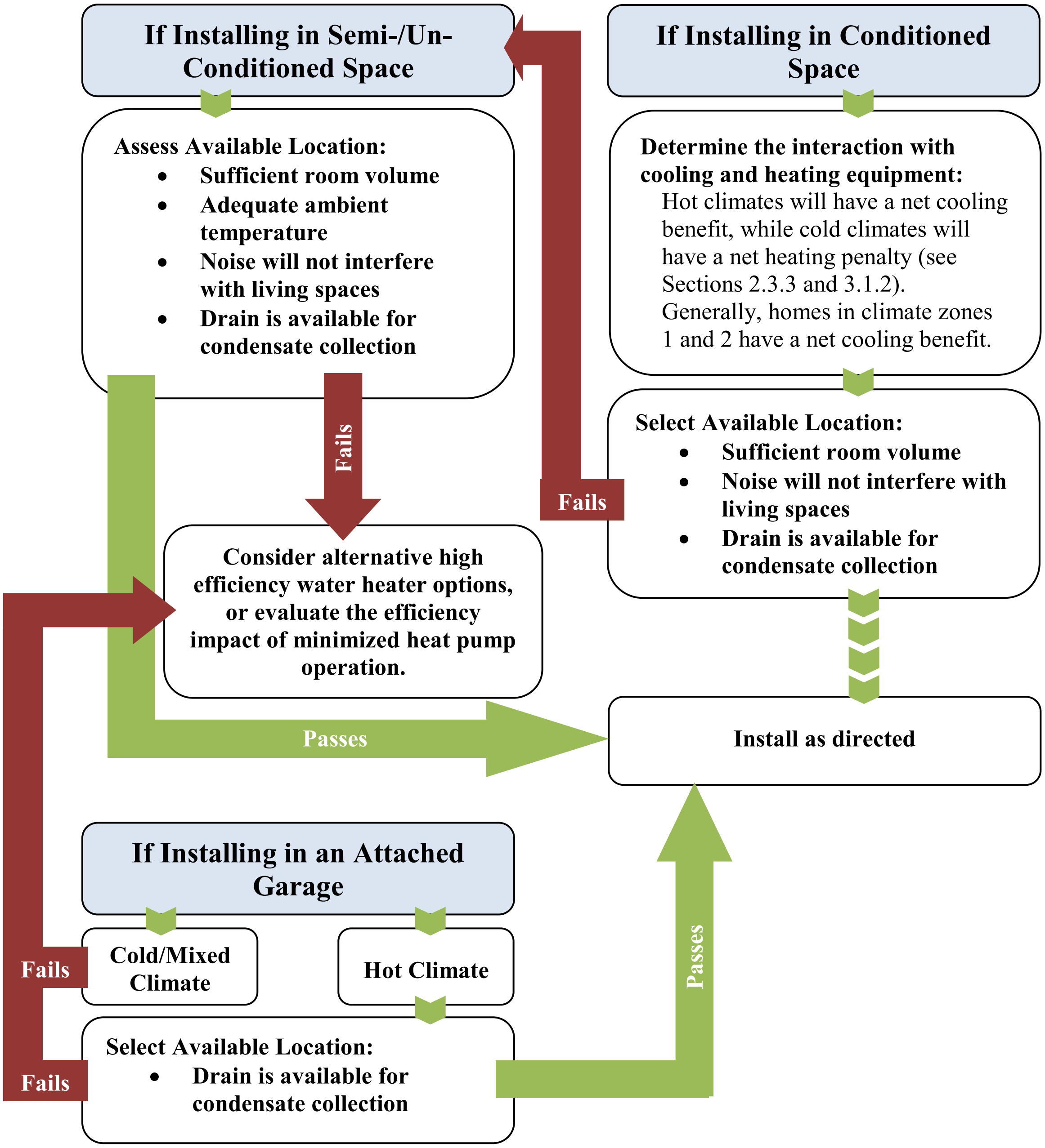
Section 1 of this guideline provides a brief description of HPWHs and their operation. Section 2 highlights the cost and energy savings of HPWHs as well as the variables that affect HPWH performance, reliability, and efficiency. Section 3 gives guidelines for proper installation and maintenance of HPWHs, selection criteria for locating HPWHs, and highlights of important differences between ERWH and HPWH installations.

Throughout this document, CARB has included results from the evaluation of 14 heat pump water heaters (including three recently released HPWH products) installed in existing homes in the northeast region of the United States.

Acknowledgements

This guideline is the product of a collaborative effort. The authors acknowledge the funding and support of the US Department of Energy's Building America Program and our utility sponsors: National Grid, NSTAR, and Cape Light Compact. Special thanks to Keith Miller and Andrew Wood of National Grid, Richard Moran of NSTAR, and Margaret Song of Cape Light Compact.

Progression Summary



1 Introduction

1.1 Background

Heat pump water heaters (HPWHs) promise to significantly reduce energy consumption for domestic hot water (DHW) over standard electric resistance water heaters (ERWHs). While ERWHs perform with energy factors (EFs) around 0.9, new HPWHs boast EFs upwards of 2.0. High energy factors in HPWHs are achieved by combining a vapor compression system, which extracts heat from the surrounding air at high efficiencies, with electric resistance element(s), which are able to help meet large hot water demands. Water heating is the third largest contributor to residential energy consumption, after space heating and space cooling (EERE 2011). Swapping ERWHs with HPWHs could result in roughly 50% reduction in water heating energy consumption for 35.6% of all households nationally, as shown in Table 1.

Table 1. 2005 RECS Data Sample of Households with ERWHs (Franco et al. 2010)

Census Region	Fraction of Households with ERWH by Region
Northeast	17.1%
Midwest	26.7%
South	58.8%
West	21.5%
National	35.6%

While HPWHs are not new, products designed for the residential market have achieved minimal market penetration in the past, primarily because past products were produced by smaller, niche-market manufacturers, encountered reliability issues, and operated with limited market infrastructure. Although HPWHs were first commercialized in the 1980s, they were typically add-ons to existing ERWHs, which required specialized knowledge for installation and often required both an HVAC contractor and a plumber to install the system. The development of drop-in HPWHs allowed for easy installation by a single trade (Tomlinson 2002).

Recently, major manufacturers, such as General Electric (GE), Rheem, AO Smith, and Stiebel-Eltron, have introduced "drop-in" HPWHs (Table 2). The development of these models has been fueled by the large electric water heater replacement market and ENERGY STAR® certification of many HPWHs, which often allows for state, federal, local, and utility rebates, tax credits, and other incentives. Furthermore, the new federal water heater standard, which takes effect in 2015, mandates EFs around 2.0 for all new electric storage water heaters with capacities greater than 55 gallons (Federal Register 2010). This regulation effectively mandates that water heaters be HPWHs in applications with large hot water demands and the need for electric storage water heaters.

Table 2. Key Specifications of Some HPWHs Currently Available in the U.S. Market

Model	Capacity (gal)	Energy Factor	First Hour Rating (GPH)
GE GeoSpring	50	2.35	63.0
AO Smith Voltex	60 / 80	2.33	68.0 / 84.0
Stiebel Eltron Accelera300	80	2.51	78.6
Rheem EcoSense	40 / 50	2.00	56.0 / 67.0
AirGenerate ATI	50 / 66	2.39 / 2.40	60.0 / 75.0

1.2 What Are Heat Pump Water Heaters?

In residential applications, the most common water heater appliances are electric resistance with storage tank (ERWH), natural gas with storage tank, and tankless natural gas. HPWHs are designed as replacements for standard ERWHs and are able to achieve higher energy factors by adding an additional heating mechanism to existing ERWH designs. The primary heating mechanism is a heat pump refrigeration cycle (like those in a refrigerator or air conditioner, but operating in reverse) that transfers heat from the surrounding air to the water stored in the tank (Figure 1). Auxiliary electric resistance elements are also included for reliability and quicker recovery. Unlike most previous models, most current HPWHs are truly hybrids: They integrate a heat pump and electric resistance element(s) into a single storage tank.

Figure 1. HPWH operation

The heat pumps can heat water in the storage tanks at high efficiencies, but the heat pumps have heating capacities lower than those of traditional electric resistance elements. Typical 4.5-kW electric resistance elements can reliably heat over 20 gallons of water per hour (GE 2011), whereas the heat pump has a longer heating rate (GE claims 8 gallons per hour at 68°F air temperature). The efficiency of a HPWH will vary considerably based on several operating parameters, such as inlet water temperature, tank temperature, inlet air temperature, and temperature set point.

These units often have several modes of operation, such as hybrid mode, heat pump mode, and electric resistance mode. The names of these modes differ by manufacturer, but most models include some combination of the above. The hybrid mode uses both the electric resistance element(s) and the heat pump to meet demand, but uses the heat pump whenever possible to maximize the efficiency of the unit. Heat pump mode includes only heat pump operation, which improves the efficiency of the unit, but reduces the recovery capacity of the water heater. Electric resistance mode works like a traditional ERWH and can be used when the ambient temperature of the space is inadequate or there is a problem with the heat pump.

2 Cost and Performance

Using HPWHs is a potentially cost-effective method of substantially reducing energy use for DHW when compared to use of electric resistance water heaters. Section 2.2 explores the energy and cost savings of HPWHs, while Section 2.3 explores the variables that affect the overall performance of HPWHs. Sections 2.4 and 2.5 discuss the dehumidification potential, reliability, and safety of HPWHs.

2.1 Performance Metrics

The efficiency of residential electric water heaters in the United States is measured and reported using the energy factor (EF) value. The energy factor represents the efficiency of the electric element and tank losses under a consistent, 24-hour test procedure. In this procedure, 64.3 gallons of water are drawn from the tank in six equal draws spaced one hour apart. The temperature of the drawn water must be 135±5˚F and the ambient temperature is 67.5˚F. The energy factor is simply the ratio of energy output to energy input during the test procedure (Burch and Erickson 2004; Federal Register 1998).

Since the energy factor is defined under the specific test conditions outlined above, for a unit that operates under real-world conditions or conditions different than the standard test, the coefficient of performance (COP) is the term used here to describe the efficiency of the unit under the measured conditions. Like EF, COP is the unit-less ratio of energy output to energy input during its operation.

When comparing energy use of water heaters using different fuels, EF or COP can be misleading because energy use is only measured at the home and does not include energy lost to extraction, conversion, or transmission of the energy. Therefore, water heaters using different fuels should be compared using a different metric. While energy usage is usually measured in site energy, which is the energy used at the home and is typically measured at a utility meter in units of kWh (electricity), therms (natural gas), or gallons (fuel oil or propane), a better metric for measured energy usage is source energy, which is the sum of energy used at the home and the energy lost to extraction, conversion, or transmission. Site energy easily can be converted to source energy using a site-to-source ratio (Deru and Torcellini 2007) for the given fuel.

When comparing water heaters that use different fuels, this guideline will use two metrics: cost to deliver each unit of water heating energy ($/delivered mmBTU) and "source COP," which is the efficiency of converting source energy into water heating energy. These metrics include the efficiency of extraction, conversion, and transmission.

2.2 Energy and Cost Savings

Traditional ERWHs are an inefficient and expensive form of water heating. As shown in Table 3 , electric resistance water heating has the lowest source COP and the highest cost per mmBTU of delivered water thermal energy. On the other hand, HPWHs have efficiencies and operating costs similar to natural gas storage water heaters, making HPWHs an excellent choice for homeowners who currently use an electric resistance, fuel oil, or propane water heater and do not have access to natural gas. Replacement of natural gas water heaters with HPWHs is not recommended in heating dominated climates because HPWHs will increase the load on the space heating system without a similar benefit to the space cooling system.

Table 3. Comparison of Water Heaters by Fuel Type

Water Heater Type	Storage Tank	Site-to-Source Ratio	Fuel Cost	EF	Source COP	$/Delivered mmBTU
Electric Resistance	Tank	3.365	$0.1126/kWh	0.90	0.27	$36.67
Heat Pump	Tank	3.365	$0.1126/kWh	2.00	0.59	$16.50
Fuel Oil	Tank	1.158	$2.8/gal	0.59	0.51	$34.22
Natural Gas	Tank	1.092	$1.1633/therm	0.59	0.54	$19.72
Natural Gas	Tankless	1.092	$1.1633/therm	0.82	0.75	$14.19
Condensing Natural Gas	Tankless	1.092	$2.03/gal	0.94	0.86	$12.38
Propane	Tank	1.151	$2.03/gal	0.59	0.51	$37.40

Marketed as replacements for electric resistance units, HPWHs promise to save considerable electric energy and money over traditional ERWHs. According to the U.S. government EnergyGuides for a 50 gallon ERWH with an EF of 0.90 and a HPWH with an EF of 2.35, a HPWH could save 2,684 kWh per year for an average family (Table 4). These water heaters are considerably more expensive to install than traditional ERWHs, but electric savings will likely save more money over the course of the water heater's life. Table 4 shows the installation and annual operating costs, according to the National Renewable Energy Laboratory's (NREL) National Residential Efficiency Measures Database and the U.S. government Energy Guide labels.

Table 4. HPWH vs. ERWH (U.S. Government EnergyGuide Labels)

Water Heater	Annual Electric Usage (kWh)†	Installation Cost*	Annual Operating Costs†
HPWH (50 gal, EF = 2.35)	1,856	$2,100	$198
ERWH (50 gal, EF = 0.90)	4,879	$590	$520

* NREL National Residential Efficiency Measures Database
† US Government Energy Guide Labels

Two methods of evaluating the cost effectiveness of energy efficiency measures are simple payback (SPB) and return on investment (ROI). The SPB period is the ratio of incremental initial cost (dollars) to annual energy savings (dollars/year).

$$SPB = \frac{\text{Initial Cost}}{\text{Annual Utility Savings}} \text{ years}$$

The ROI is the ratio of net proceeds to the investment costs.

$$\text{Simple ROI} = \frac{\text{Total Utility Savings} - \text{Measure Cost}}{\text{Measure Cost}} \times 100\%$$

Using the costs and savings in Table 4, the SPB period for HPWHs is 4.7, and the ROI is 113%.

Supporting Research

Field evaluations suggest that a 50-gallon HPWH has the potential to save a typical home 1,500 to 2,200 kWh per year, which represents a 45%-65% reduction in electricity usage for domestic hot water. These results are not comparable to U.S. government estimates because they reflect varying household usage patterns and, in some cases, the operation of the electric resistance element that reduces overall efficiency. Utilizing a TRNSYS model, actual household usage data for a new 50-gallon HPWH were compared to a typical 50-gallon ERWH with an EF of 0.92. The expected lifetimes of these units are 10 years, and 13 years, respectively. Using the Building America Standard Benchmark DHW Schedules for 1, 2, 3, 4 and 5 bedrooms (Hendron et al. 2010), expected annual energy savings for 1, 2, and 3+ bedroom houses are between 1,750 and 2,200 kWh per year (Table 5).

Table 5. Expected Annual Energy Savings by House Size

Number of Bedrooms	Average Daily Hot Water Usage (Gallons)	Expected Annual Energy Savings (kWh)	Annual Utility Bill Savings	Return on Investment	Payback Period (years)
1	35	1,750	$221	46%	6.6
2	45	2,000	$260	72%	5.8
3+	55	2,200	$286	89%	5.3

2.3 What Affects Performance?

Although the cost and energy savings discussed in the sections above are quite compelling, real world savings of each individual HPWH may be vastly different than those described above. Unlike conventional ERWHs, the efficiency of HPWHs is hard to predict and strongly dependent on hot water usage patterns (see Section 2.3.1) and ambient temperature (see Section 2.3.2). Furthermore, HPWH operation may impact the space conditioning equipment, increasing heating loads and decreasing cooling loads (see Section 2.3.3). Inadequate space and ambient temperature will also markedly reduce HPWH efficiency (see Sections 2.3.4 and 2.3.4).

2.3.1 Hot Water Usage

The primary driver of the efficiency and energy usage of a HPWH is hot water demand (e.g. gallons used per day). As with traditional ERWHs, standby losses reduce overall efficiency, particularly at lower hot water demands. Unlike ERWHs, however, HPWHs experience a reduction in efficiency as electric resistance heating is required to meet larger hot water demands.

There are two ways in which hot water consumption affects efficiency. Electricity consumption certainly increases with overall water consumption (i.e. average gallons used per day). However, electric consumption is even more dependent upon the intensity of hot water use. As the data below show, during intense, high-volume hot water draws, a hybrid HPWH will often operate in electric resistance mode. Electric resistance can provide more hot water faster, but it also consumes at least twice the electricity when compared to heat pump mode.

Figure 3 shows one day's worth of data where a HPWH uses the heat pump to satisfy all hot water needs. Figure 4 shows the same HPWH relying exclusively on the electric resistance elements to meet demand for a day with the same total hot water demand (70 gallons). Each data point in these charts is the totalized consumption over a 15 minute period. The first figure has a distribution of demand across the day, while the second day has large, concentrated draws during the afternoon and evening.

Supporting Research

Overall efficiency peaks around 20-30 gallons per day and decreases with increased demand due to an increase in hot water electric resistance element use. Overall electric usage strictly increases with domestic hot water demand. Figure 2 shows the average COP and electricity used for one HPWH model monitored during CARB's HPWH evaluation. These curves are smoothed fits to daily data and are meant to show the effect of hot water usage on efficiency and electricity usage.

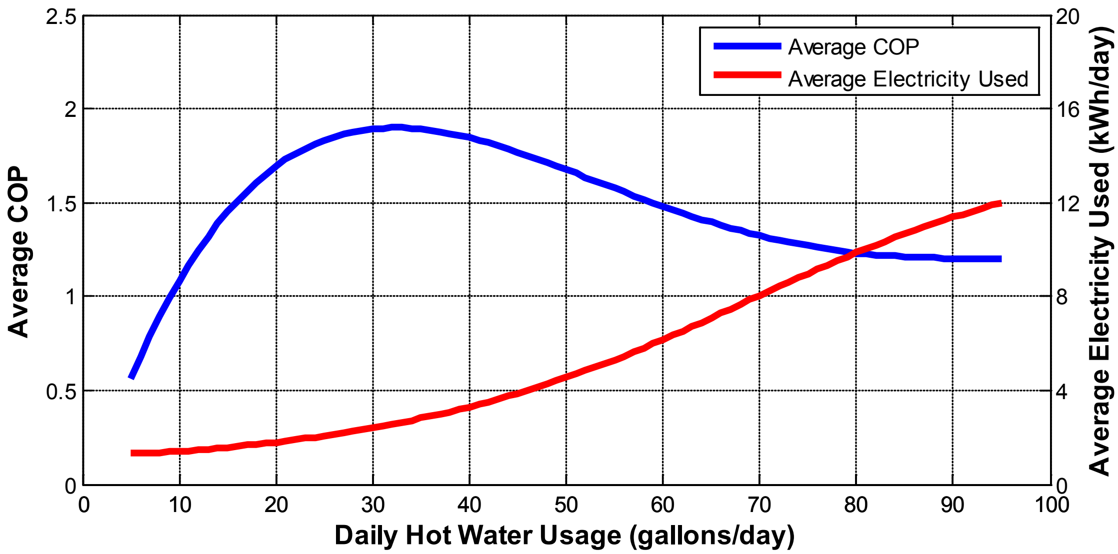


Figure 2. Efficiency and electricity usage as a function of hot water demand

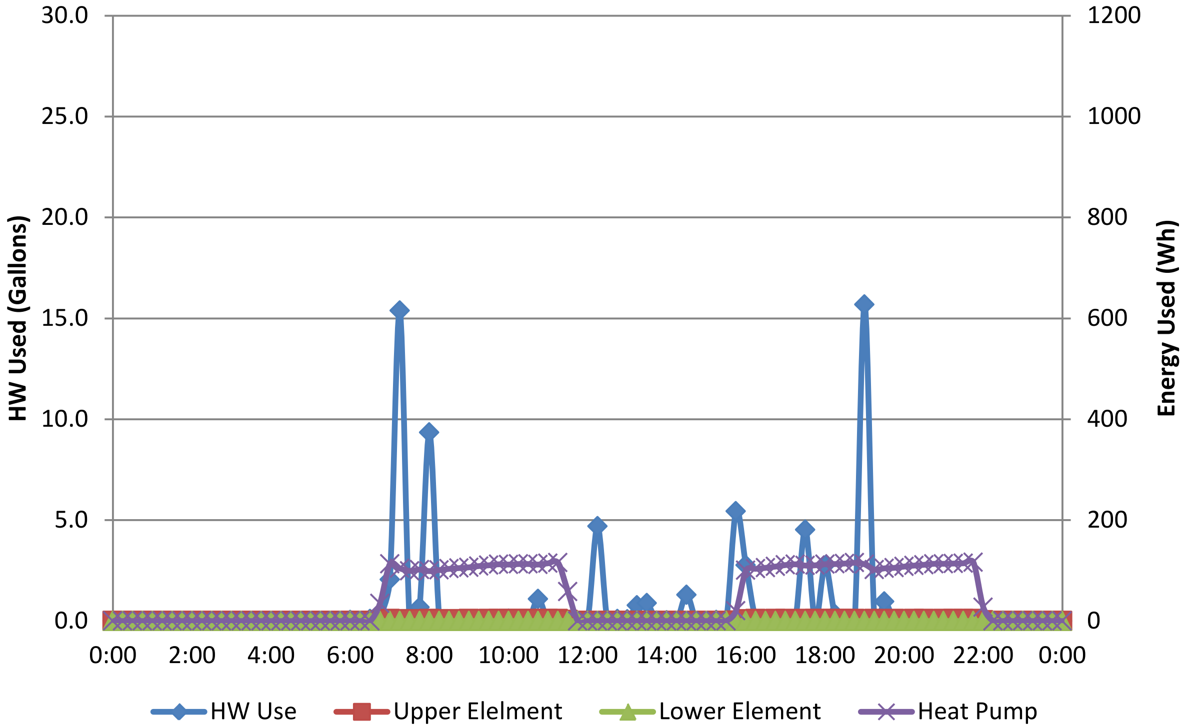


Figure 3. Majority heat pump usage to meet demand

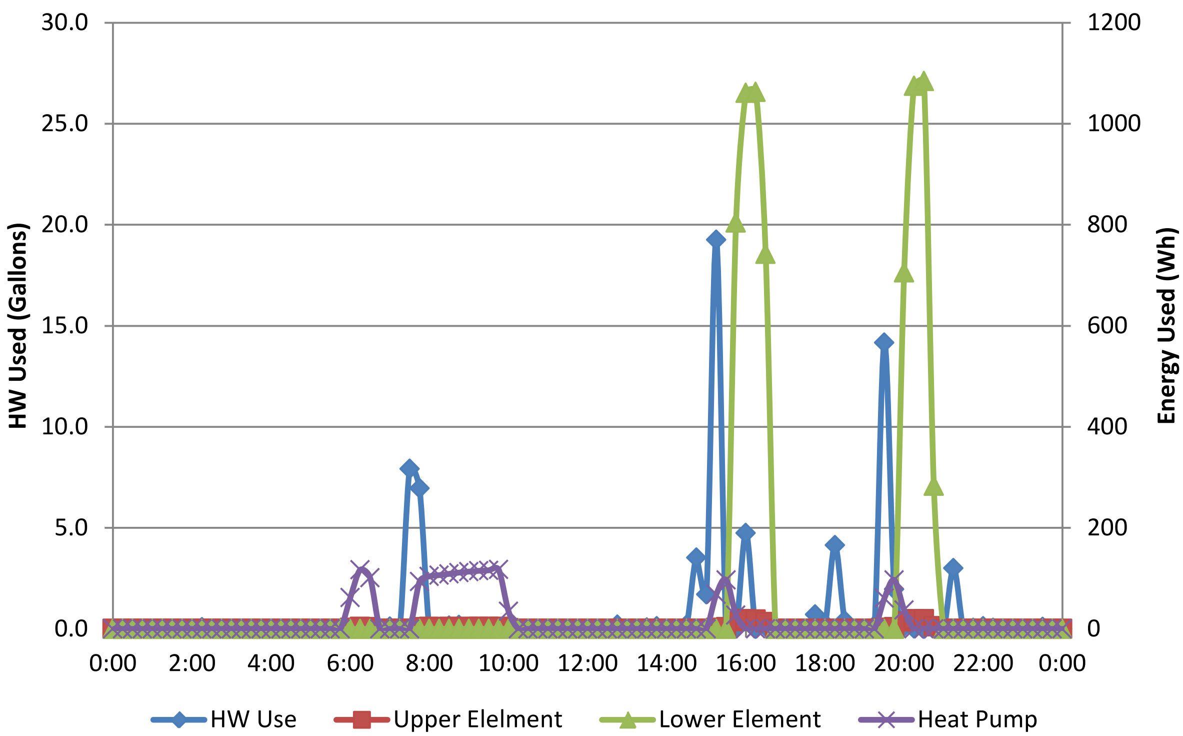


Figure 4. Majority electric resistance usage to meet demand

2.3.2 Ambient Temperature

The efficiency of a HPWH increases substantially with increased ambient temperature (i.e. the air temperature of the space where the HPWH is located). Heat pumps become much more efficient when the heat source (in this case the ambient air) becomes warmer. Warmer air also reduces standby losses.

Supporting Research

Figure 5 shows the effect of ambient temperature on the expected performance of a HPWH operating in heat pump mode. Higher ambient temperatures result in considerably higher COPs. At increased water use levels, an increase in ambient temperature from 50°F to 80°F results in an increase in COP of approximately 0.5.

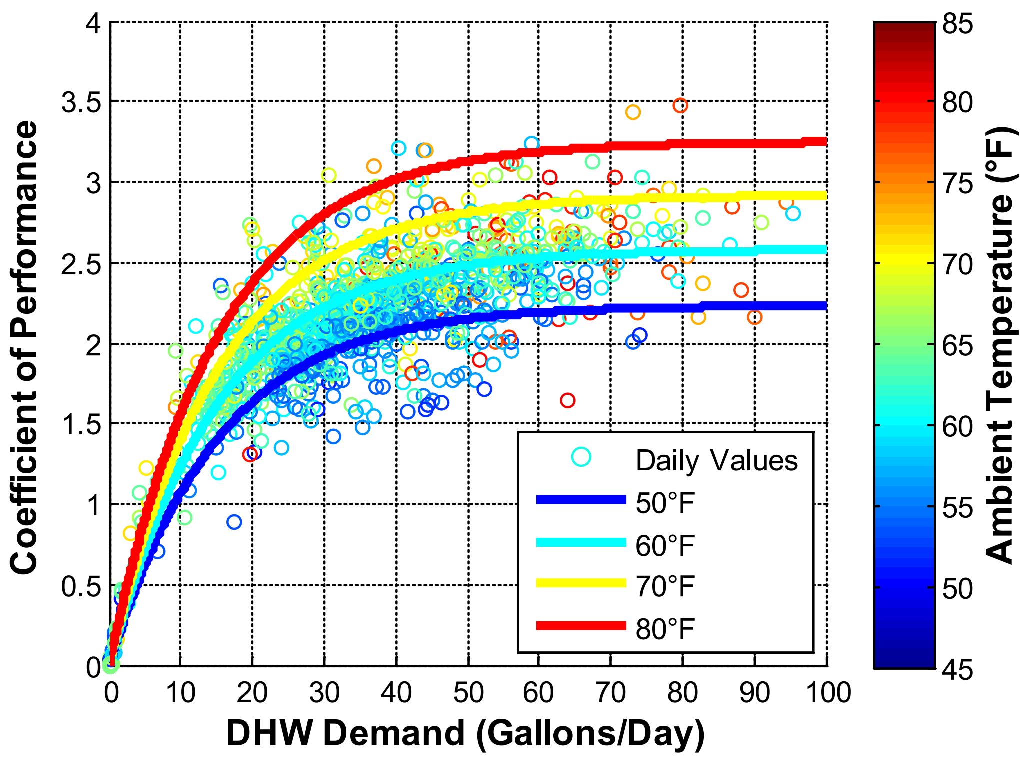


Figure 5. Efficiency of a 50-gal HPWH operating in heat pump mode

The HPWHs will only operate in heat pump or hybrid mode if the ambient temperature of the air entering the water heater is between ~45°F and ~110°F. When the temperature of the incoming air drops below the minimum temperature, the HPWH will switch into electric resistance mode, reducing the efficiency of the unit. In practice, the temperature of the space must be several degrees above the minimum temperature due to the cooling effect of the heat pump operation, which drops the temperature of the space. On the lower end of this temperature range, system efficiency can be compromised due to:

- Increased electric resistance back-up heating
- Decreased hot water output
- Decreased hot water temperature rise.

Supporting Research

As shown in Figure 6, heat pump operation dropped the ambient temperature by over 4°F, from 49°F to near 45°F, which is the minimum allowable ambient temperature for this unit. Colder air temperatures forced the electric resistance elements to turn on to meet hot water demand.

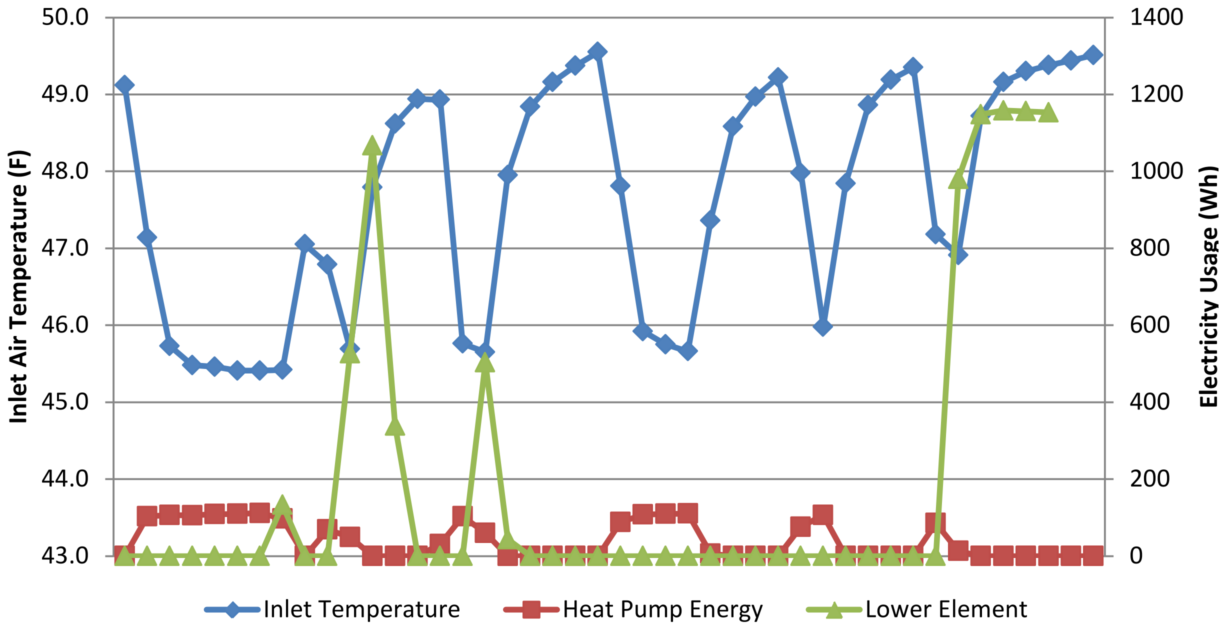


Figure 6. Electricity usage for heat pump and lower element vs. inlet air temperature

2.3.3 Interaction with Space Conditioning Systems

As mentioned above, HPWHs transfer heat from the ambient air to water; this means HPWHs can have a significant impact on the heating and cooling load of a building if the HPWH is installed in conditioned space. HPWHs may reduce the ambient temperature 2F°-6°F when in operation (Stiebel- Eltron 2010), though this is heavily dependent on HPWH run time and the space in which the HPWH is located. Often, HPWHs are touted as providing free energy due to COPs greater than 1.0, but when located within the building envelope, heat moved into the storage tank by a heat pump typically needs to be replaced by the home's heating system. HPWHs can extract between 4 and 11 MMBTU/year of energy from the surrounding space. In hot climates, locating the HPWH in attached garages is an excellent way to optimize water heating performance without concern for the cooling effect of the unit.

2.3.4 Inadequate Space

The HPWH must be able to extract sufficient energy from the surrounding air, and the energy available in the air is primarily a function of the size of the space. Therefore, HPWHs must be installed in rooms with adequate volume to ensure efficient operation (see manufacturer literature for space requirements). Adequate clearances must be provided to allow for proper airflow and maintenance (see Section 3.1.1). If a unit is installed in an area with insufficient space, the space can experience a dramatic reduction in temperature during HPWH operation.

Supporting Research

At one test site, the HPWH was installed in a location with inadequate space and showed a significant reduction in efficiency. The HPWH was installed in a small, unconditioned basement mechanical room with a door that was kept closed. The mechanical room's area was approximately 440 ft^3, significantly less than the required 750 ft^3 for the unit, contained a washer and dryer, and was used for storage. The overall COP of the unit was 30% lower than the expected COP of a HPWH installed with adequate space.

2.4 Dehumidification Potential

Because HPWHs remove heat from the ambient air using a heat pump refrigeration cycle, they also remove moisture from the air. The water vapor in the air will condense as it passes across the HPWH's evaporator coils and, as a result, will provide dehumidification. This has the potential to reduce the need for dehumidifiers in damp spaces, such as unconditioned basements. Although the dehumidification is not predictable, because it relies on operation of the HPWH, the HPWH can reduce the energy consumed by dehumidifiers in these spaces.

2.5 Reliability and Safety

Integrated (or "drop-in") HPWHs are a relatively new technology that was first commercialized in the early 2000s. Earlier models were "add-on" configurations that heated the water outside of the storage tank. Unfortunately, the first commercialized, integrated HPWHs experienced problems with reliability and safety.

Supporting Research

In 2004, evaluation of an early integrated HPWH, the WatterSaver HPWH, demonstrated effective COPs, but some consistent drawbacks with the systems and their daily operation were identified, such as excessively hot water temperature. Monitoring showed that water temperature near the top of the tank often reached more than 150°F, partly because of excessive tank stratification – water temperatures near the top could be 50°F higher than temperatures near the bottom. In fact, high-temperature switches in many of the systems shut down the water heaters completely (high-temp safety switches are designed to turn off water heaters when temperatures reach 170°F). Control boards were also replaced because of problems with exposure to hot and humid conditions. Ultimately, because of the problems with installed performance and a nonexistent service infrastructure, this product is no longer on the market.

Monitoring of the current 14 HPWHs, however, has shown no issues with safety to date. Only one unit experienced a heat pump failure shortly after installation, but was quickly repaired by an authorized service provider. Upon failing, the unit switched from hybrid mode to electric mode and, as a result, the home did not experience a loss of hot water. Furthermore, all of the HPWHs under evaluation have yet to display problems with excessive or inadequate hot water temperatures.

Although the higher complexity of HPWHs over standard ERWHs may lead to greater reliability issues, so far modern HPWHs do not seem to be experiencing the same reliability issues that plagued earlier models. An accelerated durability test of older HPWH models performed at Oak Ridge National Laboratory found no long term reliability issues with these models (Baxter and Linkous 2004). These early results suggest that modern HPWHs may last as long as traditional ERWHs under extended operation.

3 HPWH Implementation Details

As noted in the introduction, hybrid heat pump water heaters are new to the mainstream market. Installing contractors should be aware that installation of these units is not as straightforward as a standard electric resistance water heater. Heat pumps require special attention to the air space (to ensure adequate air flow) around the unit and require condensate collection and removal. Installers may not be familiar with these units or heat pump models in general, and it can be difficult to install these units in existing homes.

3.1 Selecting the Best Location for a HPWH

Selecting an appropriate location for a standard ERWH is relatively straightforward. Any space large enough for the water heater, piping, and servicing can be appropriate for an ERWH. However, HPWHs require special consideration as they require more space (see Section 2.3.4) and weigh more than traditional ERWHs. The added weight of these units, due to the heat pump components, may mean that two or more people are required to move and install the unit. Furthermore, the best location must be chosen with respect to the interaction with the space conditioning equipment, the ambient temperature of the space, and noise (see Section 3.1.2). For reference, Table 6 lists the weight, volume, clearance, and operating temperature requirements for several current HPWH models (this is presented as an example; for accurate information, refer to up-to-date literature for specific HPWHs).

Table 6. Weight, Volume, Clearances, and Operating Temperatures for Various HPWH models

Model	Dry Weight (lbs)	Wet Weight (lbs)	Minimum Room Volume (ft^3)	Minimum Clearances					HP Inlet Air Operating Temperature (°F)
				Air Inlet	Air Outlet	Front	Rear	Top	
GE	190	602	700	7"	7"	5.5"	5.5"	14"	45-120
Rheem	197	576/680	1,000	N/A	N/A	N/A	2"	8"	40-120
AO Smith	332*/ 410*	827/ 1,069	750	3'	5'	2'	6"	None	45-109
Stiebel-Eltron	287	952	500	16"	15.75"	8"	8"	16"	42-108

* shipping weight

3.1.1 Space Requirements

The HPWHs require more space than traditional ERWHs because of their additional height, weight, required air volume, and clearance requirements; HPWHs are generally taller and heavier than traditional ERWHs. Measures to manage condensate, such as placing the unit on blocks (see Section 3.2.1), may further increase the height requirements of HPWHs. The additional weight of the unit, particularly larger capacity models, may require reinforcement of the floor to ensure structural soundness.

Because HPWHs extract energy from their surrounding environment (see Section 1.2), enough air volume and adequate clearances must be provided to allow for proper operation of the unit. Improperly placed HPWHs are significantly

HPWH Space Requirements Checklist

- ✓ Does the room meet the volume requirements of the unit (> 750 ft^3)?
- ✓ Are the ceilings high enough to accommodate the extra height of the HPWH?
- ✓ Is there adequate space to allow maintenance of the heat pump components?
- ✓ Can the HPWH be placed in the room such that there is sufficient clearance for airflow around the unit?
- ✓ Is there enough clearance for removal and cleaning of the air filter?
- ✓ Is the floor able to support the additional weight of the HPWH?

less efficient than properly installed units (see Section 2.3.4). Generally, HPWHs must be installed in a room with a volume of at least 750 ft^3, which corresponds to a 10 ft by 10 ft room with 7’6” ceilings. Furthermore, HPWHs require larger clearances for proper operation. Air entry and discharge must be free of obstructions to provide proper air circulation and ensure a continuous supply of fresh air. Figure 7 shows a properly installed HPWH with adequate clearances at the air entry and discharge, while Figure 8 shows a poorly installed unit with the air discharge directed towards a wall. Added clearances are also required for removal and cleaning of the air filter and for servicing of the unit. Piping installation must be carefully considered to prevent the pipes from blocking the air filter or maintenance panels.

Figure 7. HPWH installed with adequate clearances

Figure 8. Improper HPWH with air discharge facing wall

3.1.2 Conditioned or Unconditioned Space?

When selecting an appropriate location for a HPWH, the interaction with the heating and cooling system must be closely considered. As mentioned in Section 2.3.3, HPWHs extract heat from the surrounding air and therefore increase heating loads and decrease cooling loads when installed in conditioned spaces. An analysis of the total impact on heating and cooling source energy usage (Table 7) reveals that for the vast majority of the United States, there is a net potential heating penalty on source energy usage for space conditioning. Cities in climate zone 2 may have a net potential cooling benefit. If the decision is made to relocate an interior water heater to a semi-conditioned space (i.e. garage or basement), consideration needs to be given regarding the impact on distribution system performance and hot water waiting times.

Table 7. Impact of Placing HPWH in Conditioned Space on Space Conditioning Usage

City	Climate Zone	HDD65	CDD65	Potential Impact
Atlanta, GA	3A	2,694	1,841	Heating Penalty
Baltimore, MD	4A	4,567	1,228	Heating Penalty
Boston, MA	5A	5,621	750	Heating Penalty
Chicago, IL	5A	6,311	842	Heating Penalty
Denver, CO	5B	5,942	777	Heating Penalty
Houston, TX	2A	1,414	3,001	Cooling Benefit
Orlando, FL	2A	544	3,379	Cooling Benefit
Phoenix, AZ	2B	941	4,557	Cooling Benefit
San Francisco, CA	3C	2,708	142	Heating Penalty
Seattle, WA	4C	4,729	177	Heating Penalty

Conditioned Space

In climates with a net heating penalty, it is not advisable to place HPWHs in conditioned space without further exploring the potential impact. In locations with potential cooling benefit, HPWHs may be placed in conditioned space, although special consideration must be used when deciding the best location for the HPWH. Although these units have a potential to reduce overall space conditioning loads, the cooling from these units may lead to over-cooling of the space because the operation of the unit is not controlled by a thermostat. Follow these guidelines when choosing a proper location for the HPWH:

- Never place the unit close to a thermostat, as this may result in improper heating or cooling of the home.
- Never place the unit near the kitchen. Oils from cooking can ruin the unit.
- Place the unit in a location that is not sensitive to colder temperatures.
- Make sure to meet the manufacturer's space requirements (e.g. Section 3.1.1). Do not place the unit in a closet unless the closet door has a louvered door. Even with a louvered door, locating the HPWH in a closet will likely reduce overall performance of the unit.
- Noise may be an issue because the HPWH uses a compressor and fan to move air through the unit. Do not place the unit near bedrooms or other noise-sensitive locations.

> **!** When installing a HPWH in a room with a furnace, ensure that the unit does not interfere with operation of the furnace. Air flows inside the room will change as a result of HPWH installation.

Unconditioned Space

In most U.S. climates, HPWHs can be placed in unconditioned or semi-conditioned spaces. Semi-conditioned spaces are spaces that are inside the thermal boundary, but not directly heated or cooled. The most common semi-/unconditioned locations are garages and basements. Crawlspaces are generally too short for HPWHs, and HPWHs are typically not recommended to be placed in attics (because of potential for water leaks, weight of unit, ambient temperature that fluctuates outside the heat pump's operating range, etc.).

The primary consideration for unconditioned spaces is the size of the room (see Section 3.1.1) and the ambient temperature of the space. The minimum temperature of the space should not be below 50°F. Operation of the HPWH will result in a significant drop in ambient temperature, and such a drop may result in an air temperature below the minimum recommended operating temperature in heat pump mode (see Section 2.3.2). HPWHs with electric resistance modes may be placed in colder basements, but the HPWH will not operate at its rated efficiency during colder months. In more temperate climates, the attached garage can be a suitable location, as long as plumbing lines are not too long and can be properly insulated. In colder climates, however, the basement will likely have the highest temperature of all unconditioned spaces.

Interesting Fact

At one site in CARB's evaluation of 14 HPWHs, the unit was placed in an unfinished basement in the mechanical room next to the boiler. The waste heat from the boiler increased the ambient temperature of the room in the winter, meaning that the room was 70°F or warmer throughout winter. The waste heat improves the efficiency of the HPWH and minimizes the impact of the HPWH on the space heating loads of the house.

Figure 9. HPWH installed in boiler room

3.2 Proper Installation and Maintenance

Good installers of HPWHs pay close attention to condensate management (Section 3.2.1), heat traps (Section 3.2.2), and mixing valves (if applicable, Section 1.1.1). Proper maintenance includes inspection of the condensate lines and regular cleaning of the air filter. Installations should always comply with local and state codes.

HPWH Installation Checklist

- ✓ Place the unit on blocks
- ✓ Install a drain pan
- ✓ Install a condensate pump, if applicable
- ✓ Install heat traps to prevent thermosiphoning
- ✓ Install a mixing valve, if applicable

3.2.1 Managing Condensate

As warm, moist air travels over the evaporator coils of a HPWH, some moisture in the air will condense, and the resulting condensate is removed from the unit through a condensate drain line. This condensate must be effectively removed to prevent damage to the unit. While manufacturer's condensate requirements vary slightly, in the simplest configuration a hose is connected to the condensate line and properly pitched toward a drain in the floor. If a suitable drain is not available, a condensate pump must be installed to ensure that condensate is properly removed. Based on contractor feedback, a 240V condensate pump is recommended for this application to avoid potential call backs related to tripped ground-fault circuit interrupter (GFI) outlets used to power 120V condensate pumps.

To protect the unit from a condensate line failure or other condensate issue, HPWHs should be installed on blocks with a drain pan. These precautions prevent the unit from sitting in water and ensure that the condensing water is properly transferred to a drain.

Drain pans are used to capture overflow due to condensate pump failure, piping failure, and condensate line obstructions. Because HPWHs are relatively new to the mainstream market, the installers may not be aware of the need for drain pans. Given the low cost, all HPWHs should have a drain pan installed. Concrete blocks are often used to raise the bottom of the unit above the lip of the drain pan which prevents the bottom of the unit from resting in water (and possibly corroding should a leak occur). Figure 10 shows a HPWH that does not properly remove condensate away from the unit into the drain. The unit ended up sitting in water due to a kinked condensate line. Figure 11 shows a proper HPWH installation, where the unit is set on blocks in a drain pan and a condensate pump is used.

Figure 10. Condensate problems from improper installation

Figure 11. Proper HPWH installation

If the condensate line becomes clogged or kinked, the drain hose must be removed and cleared of any debris. The owner should periodically inspect and clear any debris from the condensate line to prevent condensate overflow.

3.2.2 Heat traps

Heat traps should be installed on all hot water systems to prevent thermosiphoning, which is the transfer of heat from the storage tank down the cold or hot water lines. Thermosiphoning reduces the efficiency of the unit by increasing the standby losses to the environment. Figure 12 shows a HPWH installed without heat traps, while Figure 13 shows a properly installed HPWH with heat traps.

Figure 12. HPWH without heat traps

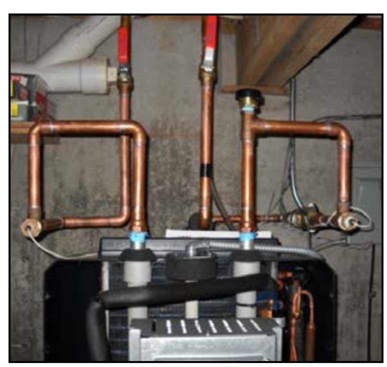


Figure 13. HPWH with heat traps

3.2.3 Mixing Valves and Setpoint Temperature

With any water heater that generates relatively high water temperatures a mixing valve should be installed to minimize the risk of burns or scalding (see Table 8). If a HPWH generates temperatures above 125F°-130°F (or if the temperature is likely to be set above this), a mixing valve should be installed (Figure 14).

Table 8. Time/Temperature Relationships in Scalds (Shriners Burn Institute)

Temperature	Time to Produce a Serious Burn
120	More than 5 minutes
125	1.5 – 2 minutes
130	About 30 seconds
135	About 10 seconds
140	Less than 5 seconds
145	Less than 3 seconds
150	About 1.5 seconds
155	About 1 second

Figure 14. Heat pump water heater with mixing valve

Mixing Valves
The hot water outlet temperature may change over the course of the year, increasing during the summer as the mains temperature increases.

HPWH Piping Issues
The inlet and outlet pipes of most ERWHs enter the top of the unit. Due to the inclusion of the heat pump at the top of the unit, some HPWHs have different locations and orientations of the water lines. In Figure 14, the water lines enter the unit at the side and are placed horizontally. This orientation will likely require additional plumbing.

Furthermore, the air filter in some units is placed near the water piping. As a result, the installer must pay close attention to the piping installation to avoid obstructing the air filter.

Just as a high water temperature could result in scalding, a low temperature could result in the growth of the bacterium Legionella, which causes lung infections. This bacterium thrives in warm water, but temperatures over 119°F will minimize Legionella growth. Temperatures above 122°F will kill 90% of the bacteria in 80-124 minutes, and temperatures above 140°F will kill 90% of the bacteria in 2 minutes (WHO 2007). Temperatures around 120°F (but not less than 119°F) are the recommended temperature set point to minimize scald potential and reduce standby losses while maintaining water quality. If the vacation mode of a water heater is used (or temperature setpoint lowered), ensure that the unit is given adequate time to recover to a temperature higher than 122°F for several hours upon return from vacation before using the hot water.

3.2.4 Filter Maintenance

If a HPWH has an air filter, the filter must be regularly cleaned to ensure that the unit runs at peak efficiency. In Figure 15, a HPWH with a dirty air filter is shown. On some units, the air filter is removed from the top of the unit, and therefore extra clearance must be provided to ensure that the unit's filter can be properly cleaned.

Figure 15. Dirty filter: finger rubbed against filter to show accumulation of dirt

3.2.5 Typical Maintenance (for HPWH or ERWH)

In addition to cleaning the air filter, both HPWHs and ERWHs require regular maintenance to ensure proper operation and extend the life of the unit. Table 9 lists the required maintenance items for water heaters and the recommended timing.

Table 9. Water Heater Maintenance Schedule

Maintenance Item	When?	Why?
Check temperature pressure relief valve	Yearly	Ensure proper operation
Discharge water from tank	Monthly	Prevent hard water deposits from accumulating
Inspection by qualified service provider	Yearly	Ensure proper operation

Check Temperature Pressure Relief Valve

Lift and release the lever handle on the temperature pressure relief valve (check manual for location).

Ensure lever moves freely.

Allow several gallons to flow through the discharge line to an open drain.

Discharge Water from Tank

Suspended solids in tap water may settle at the bottom of a water heater's tank. To ensure that these solids do not collect at the bottom of the tank, a few quarts of water should be drained from the drain valve of the tank every month. See the section below for instructions for draining the tank.

Draining the Tank

Note: Drainage hose should be rated for at least 180°F. Otherwise, turn off power to water heater and open hot water faucet until the water runs cold.

Shut off power to the water heater.

Turn off cold water supply.

Open a hot water faucet to allow air to enter the tank.

Attach a hose to the drain valve on the water heater and direct the stream of water to a drain.

Open the relief valve.

Drain water heater.

Close relief valve.

Disconnect hose from valve.

Turn on cold water supply.

Keep hot water faucet open until water runs through the faucet.

Close hot water faucet.

Turn on power to the water heater.

> **Helpful Tip**
> Even new electrical appliances may make hissing or singing sounds during operation. However, if these noises increase excessively, the electric resistance elements may need cleaning. Contact a qualified installer or plumbing contractor to inspect the unit.

Inspection by Qualified Service Provider

Periodically contact a qualified electric appliance repair service provider to inspect the operating controls, heating elements, anode rod, and wiring.

References

Amarnath, K. R.; Trueblood, C. (2010). "Heat Pump Water Heaters: Laboratory and Field Evaluation of New Residential Products." Proc. Summer Study on Energy Efficiency in Buildings (1); American Council for an Energy-Efficient Economy; pp. 12-23.

AIL Research, Inc. (2001). "Northeast Utilities Heat Pump Water Heater Field Test: 30 Crispaire Installations."

AIL Research, Inc. (2002). Nyle Heat Pump Water Heat Evaluation

A.O. Smith (2010). "Voltex™ Hybrid Electric Heat Pump Water Heater Installation Instructions and Use & Care Guide."

Baxter, V.; Linkous, R. (2004). "Heat Pump Water Heater Durability Testing – Phase II." Oak Ridge, TN: Oak Ridge National Laboratory; ORNL/TM-2004/111.

Burch, J.; Erickson, P. (2004). "Using Data to Derive Simulation-Model Inputs for Storage-Tank Water Heaters." Portland, OR: Proceedings of the Solar 2004 Conference. pp. 393-398

[CARB 2010] Consortium for Residential Buildings (2010). "Retrofitting America: A 1970s Home Energy Efficiency Analysis."
http://carb-swa.com/articles/homepage/RetrofittingAmerica_1970sHomeAnalysis.pdf

Deru, M; Torcellini, P (2007). Source Energy and Emission Factors for Energy Use in Buildings. Golden, CO: National Renewable Energy Laboratory.

[EERE 2011] U.S. Department of Energy, Energy Efficiency and Renewable Energy; "Table 2.1.5 2008 Residential Energy End-Use Splits, by Fuel Type (Quadrillian Btu)." Building Energy Data Book; http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=2.1.5; Date Access: July 17, 2011.
Federal Register, (2010). Vol. 75, No. 73 p. 20114 10CFR 430.

Federal Register, (1998). Vol. 63, No. 90 p. 25995 10CFR 430.

Franco, V.; Lekov, A.; Meyers, S.; Letschert, V. (2010). "Heat Pump Water Heaters and America Homes: A Good Fit?" Proc. Summer Study on Energy Efficiency in Buildings (9); American Council for an Energy-Efficient Economy; pp. 68-79.

[GE 2010] General Electric (2010). "Owner's Manual & Installation Instructions." 49-50254 10-09 JR

[GE 2011] General Electric (2011). "Water Heater FAQs: How long should my GeoSpring water heater run in order to reheat the water in the water heater?" http://www.geappliances.com/heat-pump-hot-water-heater/water-heater-faq.htm#recoveryTime Accessed 25 April 2011

Glanville, P., and D. Kosar, 2011. Building America Industrialized Housing Partnership II-Subtask 2.2.3: Efficient Hot Water and Distribution Systems Research. Gas Technology Institute project number 20970. and also, Pacific Gas & Electric Company, 2010. Laboratory Evaluation and Field Testing of Residential Heat Pump Water Heaters. PG&E Applied Technology Services Test Report #:491-10.04.

Hendron, B.; Burch, J.; Barker, G. (2010). "Tool for Generating Realistic Residential Hot Water Event Schedules." New York, NY: SimBuild 2010.

[IECC 2009] International Code Council, Inc. (2009). 2009 International Energy Conservation Code. Country Club Hills, IL.

[ORNL 2002] Oak Ridge National Laboratory (2002). "Field Tests of a 'Drop-In' Residential Heat Pump Water Heater."

[PGEC 2009] Pacific Gas and Electric Company (2009). "Energy Performance Analysis for Heat Pump Water Heaters." Application Assessment Report #0916.

Rheem (2009). "Use & Case Manual: Electric Residential Heat Pump Water Heaters."

Stiebel-Eltron (2010). "Operating and Installation Manual: DHW Heat Pump Water Heater Accelera® 300."

[SWS] National Renewable Energy Laboratory (2011). "Workforce Guidelines for Home Energy Upgrades."

Tomlinson, J. J. (2002). "All Pumped Up: New heat pump water heaters consume half the energy of conventional electric-resistance ones." Home Energy; November/December 2002; pp. 30-35.

Tomlinson, J. J.; Rice, C.K.; Baskin, E. (2005). "Integrated Heat Pumps for Combined Space Conditioning and Water Heating." 8th IEA Heat Pump Conference Paper.

[WHO 2007] World Health Organization (2007). "Legionella and the Prevention of Legionellosis."

Yates, D. (2010). "Keep selling heat pump water heaters after tax credit expires." *Contractor Mag;* http://contractormag.com/columns/yates/selling-pump-water-heateers-0610; June 9, 2010 Accessed 25 April 2011.

Zogg, R. (2002). "Residential Heat Pump Water Heater Technology and Markets Seminar." December 4-5, 2002; Portland, OR.

Appendix A: Measure Implementation Checklist

1. **Select the best type of location for the HPWH. Determine the interaction with cooling and heating equipment.** Should the unit be placed in conditioned space, semi-/unconditioned space, or in an attached garage? Hot climates will have a net cooling benefit, while cold climates will have a net heating penalty (see Sections 2.3.3 and 3.1.2). Generally, homes in climate zones 1 and 2 have a net cooling benefit. For climate zones 1 and 2, installation in an attached garage of unconditioned space may be appropriate.
2. **Select available location.** Can the HPWH be installed in the selected location? If the location does not meet the requirements then consider a new location or an alternative high efficiency water heater option, or evaluate the efficiency impact of minimized heat pump operation.

Sufficient room volume (750 to 1,000ft^3)	YES	NO
Adequate ambient temperature (> 50°F)	YES	NO
There is sufficient space to meet clearance requirements	YES	NO
Noise will not interfere with living spaces	YES	NO
Drain is available for condensate removal	YES	NO

3. **Can the floor support the unit?** If not, reinforce as necessary.
4. **Removal of older equipment (if applicable).** In the case of existing home retrofits, follow accepted industry procedures and practices as listed in the Standard Work Specification (SWS):
    a. Remove old water heater and associated components.
    b. Seal any unused chimney openings.
    c. Remove unused oil tank, lines, and associated equipment.
5. **HPWH installation.** Follow the guidelines for installation as listed in the Standard Work Specification (SWS). These requirements are as follows:
    a. Repair any existing water leaks before installation.
    b. Seal any penetrations to the exterior of the home created by the installation of the equipment.
    c. Install an emergency drain pan a minimum of 4” above floor. Connect a ¾” drain line or larger to tapping on pan and run to drain or pumped to daylight.
    d. If needed, install a stainless steel bladder expansion tank will on the cold water side using a direct connection with no valves between the storage tank and expansion tank.

e. Correct temperature and pressure relief valve will be installed according to manufacturer specifications. Temperature and pressure relief valve discharge tube will terminate within 6” of the floor, or as prescribed by local code.
f. Install di-electric unions according to manufacturer specifications.
g. Discharge temperature will be set to not exceed 120° or as prescribed by local code.
h. Commissioning will be in compliance with manufacturer specifications and relevant industry standards. The following will be checked once the system has been filled and purged:
    - Safety controls
    - Combustion safety and efficiency
    - Operational controls
    - Water leaks
    - Local code requirements.
i. Occupants will be educated on the safe and efficient operation and maintenance of the system, including:
    - Adjustment of water temperature and target temperature per local code
    - Periodic drain and flush
    - Expansion tank and backflow preventer (no occupant maintenance required).

In addition to the requirements outlined by the SWS, remember to install the following items for HPWHs:

a. Place the unit on blocks.
b. Install a drain pan.
c. Install a condensate pump, if applicable.
d. Install heat traps to prevent thermosiphoning.
e. Install mixing valves, if needed.

Appendix B: HPWH Installation Checklist (*leave behind with unit*)

Home Address:____________________ City:__________ State:_____			
Is the site suitable for a HPWH?	Adequate Ambient Temperature (> 50°F)		☐
	Condensate Drain Available		☐
	Noise will not Interfere with the Living Space		☐
What HPWH is being installed?	Manufacturer	____________________	
	Model #	____________________	
	Tank Size	______ Gallons	
Are minimum requirements met?	Sufficient Room Volume (> ______ ft^3)		☐
	Minimum Clearances: Air Inlet (> ______ in) Air Outlet (> ______ in) Front (> ______ in) Rear (> ______ in) Top (> ______ in)		 ☐ ☐ ☐ ☐ ☐
	Is the floor able to support the weight of the HPWH?		☐
How is the system configured?	Location of HPWH	Semi-/Un-Conditioned Conditioned Garage Attic	☐ ☐ ☐ ☐
	HPWH Operation Mode	Hybrid Mode Heat Pump Electric Resistance	☐ ☐ ☐
	Temperature Set Point (120°F recommended)	______ °F	
	Condensate Pump		☐
	Heat Trap		☐
	Mixing Valve		☐
Maintenance	How often should filter be cleaned?	Every ______ Months	

* Blanks to be filled out per manufacturer's minimum specifications for model to be installed.

EERE Information Center
1-877-EERE-INFO (1-877-337-3463)
www.eere.energy.gov/informationcenter

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE/GO-102012-3456 ▪ February 2012

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post-consumer waste.