Heat Pump Water Heaters and American Homes: A Good Fit?

Victor Franco, Alex Lekov, Steve Meyers, and Virginie Letschert
Lawrence Berkeley National Laboratory

ABSTRACT

Heat pump water heaters (HPWHs) are over twice as energy-efficient as conventional electric resistance water heaters, with the potential to save substantial amounts of electricity. Drawing on analysis conducted for the U.S. Department of Energy's recently-concluded rulemaking on amended standards for water heaters, this paper evaluates key issues that will determine how well, and to what extent, this technology will fit in American homes. The key issues include: 1) equipment cost of HPWHs; 2) cooling of the indoor environment by HPWHs; 3) size and air flow requirements of HPWHs; 4) performance of HPWH under different climate conditions and varying hot water use patterns; and 5) operating cost savings under different electricity prices and hot water use. The paper presents the results of a life-cycle cost analysis of the adoption of HPWHs in a representative sample of American homes, as well as national impact analysis for different market share scenarios. Assuming equipment costs that would result from high production volume, the results show that HPWHs can be cost effective in all regions for most single family homes, especially when the water heater is not installed in a conditioned space. HPWHs are not cost effective for most manufactured home and multi-family installations, due to lower average hot water use and the water heater in the majority of cases being installed in conditioned space, where cooling of the indoor environment and size and air flow requirements of HPWHs increase installation costs.

Introduction

A heat pump water heater (HPWH) represents a merging of two technologies: (1) an electric resistance storage water heater (ESWH) with tank and controls; and (2) a refrigeration circuit similar to that found in a residential air-conditioner. HPWHs use existing heat pump technology to extract heat from the surrounding air (typically at room temperature) for heating stored water in contrast to resistive heating, which transfers heat from the electric resistance element to the water.

The HPWH has been on the U.S. residential market for over twenty years, but has not had a significant market share. HPWHs have also been available in Europe, Japan, Australia/New Zealand, and China. Integrated HPWHs (also called drop-in HPWHs) were first introduced by ECR International in 2004 and reintroduced to the U.S. market in a significant way by General Electric in 2009 and subsequently by Rheem, AirGenerate, Stiebel Eltron, and AO Smith (See **Table 1**).[1] These HPWHs now qualify for ENERGY STAR certification and are eligible for rebates in some States as well as Federal tax credits of 30% of the total installed cost through the end of 2010. Estimated shipments in 2008 were less than 2,000 units (out of 4.2 million ESWH shipments), but with the introduction of these new models, the ENERGY STAR program hopes to increase the market share to 10% of total electric storage water heater

[1] Throughout this paper, the term "heat pump water heater (HPWH)" refers to integrated units, not add-on products.

shipments in the next few years. (USEPA 2008) In addition, new U.S. Federal standards that take effect in 2015, will require all ESWH units above 55 gallons (about 9 percent of the ESWH market) to be HPWHs.

Table 1. Current Integrated Heat Pump Water Heater Models Available in the U.S.

Manufacturer	Model	Rated Volume	EF	Retail Price
GE	GEH50D*****	50	2.35	$1,599
Rheem	HP50**	50	2.00	$1,499
Air Generate	ATI1266	66	2.20	Not Available
AO Smith	PHPT-80	80	2.30	$2,499
Stiebel Eltron	ACCELERA 300	80	2.51	$3,000

Current manufacturers of heat pump water heaters are marketing these products as direct replacements for traditional electric resistance storage water heaters. The rated storage volumes and first hour ratings of the HPWHs currently on the market are comparable to the traditional electric resistance water heaters. However, HPWHs have certain features that pose issues not faced by traditional electric resistance water heaters. First, HPWHs are slightly taller and wider than typical water heaters, so in some locations it might be difficult to fit the new water heater without some adjustments to the space. Second, because HPWHs extract heat from the surrounding air and exhaust air at a colder temperature, they require adequate air flow. In indoor locations, providing adequate airflow may require special installation considerations. Further, the exhausting of cooled air affects the indoor environment. Depending on the location and the utilization of the water heater, its operation may significantly increase the home's heating load in the heating season (while decreasing the cooling load in the cooling season).

Studies in the 1990's and early 2000's showed that heat pump water heaters had a very large energy savings potential (USDOE EERE 1993; Baxter et al. 2001). However, these studies did not comprehensively address installation cost issues, performance of HPWH under different climate conditions and varying hot water use patterns, or the cooling impact of the HPWHs on the indoor environment. More recent studies have started to deal with some of these issues (Harris et al. 2005; NEEA 2009; USEPA 2009).

This paper provides analysis of consumer economics of a HPWH with a 2.0 Energy Factor (EF), which is the minimum level required for ENERGY STAR certification. The economics of HPWHs are sensitive to the price of electricity and other factors, including the ambient air temperature from which it extracts heat and the location of the water heater, which influences the need for special installation practices. These factors may differ among different regions of the country, as well as by installation location and housing type. Therefore, in addition to presenting results for the national sample, results are presented for households located in the 4 census regions by installation location and housing type.

Methodology

The economics of HPWHs are evaluated in U.S. homes by calculating the life-cycle cost (LCC) and pay-back period (PBP) of purchasing and operating a HPWH, a 0.95 EF ESWH (most efficient electric resistance storage water heater and the Federal standard in 2015 for ESWHs equal to or below 55 gallons), and a baseline 0.90 EF ESWH (most commonlypurchased electric resistance product today and the current` minimum Federal standard). National economic impacts are evaluated by calculating National energy savings (NES) and net present value (NPV) for different HPWH market share scenarios.

LCC and PBP Analysis

Life-cycle cost is the total consumer expense over the life of an appliance, including the total installed price and operating costs (energy expenditures and maintenance and repair costs). Calculation of LCC discounts future operating costs to the time of purchase, and sums them over the lifetime of the product.

The PBP is the amount of time it takes the consumer to recover the estimated higher purchase expense of more energy efficient products as a result of lower operating costs. Numerically, the PBP is the ratio of the increase in purchase expense (i.e., from a less energy efficient design to a more energy efficient design) to the decrease in annual operating expenditures. This "simple" payback period does not take into account changes in operating expense over time or the time value of money.

The DOE Energy Information Administration (EIA) 2005 Residential Energy Consumption Survey (RECS) is used to develop a nationally-representative sample of households that use ESWHs (USDOE EIA 2009). As shown in **Table 2**, the 1,523 records in the ESWH sample represent 39.5 million U.S. households (or about 36% of all households).[2] In general, ESWHs are predominantly located in the South region. Over two-thirds of manufactured homes use an ESWH. In rural areas, 62% of homes use an ESWH. Note that 20% of the sample represents new homes for the purposes of the analysis.

Table 2. Households in ESWH Sample by Census Regions

Region Labels	Census Region	RECS 2005 Households w/ESWH			Fraction of Households with ESWH by Region
		Number of Records	**Weight (million)**	**% of Total**	
Region 1	Northeast	188	3.5	8.9%	17.1%
Region 2	Midwest	273	6.8	17.3%	26.7%
Region 3	South	828	23.9	60.6%	58.8%
Region 4	West	234	5.2	13.2%	21.5%
National Totals		**1,523**	**39.5**	**100%**	**35.6%**

The LCC and PBP analysis models both the uncertainty and variability in the inputs using Monte Carlo simulation and probability distributions. The LCC and PBP spreadsheet models incorporate both Monte Carlo simulation and probability distributions by using Microsoft Excel spreadsheets combined with Crystal Ball. RECS is used to assign a specific input variables (e.g. annual energy use and energy price) to each household in the sample.

Table 3 shows the distribution of households with ESWH by the four census regions. Within each region, it also shows the distribution ESWHs by housing type (single family and multi-family/manufactured home), and installation location (conditioned space and non-conditioned space). (These columns sum across for each region.)

[2] The analyses excludes 1.9 million households which report using electricity for water heating, but do not have storage tank water heaters, and 3 million households which have storage type water heaters shared between one or more households.

Table 3. Fraction of Households with ESWH in each Region by Housing Type and Installation Location

Census Region	Total Households by Region	Single Family		Multi-Family and Mfr Home		Total
		Unconditioned Space	Conditioned Space	Unconditioned Space	Conditioned Space	
Northeast	8.9%	56.3%	25.4%	1.0%	17.3%	100%
Midwest	17.3%	49.8%	31.5%	0.7%	18.1%	100%
South	60.6%	41.8%	27.3%	9.8%	21.1%	100%
West	13.2%	41.0%	21.1%	5.1%	32.8%	100%
Total	**100.0%**	**44.3%**	**27.0%**	**6.9%**	**21.8%**	**100%**

Consumer product cost. Consumer product costs are based on U.S. DOE research that derived the consumer cost based on manufacturer cost and contractor/builder and distributor markups for electric water heaters (USDOE EERE 2010).[3] To develop manufacturer cost, DOE generated bills of materials (BOMs), which describe the product details, and developed a cost model that converted the BOM information into manufacturer production cost. The manufacturer cost of a heat pump water heater includes the cost of the additional heat pump component. The analysis applies markups to transform the manufacturer costs into a consumer cost.[4] We derived separate markups for replacement and new construction applications. The markup methodology assumes lower overall markup for higher efficiency equipment, because some distribution costs do not increase with increased efficiency.[5]

Components of the consumer price for the considered ESWH efficiency levels are shown in **Table 4**. Since DOE analyzes efficiency levels as candidates for minimum efficiency standards, its analysis of manufacturer costs for HPWHs assumed a high level of production of such products. Thus, the prices in **Table 4** reflect economies of scale in production that are not yet captured for the HPWHs on the current market. (Current retail prices of 50-gallon HPWHs at 2.00 EF are about $1,500.) In addition, because HPWHs are considered "premium" products, it is likely that the current markups on HPWHs are higher than the markups reported in Table 4. This study did not account for the tax credits that are available for HPWHs purchased by Dec. 31, 2010 or state and utility rebates.

Table 4. Components of Consumer Price for 50-gallon ESWH

Energy Factor	Manufacturer Cost (including Shipping Costs) *(2009$)*	Overall Markup*	Consumer Price* *(2009$)*
0.90	151	1.97	297
0.95	226	1.92	434
2.00	622	1.75	1,088

* Weighted average for replacement and new construction applications

Installation costs. The installation costs for each of the options come from US DOE research conducted by the authors (USDOE EERE 2010). This work was partly based on RSMeans cost estimates. The installation cost covers all labor and material costs associated with the replacement of an existing water heater or the installation of a water heater in a new home, as well as delivery, removal, and permit fees. The analysis of installation costs depend on the water

[3] DOE research used a reverse-engineering approach to obtain manufacturers' costs.
[4] The overall markup approach is explained in US DOE Heating Products Rulemaking TSD (USDOE EERE 2010).
[5] The lower overall markup cost for higher efficiency equipment is explained in the US DOE Heating Products Rulemaking TSD (USDOE EERE 2010).

heater installation location for each sample household. Regional labor costs are applied to each RECS sample household to more accurately estimate installation costs by region. (See **Table 3** for the fraction of installations by installation location and region.) The analysis includes additional installation costs for those designs with increased insulation thickness and/or HPWH.

For ESWH designs with increased insulation (0.95 EF), some additional installation costs are applied, including an incremental drain pan cost as well as about 40 percent of replacement installations encounter space constraint installation costs.

For HPWH installations, several additional costs are applied, including additional labor cost for the extra time that might be required to install this product, one quarter of all replacement installations are assumed to require a condensate pump and longer water line to the drain, incremental drain pan cost, space constraint costs, and venting costs.

Space constraints encountered when installing heat pump water heaters are assumed to be similar to those encountered when installing ESWHs with 3 inch insulation (0.95 EF). In addition, heat pump water heaters are required to be in well-ventilated spaces. Based on the water heater location, about 40 percent of replacement installations would encounter space constraints. For half of these cases, where ventilation is not a significant issue, households would either choose a smaller water heater with a higher setpoint and a tempering valve or incur costs to modify the space to accommodate the heat pump water heater.[6]

For the other half of cases (where ventilation is an issue), door jambs removal/replacement and adding a louvered door is the least costly option, the majority of households would use this approach, while for some households this is not sufficient and would require the installation of a venting system, which would provide adequate air flow and also alleviate excessive cooling of the indoor space near the water heater (see discussion below).

HPWHs installed in a conditioned space can increase heating loads during the heating season. About 35 percent of households in the sample where estimated to have significant indoor cooling due to operation of the heat pump water heater in the heating months ("significant" means that the heat pump water heater adds 3 MMBtu to the indoor space over the heating season), which would incur the cost of having a venting system installed to exhaust and supply air. (For new construction, the unit is assumed to be installed in a space where this is not an issue.) In some cases it is necessary to install the venting system outside the wall structure, where the exposed vents would likely be covered. Therefore, for about one-fourth of the venting system installations would incur an additional cost for covering the exposed vents.

The installation costs for ESWHs at each considered energy efficiency level are shown in **Table 5**. **Table 6** shows the components of the total installed price at each considered energy efficiency level.

Table 5. Installation Costs for ESWHs

Energy Factor	Installation Options	Installation Cost *(2009$)**			Avg. Incremental Cost *(2009$)*
		Minimum	Maximum	Average	
0.90	Baseline	$145	$493	$279	--
0.95	Baseline, large drain pan, space constraints	$148	$880	$339	$60
2.00	Baseline, large drain pan, space constraints, condensate pump, venting	$148	$2,784	$538	$259

*Average installation cost represents the weighted average cost for replacement and new construction applications.

[6] The fraction of installations that would use a tempering valve includes only those cases where the water heater setpoint would not need to exceed 140°F, as recommended in GE HPWH product literature.

Table 6. Components of Average Total Installed Price for ESWHs

Energy Factor	Product Price *(2009$)*	Installation Cost *(2009$)*	Total Installed Price *(2009$)*	Total Installed Price *(2009$)*
0.90	$282	$279	$561	--
0.95	$362	$339	$702	$141
2.00	$1,040	$538	$1,578	$1,016

Energy use. The water heater analysis model (WHAM) and a hot water draw model, where used to estimate ESWH energy use by each of the sample households. For the recent rulemaking, we modified earlier versions of the tools, which were used to conduct the previous rulemaking that concluded in 2001.

The annual energy consumption of water heaters in actual housing units is determined by considering the primary factors that determine energy use: (1) hot water use per household; (2) the energy efficiency characteristics of the water heater; and (3) water heater operating conditions other than hot water draws. The hot water draw model is used to determine hot water use for each household in the sample. **Table 7** shows average daily hot water draw results by region and housing type. Due to the large sample of households, the range of average daily hot water use is quite large (from 1 to 343 gallons per day). The energy use of water heaters is calculated using WHAM, which accounts for a range of operating conditions and energy efficiency characteristics.

Table 7. Average Daily Hot Water Draw by Census Region and Housing Type

Census Region	Single Family (gal/day)	Multi-Family and Mobile Home (gal/day)	All Housing (gal/day)
Northeast	40.8	22.1	37.4
Midwest	40.8	24.7	37.8
South	47.0	35.2	43.3
West	52.9	30.6	44.4
National	**45.9**	**32.4**	**42.0**

For HPWHs, energy efficiency and consumption are dependent on ambient temperature. To account for this factor, WHAM is expanded to include the calculation approach used in the New York State Energy Research and Development Authority (NYSERDA) heat pump water heater site screening tool (Maxwell 2004) and DOE's weatherization assistance program (Kelso 2003), where a performance adjustment factor that is a function of the average ambient temperature is applied to adjust recovery efficiency (*RE*) parameter. A HPWH operates either in heat pump or in electric resistance mode. The electric resistance mode of operation is accounted for in this analysis when the monthly ambient temperature is less than 32^{o}F or more than 100^{o}F or when the slower recovery rate of the heat pump is not sufficient to satisfy water demand.

As explained above, overcooling of the indoor space as a result of the unit's operation is a potential problem for HPWHs and it is assumed that all of households with significant cooling during the heating season (greater than 3 MMBtu/yr) in conditioned spaces would incur the cost of a venting system. The remaining households with this effect are assumed to operate their heating and cooling systems to compensate for the effects of the heat pump water heater and the indirect increase in home heating (and the decrease in cooling during summer months), which is included in the HPWH energy use analysis.

Energy prices. The ESWH annual energy costs for each sample household are derived by multiplying the estimated month energy use by average monthly energy prices. Using data from EIA, DOE calculated average electricity prices in 2008 for each of 13 geographic areas: the nine U.S. Census Divisions and four large States (California, Florida, New York, and Texas) treated separately. **Table 8** displays the 2008 monthly average electricity prices by the 4 Census Regions. To project future prices, change in price forecast estimates from EIA's *Annual Energy Outlook 2010 Early Release* (*AEO2010)* (DOE EIA 2009) where used.

Table 8. Residential Electricity Prices in 2008 by Census Region

Geographic Area	Weighted Average *(2009$/kWh)*
Northeast	0.152
Midwest	0.099
South	0.107
West	0.107
United States	0.118

Maintenance and repair cost. The maintenance cost and the repair cost cover all labor and material costs associated with the maintenance or repair. In addition, the determination of the repair cost requires determining the service life of the components that are likely to fail.

Manufacturers recommend that ESWHs be drained and flushed annually to minimize deposition of sediment, maintain operating efficiency, and prolong product life. The available evidence indicates that this practice is done in 10 percent of households, mostly in locations with hard water (Smith 2010) and that only 25 percent hire a contractor to perform the maintenance work. For a HPWH, manufacturers also recommend annual cleaning of the air filter and to check the evaporator and refrigeration system. Manufacturer literature recommends that professional help is not needed for this maintenance. However, for instances in which the heat pump water heater might be more exposed to the outdoor environment, such as garages and crawlspaces, a 5-year preventative maintenance cost based on Australian HPWH outdoor installations (Rheem 2009) to 27 percent of garage and crawl space installations based on a survey conducted for central air conditioners (USDOE EERE 2004).

The repair cost for ESWHs includes the cost of replacing the heating element. In addition, the repair cost for HPWHs includes the cost of replacing the compressor and the evaporator fan where necessary.

Discount rate. The LCC analysis discounted future operating costs to 2010 and summed them over the lifetime of the furnace. For new construction, the discount rate used reflects after-tax real mortgage rates and on average equals 3.0%, while for the replacement market, the discount rate averages 5.1% (USDOE EERE 2010).

Product lifetime. The product lifetime is characterized using a Weibull probability distribution that with an average value of 13 years and ranging from the minimum of 6 years to maximum lifetime of 30 years, based shipments, housing stock with ESWH data, RECS ESWH equipment age data, as well as other sources, including *Appliance* magazine (Appliance Magazine 2009). An accelerated durability test of HPWHs suggests that these units have similar lifetime as standard electric resistance storage water heaters (Baxter et al. 2002).

National Impact Analysis

Using the LCC and PBP inputs, we estimated the national level impacts that would result from higher market penetration of HPWHs. The NIA calculates the national energy savings at the site level for different HPWH market share scenarios and then uses conversion factors from AEO 2010 to convert site savings to primary energy savings.[7] The NIA also calculates the net present value for consumers as the difference between the value of operating cost savings and the total incremental installed costs for HPWHs. The NIA also includes the impact of a 10% rebound effect (also called a take-back effect or offsetting behavior), which refers to increased energy consumption resulting from actions that increase energy efficiency and reduce consumer costs.[8]

Results

The tables in this section show the LCC savings (compared to purchase and use of the baseline ESWH) and the PBP for HPWHs at 2.0 EF. They also report the share of households with a net LCC benefit and with a net LCC cost.

Table 9 shows the results assuming current retail prices (without tax credit or rebates) and the installation costs estimated for the DOE analysis. Only 22% of households have a net LCC benefit. **Table 10** shows the results for the national sample based on the equipment price estimates developed for the DOE analysis. The average LCC savings for HPWHs is $130. However, 51% of the households have a net cost (i.e., negative savings).

Table 11 shows the results separately for replacement installations and new home installations. The economics are much more favorable for the latter, mainly because the costly modifications that are necessary for some replacement installations are not applicable. **Table 12** shows the average LCC savings results for HPWHs by region, housing type, and installation location. The economics are most favorable in the Northeast, largely due to the high electricity prices in this region. The economics are also favorable in the West, primarily due to higher daily hot water use in this region.

Table 9. LCC and PBP Results: National (Assuming Current Retail Prices)

Energy Factor	Life-Cycle Cost *(2009$)*			Life-Cycle Cost Savings			Payback Period[9]	
	Average Installed Price	Average Lifetime Operating Cost	Average LCC	Average Savings *(2009$)*	Households with Net Cost	Households with Net Benefit	Median *(years)*	Average *(years)*
0.90	$561	$2,687	$3,248	--	--	--	--	--
2.00	$2,238	$1,556	$3,794	-$529	78%	22%	15.8	37.6

[7] Site energy is the amount of heat and electricity consumed on site by a building as reflected in utility bills. Primary energy is the raw fuel that is burned to create heat and electricity, such as fuel used to generate electricity at a power plant, plus other losses in producing and transporting the fuel and electricity.

[8] The logic behind the rebound effect is that more energy efficient products lower the marginal cost of the end-use service relative to lower energy efficient products so consumers take some of the energy savings back in increased comfort or service.

[9] Large differences in the average and median values for PBP are due to outliers in the distribution of results. A limited number of excessively long PBPs produce an average PBP that is very long. Therefore, the median PBP usually is a more representative value to gauge the length of the PBP.

Table 10. LCC and PBP Results: National

Energy Factor	Life-Cycle Cost *(2009$)* Average Installed Price	Average Lifetime Operating Cost	Average LCC	Life-Cycle Cost Savings Average Savings *(2009$)*	Households with Net Cost	Households with Net Benefit	Payback Period Median *(years)*	Average *(years)*
0.90	$561	$2,704	$3,265	--	--	--	--	--
0.95	$702	$2,527	$3,229	$36	32%	68%	6.1	9.4
2.00	$1,578	$1,556	$3,135	$130	51%	49%	9.2	22.5

Table 11. LCC and PBP Results: Replacement and New Home Installations

Energy Factor	Life-Cycle Cost *(2009$)* Average Installed Price	Average Lifetime Operating Cost	Average LCC	Life-Cycle Cost Savings Average Savings *(2009$)*	Households with Net Cost	Households with Net Benefit	Payback Period Median *(years)*	Average *(years)*
REPLACEMENTS								
0.90	$579	$2,656	$3,235					
0.95	$730	$2,483	$3,213	$22	39%	61%	6.1	10.3
2.00	$1,630	$1,537	$3,167	$68	54%	46%	9.6	24.6
NEW HOMES								
0.90	$494	$2,889	$3,382					
0.95	$589	$2,700	$3,290	$93	4%	96%	5.9	5.8
2.00	$1,377	$1,631	$3,008	$375	38%	62%	7.9	14.5

Table 12. Average LCC Savings for HPWH by Region, Housing Type, and Installation Location

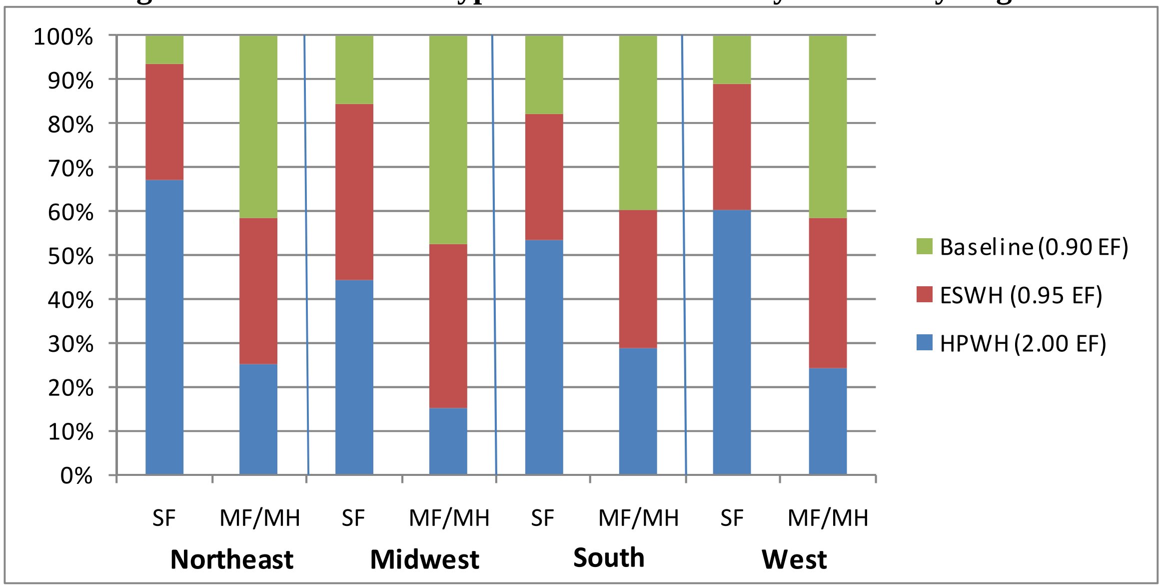
Census Region	Single Family* Unconditioned Space *(2009$)*	Single Family* Conditioned Space *(2009$)*	Multi-Family and Mfr Home** Unconditioned Space *(2009$)*	Multi-Family and Mfr Home** Conditioned Space *(2009$)*	Total *(2009$)*
Northeast	$843	$327	$427	-$406	$492
Midwest	$220	-$106	-$516	-$597	-$35
South	$427	-$9	-$17	-$302	$11
West	$703	$192	-$32	-$443	$181
Total	**$471**	**$22**	**-$21**	**-$380**	**$130**

* 62% of installations are in unconditioned space.
** 24% of installations are in unconditioned space.

The economics of HPWHs are more favorable for single-family homes than for other housing types. There are several reasons for this. First, these homes have a smaller share of installations in conditioned space, where there are often space constraints and venting issues, so the installation costs are lower. Second, the households in single-family homes have greater hot water use, which leads to higher energy savings for a HPWH. Lastly, because multi-family homes and manufactured homes have more installations in conditioned space, there are more households that incur an additional cost due to operation of the heating system to make up for the cooling effect of the HPWH.

Figure 1 shows the fraction of households for which a specific water heater technology has the lowest overall LCC in each region, by housing type. The HPWH has the lowest LCC for over half of the households in single-family homes in all regions except the Midwest. In no region is it the most favorable technology for multi-family homes and manufactured homes.

Figure 1. Water Heater Type with Lowest Life Cycle Costs by Region



The net energy savings (NES) and consumer net present value (NPV) results for different shares of electric storage water heater shipment switching to heat pump water heaters over the next decade are shown in **Table 13**. Total ESWH shipments during this 10-year period are estimated to be 51.1 million. Because HPWHs are most likely to be purchased by consumers for whom they are most cost-effective, we assume that each HPWH market share level is met by the households with the highest LCC savings. For example, the 10% market share level (which would be mostly met with 2015 standard requirements for water heaters above 55 gallons) includes households having LCC savings in the 90th percentile and above.

Table 13. National Impact Analysis Results from 2011-2020

Market Share of HPWH Shipments	National Energy Savings Quads	National Present Value (Billion, 2009$)
10%	0.53	6.08
25%	1.11	11.44
50%	1.85	16.19
100%	2.51	8.95

Discussion

The economics of HPWHs are sensitive to both the price of the equipment and the installation costs. The main results of this study assume that the average equipment price declines by approximately one-third compared to the current retail price. This is estimated to occur with a high volume of production, but whether the market will reach such levels in the near future is unclear. The recently established Federal standards for large-volume electric water heaters, which will take effect in 2015, require heat pump technology, and thus will increase production of HPWHs. To some degree, economies of scale in production of large-volume electric water heaters could spill over into the more common tank sizes. If retail prices do not decline significantly, tax credits or other incentives would be necessary to make HPWHs cost-effective for the majority of American homes.

Another factor that impacts the HPWH cost effectiveness is the water use. The higher water use is a big reason why large water heaters as well as installations in single family homes are more cost effective. On the other hand, almost a third of the shipments go to multi-family and manufactured homes where the hot water use is about half of the use in single-family homes.

The results show two clear bifurcations with respect to the cost-effectiveness of HPWHs. The economics are favorable for new homes, but less so for replacements. This result suggests that building code requirements would be a reasonable policy to encourage penetration of HPWHs. The economics are also favorable for most single-family homes, but are unfavorable for multi-family and manufactured homes. The extent to which design changes in HPWHs could reduce the cost of installations in conditioned spaces is a topic worth investigating.

The study did not include a comparison of the economics of HPWHs or electric resistance water heaters to condensing gas storage or tankless water heaters, solar water heaters, or other technologies which might be more efficient and cost effective to some households.

Conclusion

HPWHs show economic benefit for close to half of households nationally if they are produced at high volume, or if the current price is reduced by one-third with tax credits or other incentives. While the national average LCC savings are positive, this result masks important differences among regions and housing types. The economics are most favorable in the Northeast, largely due to the high electricity prices in this region. The economics are also favorable in the West, largely due to higher daily hot water use in this region. Most importantly, the economics of HPWHs are more favorable for new homes than for replacement applications, and more favorable for single-family homes. Although only about 50% of the households will benefit from HPWHs, if all these households switched to HPWHs over the next 10 years period they could account for almost 75% of the total national energy savings and provide a large amount of economic benefits.

References

Appliance Magazine. 2009. **The Life Expectancy/Replacement Picture**. September, 2009.

Baxter, V. D. and R. L. Linkous. 2002. **Durability Testing of a Drop-In Heat Pump Water Heater**, May, 2002. ORNL. Report No. ORNL/TM-2002/92. Available online: http://www.ornl.gov/~webworks/cppr/y2001/rpt/120429.pdf.

Baxter, V. D., J.J. Tomlinson, R.W. Murphy, B.G. Ashdown, and M.V. Lapsa. 2001**. Residential Heat Pump Water Heater (HPWH) Development Status – USA**. ORNL. http://www.ornl.gov/~webworks/cppr/y2001/pres/122293.pdf

Kelso, J. 2003. **Incorporating Water Heater Replacement into The Weatherization Assistance Program**, May 2003. D&R International, Ltd. Information Tool Kit.

Harris, J. C. Neme, and C. Calwell. 2005. **Residential Heat Pump Water Heaters: Energy Efficiency Potential and Industry Status**: Prepared for Natural Resources Defense Council. November 2005.

Northwest Energy Efficiency Alliance (NEEA). 2009. **A Specification for Residential Heat Pump Water Heaters Installed in Northern Climates**: Version 3.0 Final. October 25, 2009

Maxwell, J. 2004**. Heat Pump Water Heater Economic Model**. NYSERDA. 2004.

Rheem Manufacturing Company. 2009. **Owners Guide and Installation Instruction**: Air Sourced HPWH. http://www.rheem.com.au/images/pdf/owners_heatpump_126524B_0610.pdf.

Smith, D. C. 2009. , **Consultant Report - Water Heater Maintenance and Repair**, April 8, 2009. Florence, SC.

U.S. Department of Energy (USDOE) - Energy Information Administration (EIA). 2009. **Residential Energy Consumption Survey**: 2005 Public Use Data Files. http://www.eia.doe.gov/emeu/recs/recspubuse05/pubuse05.html.

USDOE EIA. 2009. **Annual Energy Outlook 2010 Early Release**, 2010. Washington, DC. Report No. DOE/EIA-0383(2010). Available online: <http://www.eia.doe.gov/oiaf/aeo/.>

USDOE - Energy Efficiency and Renewable Energy (EERE). 1993. **Technical Support Document:** Energy Efficiency Standards for Consumer Products: Room Air Conditioners, Water Heaters, Direct Heating Equipment, Mobile Home Furnaces, Kitchen Ranges and Ovens, Pool Heaters, Fluorescent Lamp Ballasts & Television Sets. Washington, DC Vol. 1 of 3. Report No. DOE/EE-0009.

USDOE EERE. 2002. **Technical Support Document:** Energy Efficiency Standards for Consumer Products: Residential Central Air Conditioners and Heat Pumps Including. May, 2002. Washington, D.C. http://www.eere.energy.gov/buildings/appliance_standards/

USDOE EERE. 2010. **Final Rule Technical Support Document**: Energy Efficiency Standards for Consumer Products: Heating Products. Washington, DC.

United States Environmental Protection Agency (USEPA). 2008. Energy Star Residential WHs: Final criteria analysis. http://www.energystar.gov/index.cfm?c=new_specs.water_heaters.

USEPA. 2009. **Water Heater Market Profile - 200**9: http://www.drintl.com/HtmlEmail/Water_Heater_Market_Profile_Sept2009.pdf