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ABSTRACT HEADING

The U.S. Department of Energy (DOE) recently completed a rulemaking process in which it amended the existing energy efficiency standards for residential water heaters. A key factor in DOE's consideration of new standards is the economic impacts on consumers. Determining such impacts requires a comparison of the additional first cost of energy efficiency design options with the savings in operating costs. This paper describes the method used to conduct the life-cycle cost (LCC) and payback period analysis for gas and electric storage water heaters. It presents the estimated change in LCC associated with more energy-efficient equipment, including heat pump electric water heaters and condensing gas water heaters, for a representative sample of U.S. homes. The study included a detailed accounting of installation costs for the considered design options, with a focus on approaches for accommodating the larger dimensions of more efficient water heaters. For heat pump water heaters, the study also considered airflow requirements, venting issues, and the impact of these products on the indoor environment. The results indicate that efficiency improvement relative to the baseline design reduces the LCC in the majority of homes for both gas and electric storage water heaters, and heat pump electric water heaters and condensing gas water heaters provide a lower LCC for homes with large rated volume water heaters.

INTRODUCTION

Water heating accounts for 14% of residential energy use in the U.S. (DOE EIA 2010) Most U.S. homes use either gas (52% of homes) or electricity (42% of homes) for water heating. (DOE EIA 2005)

Water heaters have been subject to national energy conservation standards for over 20 years. Residential water heaters, for statutory purposes, are defined as having a heat input of less than 75,000 Btu per hour (22.0 kW) and a storage volume between 20 to 100 gallons (76 to 379 liters) for gas storage water heaters and a maximum input rate of 41,000 Btu per hour (12 kW) and storage volume between 20 to 120 gallons (76 to 454 liters) for electric storage water heaters.[1] Standards that required compliance beginning in 2004 set minimum energy factors (EFs) for gas and electric storage water heaters (SWHs) that vary based on the storage volume of the water heater. For the most common storage volumes - 40 gallons (151 liters) for gas SWH and 50 gallons (189 liters) for electric SWH), the minimum EFs were 0.59 for gas SWHs and 0.90 for electric SWHs.

[1] Hereafter, the term "water heaters" is used to refer to residential water heaters as defined above.

In the past several years, the Department of Energy (DOE) conducted a rulemaking to consider amended standards for water heaters. A key factor in DOE's consideration of new standards is the economic impacts on consumers. Determining such impacts requires a comparison of the additional first cost of energy efficiency design options with the savings in operating costs. The analytical approach and results reported here were part of DOE's rulemaking process for the final rule, which was issued on April 16, 2010. Complete details of the analysis may be found in the Technical Support Document (TSD) to the final rule.[2]

DESIGN OPTIONS FOR WATER HEATERS

The reference point for higher-efficiency designs is the baseline, which represents the most commonly-used type of water heater. DOE then considered a number of higher-efficiency designs, as shown in Table 1. The main designs considered are thicker insulation, electronic ignition, and power vent. Particularly noteworthy for water heaters is that technologies currently exist that provide much higher efficiency than the conventional designs that have been used in the past. These technologies are condensing designs for gas SWHs and heat pump designs for electric SWHs.

Table 1. Efficiency Levels Considered for Gas-Fired and Electric Storage Water Heaters

Efficiency Level (EF)*	**Technology**
Gas-Fired Storage*	
Baseline (EF = 0.59)	Standing Pilot and 1" (2.5 cm) Insulation
EF = 0.62	Standing Pilot and 1.5" (3.8 cm) Insulation
EF = 0.63	Standing Pilot and 2.0" (5.1 cm) Insulation
EF = 0.64	Electronic Ignition, Power Vent and 1" (2.5 cm) Insulation
EF = 0.65	Electronic Ignition, Power Vent and 1.5" (3.8 cm) Insulation
EF = 0.67	Electronic Ignition, Power Vent and 2" (5.1 cm) Insulation
EF = 0.77	Condensing, Power Vent, 2" (5.1 cm) Insulation
Electric Storage*	
Baseline (EF = 0.90)	1.5" (3.8 cm) Foam Insulation
EF = 0.91	2" (5.1 cm) Foam Insulation
EF = 0.92	2.25" (5.7 cm) Foam Insulation
EF = 0.93	2.5" (6.4 cm) Foam Insulation
EF = 0.94	3" (7.6 cm) Foam Insulation
EF = 0.95	4" (10.2 cm) Foam Insulation
EF = 2.00	Heat Pump Water Heater, 2" (5.1 cm) Foam Insulation
EF = 2.35	Heat Pump Water Heater, More-Efficient Compressor, 2.5" (6.4 cm) Foam Insulation

* EF ratings are given for 40 gal (151 l) model for GSWHs and 50 gal (189 l) model for ESWHs.

Condensing gas SWHs utilize a secondary heat exchanger to extract the heat from the moisture content in the flue gases. Condensing gas SWHs are as yet only used in commercial sizes, but at least one condensing gas-fired storage water heater is actively marketed for residential applications.

Heat pump water heaters (HPWHs)[3] are over twice as energy-efficient as conventional electric resistance water heaters. A HPWH represents a merging of two technologies: (1) an electric resistance storage water heater with tank and controls; and (2) a refrigeration circuit similar to that found in a residential air-conditioner. Integrated HPWHs are currently being marketed by several manufacturers and now qualify for ENERGY STAR certification.

Our analysis considered several issues that affect the consumer economics of HPWHs and condensing gas SWHs. First, HPWHs are slightly taller and wider than typical water heaters, so in some locations it might be difficult to fit the new water

[2] The DOE rulemaking considered and adopted standards for oil-fired SWHs and gas instantaneous water heaters in addition to standards for gas and electric SWHs.
[3] Throughout this paper, the term "heat pump water heater" refers to integrated units, not add-on products.

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). Condensing water heaters are slightly 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. In addition, in replacement market a new plastic venting system is required.

CONSUMER IMPACT ANALYSIS

Analytical Method

We conducted life-cycle cost (LCC) and payback period (PBP) analyses to evaluate the economic impacts on consumers of potential amended energy conservation standards for water heaters. The LCC represents total consumer expenses during the life of an appliance, including equipment, installation, and operating costs (expenses for energy use, maintenance, and repair). To compute LCCs, we discounted future operating costs to the time of purchase, and then summed those costs over the life of the appliances. The PBP is calculated using the change in purchase cost (normally higher) at a higher efficiency level, divided by the change in annual operating cost (normally lower).

To conduct the consumer impact analysis, we developed nationally-representative samples of households that use gas or electric SWHs. The samples were drawn from the DOE Energy Information Administration (EIA) 2005 Residential Energy Consumption Survey (RECS 2005). The sample for gas SWHs was comprised of 2,166 records, representing 55.2 million homes, while the sample for electric SWHs was comprised of 1,523 records, representing 39.5 million homes. We assigned each household a water heater with a specific storage volume and determined the energy consumption for water heaters of varying efficiency. We considered a range of storage volumes for each efficiency level.

The LCC and PBP analysis models both the uncertainty and variability in the inputs using Monte Carlo simulation and probability distributions for several inputs. For each household, we measured the LCC change and the PBP associated with a given efficiency level relative to the water heater assumed to be purchased in the base case. The base case reflects the future market in the absence of amended energy conservation standards, including the demand for products that exceed the current standards. Thus, the base-case water heater for a given household is not necessarily the same as the baseline model.

The analysis assumes that the water heaters are purchased in 2015, as this is the year in which compliance with amended standards is required.

Consumer Product Cost

Consumer product costs are based on U.S. DOE analysis that estimated the manufacturer selling price of baseline and higher-efficiency water heaters. DOE's engineering analysis develops cost-efficiency relationships that show the manufacturing costs of achieving increased efficiency. DOE used an efficiency level approach to identify incremental improvements in efficiency for each product and a cost-assessment approach to develop the manufacturer production cost (MPC) at each efficiency level. DOE first identified the most common water heating products on the market and determined their corresponding efficiencies and the distinguishing technology features. DOE then gathered information about these selected products using reverse-engineering methodologies, product information from manufacturer catalogs, and discussions with manufacturers and other experts of water heaters. This approach identified potential technology paths manufacturers use to increase energy efficiency. DOE used this information to generate bills of materials (BOMs), which is then converted into MPCs. By applying derived manufacturer markups to the MPCs, DOE calculated the manufacturer selling prices (MSPs).

We applied markups to transform the manufacturer selling prices into a consumer cost. In order to develop markups, we identified how the products are distributed from the manufacturer to the customer (the distribution channels). We derived separate markups for replacement and new construction applications. For each distribution channels, we used economic data from the U.S. Census Bureau and other sources to define how prices are marked up as the products pass to the customer. The price includes sales tax for replacement applications.

The consumer price for the considered water heater efficiency levels are shown in Table 2. Since DOE analyzes efficiency levels as candidates for minimum efficiency standards, its analysis of manufacturer costs assumed a high level of production at each efficiency level.

Table 2. Water Heater Prices Used in the Analysis

Gas SWH		Electric SWH	
Efficiency Level	**Consumer Price*** *(2009$)*	**Efficiency Level (EF)**	**Consumer Price*** *(2009$)*
Baseline, EF = 0.59	$450	Baseline, EF = 0.90	$281
EF = 0.62	$468	EF = 0.91	$291
EF = 0.63	$509	EF = 0.92	$301
EF = 0.64	$705	EF = 0.93	$304
EF = 0.65	$723	EF = 0.94	$325
EF = 0.67	$771	EF = 0.95	$362
EF = 0.77	$988	EF = 2.00	$1,039
		EF = 2.35	$1,163

* Weighted average for replacement and new construction applications

Installation Costs

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 cost estimation was partly based on RSMeans cost estimates. Regional labor costs were applied to each RECS sample household to more accurately estimate installation costs.

We included several installation costs to address the space constraints that water heaters having thicker insulation may face in some homes. To estimate the fraction of households that would require various modifications, we considered the water heater location determined for each sample household. We determined the location using information from the 2005 RECS, which reports whether the house has a heated or unheated basement and the presence or absence of a garage, crawlspace, or attic.

For gas SWHs, we estimated that 8–13 percent and 15–25 percent of all replacement installations would require significant modifications in order to install a design with 1.5-inch (3.8 cm) or 2-inch (5.1 cm) insulation, respectively. After considering that some houses could choose a different dimension water heater, we assumed that major modifications would be necessary for 20 percent of replacement installations with 2-inch (5.1 cm) insulation and for 10 percent of replacement installations with 1.5-inch (3.8 cm) insulation. We estimated that half of the cases would choose a smaller water heater with a higher setpoint and tempering valve or a smaller water heater with similar first hour rating as the existing unit. The other half would choose door jamb removal/replacement to fit a wider water heater through an indoor closet or attic.

The incremental installation cost for the power vent design includes the cost of an electrical outlet and a single plastic pipe vent. The installation cost for the condensing design is the same as above, with the additional cost of the condensate disposal.

One specific concern addressed by the analysis is about the safety of atmospheric venting of 40 gallon (151 liter) gas SWHs at 0.63 EF. This concern relates to vent temperatures from water heaters with recovery efficiencies of 78 percent and higher that could encounter condensation and the resulting corrosive environment in vent connectors during water heater cycling. Although there are several currently available 40 gallon (151 liter) gas SWH models at 0.63 EF that utilize atmospheric venting and do not have any special venting requirement, we assumed that a stainless steel vent connector would be required for all models with RE of 78 percent and higher. Applying this assumption resulted in application of a cost for a stainless steel vent connector for 57 percent of installations at 0.63 EF, as well as for 53 percent of installations at 0.62 EF.

The estimated average installation cost (weighted average cost for replacement and new construction applications) for gas SWHs is $630 for the baseline model, $703 for 0.62 EF, $736 for 0.63 EF, and $905 for the condensing design.

For electric SWHs, we assumed that major modifications would be necessary for 40 percent of replacement installations with 3 inch (7.6 cm) or greater insulation and for 20 percent of replacement installations with 2 inch (5.1 cm) or greater insulation. We estimated that half of the cases where major modifications would be necessary would install a water heater with a smaller rated volume and adding a tempering valve, and half would need to apply door jamb removal/replacement.

For heat pump water heater installation, we applied several additional costs, including on average one additional hour of labor for the extra time required to install this product. We assumed that the space constraints encountered when installing heat pump water heaters would be similar to those encountered when installing electric storage water heaters with 3 inch (7.6 cm) insulation. In addition, heat pump water heaters are required to be in well-ventilated spaces. Based on the water heater location, we estimated that of the cases that would encounter space constraints, some would choose a smaller water heater with a tempering valve, and others would choose door jambs removal/replacement and adding a louvered door. In addition, because there are concerns about the extent to which installing a louvered door will provide adequate air flow for closet installations of heat pump water heaters, we assumed that some households would instead install a venting system, which would provide adequate air flow and also alleviate excessive cooling of the indoor space near the water heater.

About 35 percent of households were 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 at least 3 MMBtu (3.2 GJ) to the indoor space over the heating season). For each household we estimated that all indoor replacement installations where the household would face a significant cooling effect would incur the cost of having a venting system installed to exhaust and supply air, which averages $469. (For the remainder of homes experiencing a cooling effect, the extra cost for space heating was accounted for in the energy use calculations, as described below.)

The estimated average installation cost for electric SWHs is $288 for the baseline model, $330 for 0.93 EF design, $349 for 0.94 and 0.95 EF designs, and $535 for the HPWH at 2.00 EF.

Energy Use

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 such as water and ambient temperatures.

The hot water draw model accounts for a number of factors, including the number and ages of the people who live in the household, the way they consume hot water, the presence of hot-water-using appliances, the tank size and thermostat set point of the water heater, and the climate in which the residence is situated. To account for decrease in hot water use by clothes washers and dishwashers in the period since the model was developed, we adjusted the parameters in the model. Estimated average daily hot water use was 41.3 gallons (156 liters) for households having electric storage water heaters, and 44.1 (167 liters) gallons for households having gas-fired storage water heaters. However, the range of average daily hot water use is quite large. These values are well below the value used in the DOE test procedure, 64.2 gallons (243 liters). These results are similar to the findings in other recent hot water draw studies.

We calculated water heater energy use using Water Heater Analysis Model (WHAM) calculation method, which accounts for a range of operating conditions and energy efficiency characteristics of water heaters. To describe energy efficiency characteristics of water heaters, WHAM uses parameters from DOE's test procedure: recovery efficiency (RE), standby heat-loss coefficient (UA), and rated input power (P_{ON}). Water heater operating conditions are indicated by the daily hot water draw volume, inlet water temperature, thermostat setting, and air temperature around the water heater (ambient air temperature). We estimated the specific conditions for each sample household using RECS data, weather data, and data about supply water temperatures. We assigned water heater thermostat settings to the sample households based on a 2006 survey. Total gas SWH energy use includes electricity consumption.

HPWH Modifications. For HPWHs, the efficiency and energy consumption are dependent on ambient temperature. To account for this, a function of the average ambient temperature was applied to adjust the RE parameter in the WHAM equation. A HPWH operates either in heat pump or in electric resistance mode. The electric resistance mode of operation was accounted for when the monthly ambient temperature is less than 32°F (0°C) or more than 100°F (38°C), or when the slower recovery rate of the heat pump is not sufficient to satisfy water demand.

For HPWHs that are located indoors, overcooling of the indoor space as a result of the unit's operation is a potential problem. We assumed that the majority of households that would be affected by indoor operation of a HPWH would not choose to incur the cost of a venting system, and would instead operate their heating and cooling systems to compensate for the effects of the heat pump water heater. To account for this indirect increase in home heating (and the decrease in cooling during summer months), we estimated the associated energy consumption by space heating and air conditioning equipment for the RECS homes and included this energy use in the analysis.

Table 3 shows the average annual energy use by efficiency level. The results are lower than the energy use estimated using the DOE test procedure by 34% for gas SWHs and 46% for electric SWHs. The two main reasons for the difference are lower hot water use and lower setpoint temperature in the field.

Table 3. Average Annual Energy Use by Efficiency Level for Gas and Electric Storage Water Heaters

Gas Storage Water Heaters			**Electric Storage Water Heaters**	
Efficiency Level *(EF)*	**Average Energy Consumption**		**Efficiency Level** *(EF)*	**Average Energy Consumption** *MMBtu/yr (kWh/yr)*
	Gas *MMBtu/yr (kWh/yr)*	**Electricity** *MMBtu/yr (kWh/yr)*		
0.59 (baseline)	16.5 (4836)	0 (0.0)	0.90 (baseline)	8.9 (2604)
0.62	15.7 (4601)	0 (0.0)	0.91	8.8 (2569)
0.63	15.2 (4455)	0.02 (5.9)	0.92	8.7 (2535)
0.64	14.7 (4308)	0.23 (68.5)	0.93	8.6 (2515)
0.65	14.2 (4162)	0.23 (67.2)	0.94	8.4 (2467)
0.67	13.7 (4015)	0.22 (65.6)	0.95	8.3 (2431)
0.77	11.9 (3488)	0.21 (60.6)	2.00	4.8 (1399)
			2.35	4.2 (1216)

Other Inputs

The annual water heating energy costs for each sample household were derived by multiplying the estimated monthly energy use by average monthly energy prices. Using data from EIA, we calculated average natural gas and 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. To project future prices, we used the annual percentage changes in the price forecasts in EIA's Annual Energy Outlook 2010.

The maintenance cost and the repair cost cover all labor and material costs associated with maintenance or repair. Determination of the repair cost requires determining the service life of the components that are likely to fail. Maintenance costs include draining the tank for gas and electric SWHs and FVIR maintenance costs for gas SWHs. In addition, for HPWHs we applied a 5-year preventative maintenance cost for units installed in exposed spaces such as garages.

For gas SWHs, we estimated a repair cost for pilot ignition, electronic ignition, power vent, and condensing design. The efficiency levels that include power vent or condensing design encounter fan as well as electronic ignition repair costs. 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.

For the replacement market, the discount rate used to discount future operating costs to the year of purchase reflects rates in various debt or asset classes that might be used to purchase the appliance, including those that might be affected indirectly. The average value was 5.1%. For new construction installations, the discount rate reflects after-tax real mortgage rates and on average equals 3.0%.

We estimated average water heater lifetime based on an analysis of historical data of the shipments and the number of units the U.S. housing stock. We characterized the lifetime using a Weibull probability distribution ranging from a minimum of 6 years to maximum of 30 years, with an average value of 13 years. We used the same lifetime for all efficiency levels, including HPWHs, as indicated by available information.

Base Case Efficiency Assumptions

As mentioned previously, the analysis measures the LCC change and the PBP associated with a given efficiency level relative to the water heater assumed to be installed in the base case. To estimate the base-case market shares of various energy efficiency levels for water heaters in the compliance year, we began with data on shipments by efficiency level for 2002-2006 from AHRI, supplemented with data on the number of water heater models at different energy efficiency levels reported in AHRI Directories. To estimate the shares of condensing SWHs and HPWHs, we considered the market penetration goals set by the ENERGY STAR program, in combination with assessment of constraints on such penetration.

LCC AND PAYBACK PERIOD RESULTS

For each of the considered efficiency levels, in addition to average LCC savings and payback period, we calculated the fraction of households for which the LCC will either decrease (net benefit), increase (net cost), or exhibit no change (no impact). No impacts occur when the base-case water heater efficiency equals or exceeds the considered efficiency level. The average results refer only to households impacted at a given efficiency level.

Table 4 and Table 5 show the LCC and payback results for gas and electric SWHs, respectively. For the latter, the efficiency levels above the baseline that apply to standard electric resistance units have small average LCC savings. The savings for the HPWH levels are higher, but half of the households would experience a net cost (LCC increase).

Table 4. LCC and PBP Results for Gas Storage Water Heaters

Efficiency Level (EF)	**LCC**					**Median Payback**
	Average LCC	**Average Savings**	**Net Cost**	**No Impact**	**Net Benefit**	
	2009$	2009$	%	%	%	years
0.62	$3,528	$16	25%	36%	39%	2.0
0.63	$3,537	$7	32%	22%	45%	4.5
0.64	$3,845	-$267	72%	12%	16%	35.4
0.65	$3,812	-$235	70%	6%	23%	26.0
0.67	$3,793	-$218	70%	6%	23%	21.5
0.77	$3,771	-$195	70%	1%	28%	15.6

Table 5. LCC and PBP Results for Electric Storage Water Heaters

Efficiency Level (EF)	**LCC**					**Median Payback**
	Average LCC	**Average Savings**	**Net Cost**	**No Impact**	**Net Benefit**	
	2009$	2009$	%	%	%	years
0.91	$3,269	-$1	7%	68%	25%	3.8
0.92	$3,255	$5	11%	44%	45%	4.0
0.93	$3,245	$11	12%	39%	48%	4.0
0.94	$3,236	$18	21%	17%	62%	5.0
0.95	$3,236	$18	32%	10%	59%	6.7
2.00	$3,136	$112	50%	5%	45%	9.4
2.35	$3,076	$171	50%	1%	49%	9.0

The average results for the entire household samples mask important findings. Because households with large-volume water heaters tend to have higher hot water use, efficiency measures provide more energy cost savings relative to the additional first cost. Table 6 shows the average LCC savings for small-volume water heaters (defined as having rated storage volume less than 56 gallons (212 liters) and large-volume water heaters (defined as having rated storage volume equal to or greater than 56 gallons (212 liters)). Large-volume water heaters account for approximately 4% of gas SWH shipments and 9% of electric SWH shipments. For households with such equipment, the average LCC savings are positive for the condensing gas SWH (EF=0.77), and are much substantial for HPWHs (EF=2.00 and EF=2.35).

Table 6. Average LCC Savings by Efficiency Level for Small- and Large-Volume Water Heaters

Efficiency Level	Gas SWH		Efficiency Level	Electric SWH	
	Small	Large		Small	Large
EF = 0.62	$15	$19	EF = 0.91	-$2	$15
EF = 0.63	$6	$18	EF = 0.92	$3	$24
EF = 0.64	-$271	-$147	EF = 0.93	$9	$31
EF = 0.65	-$241	-$83	EF = 0.94	$13	$72
EF = 0.67	-$224	-$65	EF = 0.95	$10	$98
EF = 0.77	-$206	$77	EF = 2.00	$62	$626
			EF = 2.35	$118	$717

CONCLUSION

The results of our analysis indicate that efficiency improvement relative to the baseline design reduces the LCC in the majority of homes for both gas and electric storage water heaters, and heat pump electric water heaters and condensing gas water heaters provide a lower LCC for homes with large rated volume water heaters. The favorable economics of condensing technology for large-volume gas SWHs and of heat pump technology for large-volume electric SWHs was an important factor in DOE's decision to set separate standards for small and large-volume gas and electric SWHs. By setting higher standards for the market segment for which higher energy efficiency is cost-effective, DOE will help accelerate the penetration of advanced water heating technology into the U.S. market.

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