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DOCKET NO. 39796

PETITION OF ELECTRIC UTILITY MARKETING MANAGERS OF TEXAS TO APPROVE DEEMED SAVINGS DERIVED FOR NEW MEASURE	§ § § § §	**PUBLIC UTILITY COMMISSION OF TEXAS**

PETITION TO APPROVE DEEMED SAVINGS ESTIMATES FOR NEW RESIDENTIAL HEAT PUMP WATER HEATER MEASURE FOR ENERGY EFFICIENCY PROGRAMS

TO THE HONORABLE PUBLIC UTILITY COMMISSION OF TEXAS:

NOW COMES, AEP Texas Central Company, AEP Texas North Company, CenterPoint Energy Houston Electric, LLC, El Paso Electric Company, Entergy Texas, Inc., Oncor Electric Delivery Company LLC, Southwestern Electric Power Company, Texas-New Mexico Power Company, and Southwestern Public Service Company, (the Electric Utilities or Joint Petitioners) pursuant to P.U.C. SUBST. R. 25.181(i)(4) file this Petition to approve deemed savings values for a new residential heat pump water heater (HPWH) measure. In support thereof, the Electric Utilities would respectfully show as follows:

I. INTRODUCTION

P.U.C. SUBST. R. §25.184(d)(2) previously governed the Measurement and Verification (M&V) Guidelines and Stipulated Values, prior to its repeal in the Public Utility Commission of Texas' (Commission or PUC) Order in Project No. 33487. The Commission's repeal of §25.184 removed deemed savings estimates from the rule so that such materials could be more easily modified to reflect changes in circumstances relating to energy efficiency. In its Order in Project No. 33487, the Commission also amended §25.181 to include a process in new amended subsection §25.181(i)(4) for electric utilities to make changes to standardized materials (such as standardized forms, procedures, deemed savings estimates and program templates) utilized in their energy efficiency programs. This Petition presents proposed modifications to standardized procedures and deemed savings estimates as contemplated in §25.181(i)(4). Accordingly, the Electric Utilities' petition for the approval of a residential HPWH energy efficiency measure and

the deemed savings values necessary to implement such a measure. Pursuant to §25.181(i)(4), this Petition is being filed 60 days prior to the intended implementation of the new values. Additionally, per the rule, all relevant documents provided with this Petition pertaining to the deemed savings values modifications petitioned herein are also being provided to Retail Electric Providers (REPs) and Energy Efficiency Service Providers (EESPs).

The values proposed herein will serve as estimates of the savings in electrical energy and peak demand associated with the installation of a heat pump water heater in a residential setting. The new measure will be applicable to both new construction and replacement of electric water heating equipment in existing homes. These savings estimates will, in turn, be used to determine the incentive payments made to EESPs that successfully implement the residential heat pump water heater measure, and will affect the savings that the electric utilities may count toward their goals for energy efficiency.

The new deemed savings estimates proposed in this Petition support a new measure that should encourage additional energy efficiency projects in the residential sector and reduce the expense of program offerings.

II. BUSINESS ADDRESSES AND AUTHORIZED REPRESENTATIVES

The business addresses and authorized representatives for each of the Joint Petitioners are as follows:

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SPS requests that all information, responses to requests for information and documents in this proceeding be served upon each of the above representatives at the addresses or fax numbers specified above.

III. JURISDICTION

The Commission has jurisdiction over the subject matter of this Petition pursuant to Section 39.905 of the Public Utility Regulatory Act, TEX. UTIL. CODE ANN. (Vernon's 2007) (PURA).

IV. NEED FOR AND DESCRIPTION OF UPDATES

The Joint Petitioners request that the proposed residential HPWH measure be adopted to provide the utilities and their EESPs deemed savings estimates for a new, market-ready technology. The new measure will encourage additional energy efficiency projects in the residential sector. Specifically, the Petition proposes deemed savings for residential heat pump water heaters installed in one of five climate zones around the state. Both existing homes with electric storage water heating and new residential construction would be eligible for the initiative. Deemed savings for a given installation are determined based on the size of the storage tank associated with the HPWH, whether it is installed in conditioned or unconditioned space, and, if in conditioned space, the primary heat source type (gas, heat pump, or electric resistance).

The Petition also proposes an estimated useful life (EUL) of thirteen years for the heat pump water heater measure. This EUL is consistent with the judgment of the American Council for an Energy-Efficient Economy, as listed on its website.[1]

V. METHODOLOGY

The Joint Petitioners have developed these deemed savings by applying a set of standard calculations for estimating the energy use of electric storage water heaters and HPWHs to the specific climate conditions of five Texas climate areas. In developing these deemed savings, Joint Petitioners relied on a number of sources: (1) Department of Energy Technical Support Documents (TSDs) developed in the process of creating and implementing existing Federal Standards for electric storage water heaters, including both the Final Rule TSD[2] and the TDS for

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[1] Water Heating. American Council for an Energy Efficient Economy. Online. Available: http://www.aceee.org/consumer/water-heating. Accessed: September, 2011.

[2] Residential Heating Products Final Rule Technical Support Document. US Department of Energy: Energy Efficiency and Renewable Energy. Online. Available:

the final rule establishing the previous standard[3] and (2) documents and tools developed by DOE for the Building America Benchmark program, including Domestic Hot Water Event Schedule Generator[4] developed by the National Renewable Energy Laboratory (NREL) and an Oak Ridge National Laboratory (ORNL) report on field testing of residential heat pump water heaters.[5]

The deemed savings were developed by comparing the expected annual energy usage of homes in which water is heated with a conventional electric storage water heater (with resistance heating elements) to that of homes with heat pump water heaters installed in either conditioned or unconditioned space. For homes in which heat pump water heaters are installed within conditioned space, the total impact on electric energy usage and peak demand includes an interactive effect due to the nature of how heat pumps work: they extract heat from the surrounding air, reducing cooling loads in cooling season but inflicting a heating penalty in heating season. The deemed savings for a given unit take into account the climate zone, tank volume, and, for those homes in which the unit is installed in conditioned space, the principal heating source of the home (gas furnace, electric resistance, or an electric heat pump). They are designed to apply to residential, electric, storage-type water heaters with storage capacities between 40 and 80 gallons, which is the range of storage tank size of heat pump water heaters approved by ENERGY STAR® in the summer of 2011. These deemed savings should apply to replacement of an electric storage water heater in existing homes and the installation of heat pump water heaters in new construction.

Baseline

The baseline condition is an electric storage water heater. The baseline efficiency is based on the Department of Energy (DOE) energy efficiency standard for electric storage water heaters, as published in 10 CFR Part 430 of the Federal Register:[6]

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http://www1.eere.energy.gov/buildings/appliance_standards/residential/heating_products_fr_tsd.html.

[3] Residential Water Heaters Technical Support Document for the January 17, 2001, Final Rule. US Department of Energy: Energy Efficiency and Renewable Energy. Online. Available: http://www1.eere.energy.gov/buildings/appliance_standards/residential/waterheat_0300_r.html.

[4] National Renewable Energy Laboratory. Spreadsheet Tool. Online. Available: http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html.

[5] Field Tests of a "Drop-In' Residential Heat Pump Water Heater. Oak Ridge National Laboratory. ORNL/TM-2002/207, September 2002. Online. Available: http://www.ornl.gov/~webworks/cppr/y2002/rpt/115540.pdf

[6] *10 CFR Part 430. Energy Conservation Program: Energy Conservation Standards for Residential Water Heaters,*

$$\text{Energy Factor}_{Base} = 0.97 - 0.00132 \times \text{Rated Storage Volume (gal)}$$

This equation reflects the efficiency standard for electric storage water heaters that is currently in effect. In April of 2010, DOE promulgated a new standard for electric storage water heaters; however, that standard does not go into effect until April of 2015.

Energy Efficient Replacement

The efficient condition (i.e. equipment eligible to receive an incentive through a program) is a heat pump water heater (HPWH) that meets ENERGY STAR® qualifications.[7] An energy factor (EF) of 2.2 is used to characterize the performance of HPWHs: this EF is the average efficiency of ENERGY STAR® HPWHs as of June 2011. Since the HPWH's performance is climate specific, the HPWH energy factors are adjusted for inlet air temperature and storage volume.

Factors Influencing Deemed Savings

The key variables that influence estimated savings are the hot water consumption in gallons (vol.), entering water temperature (T_{mains}), storage tank set point (T_{tank}), and energy factor (EF). Typical hot water consumption is estimated using equations developed by the National Renewable Energy Laboratory (NREL) relating the number of bedrooms in a home to residential hot water end uses.[8] The entering water temperature is adjusted based on climate zone and average annual ambient temperatures. The storage tank set point is set at a constant of 120°F based on manufacturer recommendations. The deemed savings also account for interactive air-conditioning effects associated with the HPWH when located inside conditioned space.

The deemed savings estimates derived by this process are provided in the following section. Detailed description of the methods used and calculations performed in the derivation of these deemed savings is provided in the Appendix.

Direct Heating Equipment, and Pool Heaters; Final Rule. Online. Available: http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/htgp_finalrule_fedreg.pdf. Accessed July 2011.

[7] ENERGY STAR® Requirements (as of Jan-2011) - HPWH must have a maximum current rating of 24 amperes, voltage no greater than 250 volts, and a transfer of thermal energy from one temperature to a higher temperature level for the purpose of heating water. Unit must have "integrated" or "drop-in" configuration. EF>= 2.0, first-hour rating (FHR) >= 50 gal/hr, Warranty >= 6 yrs on sealed systems, Safety UL 174 & UL 1995.

[8] R. Hendron et al. "Development of an Energy Savings Benchmark for All Residential End-Uses." Online. Available: http://www.nrel.gov/docs/fy04osti/35917.pdf. Pg. 2.

VI. SUMMARY OF PROPOSED CHANGES

A single change is proposed: the adoption of a residential HPWH energy efficiency measure with an estimated useful life of thirteen years and deemed electric demand and energy savings for the installation of an HPWH in a residential application as presented in Tables 1 through 5.

The proposed deemed savings are intended to be valid for installation in a retrofit application (replacement of an electric storage water heater) or in new construction. Four basic variables specify the appropriate deemed demand and energy savings values for a given project:

- the climate zone,
- the HPWH tank size,
- the HPWH installed location (Conditioned vs. Unconditioned Space), and
- for HPWH installations in conditioned space, the building heating type (electric resistance, air-source heat pump, or gas furnace)

Deemed savings are specified for heat pump water heaters installed in four size ranges: 40-49 gallon, 50-59 gallons, 60-79 gallons, and 80 or more gallon sizes. These sizes correspond to the four basic sizes of HPWHs commercially available at the time these deemed savings were developed as discussed above (see Market Availability). These deemed savings are not considered applicable to any future integrated heat pump water heater products that may appear on the market with tank size below 40 gallons.

Table 1. Residential HPWH Deemed Savings for Climate Zone 1, Amarillo, TX

Savings (Units)	Water Heater Location	Heating Type	HPWH Tank Size Range, Gallons			
			40-49	50-59	60-79	80 and above
Energy (kWh)	Conditioned Space	Gas	1,318	1,598	1,914	2,253
		Heat Pump	956	1,227	1,536	1,867
		Elec. Resistance	559	822	1,122	1,444
	Unconditioned Space	All	1,183	1,455	1,764	2,095
Demand (kW)	Conditioned Space	All	0.17	0.2	0.24	0.27
	Unconditioned Space		0.13	0.17	0.2	0.24

Table 2. Residential HPWH Deemed Savings for Climate Zone 2: Dallas, TX

Savings (Units)	Water Heater Location	Heating Type	HPWH Tank Size Range, Gallons			
			40-49	50-59	60-79	80 and above
Energy (kWh)	Conditioned Space	Gas	1,119	1,346	1,603	1,878
		Heat Pump	864	1,086	1,338	1,608
		Elec. Resistance	584	801	1,048	1,312
	Unconditioned Space	All	985	1,210	1,466	1,739
Demand (kW)	Conditioned Space	All	0.13	0.15	0.18	0.2
	Unconditioned Space		0.1	0.12	0.15	0.17

Table 3. Residential HPWH Deemed Savings for Climate Zone 3: Houston, TX

Savings (Units)	Water Heater Location	Heating Type	HPWH Tank Size Range, Gallons			
			40-49	50-59	60-79	80 and above
Energy (kWh)	Conditioned Space	Gas	1,094	1,304	1,542	1,796
		Heat Pump	891	1,097	1,331	1,581
		Elec. Resistance	669	871	1,101	1,347
	Unconditioned Space	All	925	1,136	1,375	1,630
Demand (kW)	Conditioned Space	All	0.13	0.15	0.17	0.2
	Unconditioned Space		0.09	0.12	0.14	0.17

Table 4. Residential HPWH Deemed Savings for Climate Zone 4: Corpus Christi, TX

Savings (Units)	Water Heater Location	Heating Type	HPWH Tank Size Range, Gallons			
			40-49	50-59	60-79	80 and above
Energy (kWh)	Conditioned Space	Gas	1,065	1,262	1,485	1,723
		Heat Pump	914	1,109	1,329	1,565
		Elec. Resistance	750	942	1,159	1,392
	Unconditioned Space	All	868	1,066	1,289	1,528
Demand (kW)	Conditioned Space	All	0.12	0.14	0.16	0.19
	Unconditioned Space		0.09	0.11	0.13	0.16

Table 5. Residential HPWH Deemed Savings for Climate Zone 5: El Paso, TX

Savings (Units)	Water Heater Location	Heating Type	HPWH Tank Size Range, Gallons			
			40-49	50-59	60-79	80 and above
Energy (kWh)	Conditioned Space	Gas	1,152	1,387	1,653	1,938
		Heat Pump	897	1,127	1,387	1,667
		Elec. Resistance	617	842	1,097	1,371
	Unconditioned Space	All	1,018	1,251	1,516	1,799
Demand (kW)	Conditioned Space	All	0.14	0.16	0.19	0.22
	Unconditioned Space		0.11	0.13	0.16	0.19

Estimated Useful Life (EUL)

The EUL for this measure is thirteen years. This EUL is consistent with the judgment of the American Council for an Energy-Efficient Economy as listed on its website.[9]

VII. PROPOSED NOTICE AND PROCEDURE

The Joint Petitioners propose providing notice of the proposed revisions by e-mail to all REPs, interested persons and entities on the Energy Efficiency Implementation Project (EEIP) list-serve, and to EESPs participating in related utility programs. The Joint Petitioners further propose that comments be filed in this Project three weeks after completion of notice and a week thereafter the Commission's Staff files its recommendation to the Commission. The Joint Petitioners believe that informal disposition according to P.U.C. Proc. R. 22.35 with a 15-day intervention period is appropriate.

VIII. CONCLUSION AND PRAYER

The Electric Utilities present this Petition to the Commission in an effort to improve the programs they are implementing to advance the State's goal for energy efficiency. The Electric Utilities respectfully request that the Commission grant approval of the recommended residential

[9] Water Heating. American Council for an Energy Efficient Economy. Online. Available: http://www.aceee.org/consumer/water-heating. Accessed: September 2011.

heat pump water heater measure with the above-listed deemed savings and a measure EUL of thirteen years, and for such other and further relief for which they may be justly entitled.

DATED: Sept. 23, 2011

Respectfully submitted,

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Appendices

Appendix A. Working Papers for Residential Heat Pump Water Heater Deemed Savings

This document presents deemed savings for the installation of heat pump water heaters (HPWH) in lieu of standard electric storage water heaters (EWH) on a per-unit basis. The deemed savings are derived such that savings can be attributed to the installation according to the storage capacity of the installed unit, and are based on the assumption that most units are installed to replace similarly-sized EWHs. Deemed savings for this measure account for the interaction between a HPWH installed inside conditioned space and a home's air-conditioning equipment, estimating an electric cooling energy benefit and a heating penalty for homes with three primary heating types: gas furnace (for which there is no electric heating penalty), electric resistance, and heat pump.

Deemed savings herein developed are for heat pump water heaters installed in the residential market. Deemed savings are applicable to both new construction and retrofit installations: for new construction, homes must be all-electric, and for retrofit, the unit being replaced must be an electric, storage-type water heater with capacity between 40 and 80 gallons and maximum energy input of 4.5 kilowatts. Units with maximum energy input over 4.5 kW are ineligible.[10]

Definition of Baseline Condition

The baseline condition is an electric storage water heater. The baseline efficiency is based on Title 10, Department of Energy, Sub Chapter D, Energy Conservation, Part 430 - Energy Conservation Program for Consumer Products, (10 CFR Part 430.32); Energy factor as of January 20, 2004.

$$\text{Energy Factor}_{Base} = 0.97 - 0.00132 \times \text{Rated Storage Volume (gal)}$$

Application of this equation to the tank sizes for which deemed savings are developed produce the base energy factors (EF_{Base}) listed in Table A-1.

Table A-1. Baseline Energy Factor (EF_{Base}) by Storage Volume

Tank Size (Gal)			
40 - 49	**50 - 59**	**60 - 79**	**80 and up**
0.917	0.904	0.884	0.864

The Energy Factors of baseline electric storage water heaters range from 0.92 for a 40-49 gallon unit to 0.86 for a unit with an 80 gallon tank or larger.

Definition of Efficient Condition

The efficient condition is a heat pump water heater that meets ENERGY STAR® qualifications.[11]

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[10] Note that this exclusion does not apply to electric resistance storage water heaters that have two 4.5 kW heating elements, but are designed such that these elements do not simultaneously engage.

[11] ENERGY STAR® Requirements (as of January 2011) HPWH must have a maximum current rating of 24 amperes, voltage no greater than 250 volts, and a transfer of thermal energy from one temperature to a higher

An EF of 2.2 was used to develop the efficient condition: this EF is the average efficiency of the HPWH on the market as of July 2011.

HPWH Performance Adjustment for Ambient Temperature

The efficiency of a HPWH decreases with the ambient temperature. Accordingly, energy factors for HPWHs are adjusted for inlet air temperature, which varies by weather zone, time of year, and HPWH location (conditioned vs. unconditioned space). The values and equations presented in Table 6 are used to characterize the conditions surrounding the HPWH (inlet air temperature).

Table 6. Ambient Air Temperature (T_{amb}) within selected Climate Zone

Water Heater Location	Ambient Air Temperature (T_{amb})
Conditioned Space	68°F (Heating Season)[b] 78°F (Cooling Season)[c]
Unconditioned Space (Garage)[d]	Average Seasonal Temperature[a] + 11°F (Heating Season) Average Seasonal Temperature[a] + 7°F (Cooling Season)

a. Average Seasonal Temperature is the average monthly dry bulb temperature for the selected climate zone.

b. Heating Season is defined as the months where the average monthly temperature is less than 65°F.

c. Cooling Season is defined as the months where the average monthly temperature is greater than or equal to 65°F.

d. Seasonal temperature adjustments for HPWHs installed in unconditioned space are made using the garage temperature adjustments recommended in ASHRAE 152-2004 (Tables 6.1b and 6.2b) on the assumption that the garage is the likely place for Texas HPWH installations outside of conditioned space.

The following performance adjustment (PA) equations adjust the average HPWH EF of 2.2 based on the ambient temperatures (T_{amb}). PAs were estimated for each month by weather zone.

Equations for Performance Adjustment Based on Ambient Temperature:[12]

$$PA[\%] = 0.00008 \times T_{amb}^3 + 0.0011 \times T_{amb}^2 - 0.4833 \times T_{amb} + 0.0057, \text{ when } T_{amb} > 32°F$$

$$PA[\%] = \frac{1}{EF} - 1, \text{ when } T_{amb} \leq 32°F$$

$$EF_{adj} = EF \times (1 + PA[\%])$$

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temperature level for the purpose of heating water. Unit must have "integrated" or "drop-in" configuration. EF>= 2.0, first-hour rating (FHR) >= 50 gal/hr, Warranty >= 6 yrs on sealed systems, Safety UL 174 & UL 1995.

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

The energy factors for HPWHs that result from the performance of these adjustments (EF_{adj}) are presented in Table 7 for Climate Zone 5 – El Paso, TX.

Table 7. Adjusted HPWH Energy Factors (EF) for Zone 5, El Paso, TX

Month	Conditioned Space	Unconditioned Space
January	2.14	2.01
February	2.14	2.05
March	2.14	2.11
April	2.35	2.25
May	2.35	2.46
June	2.35	2.69
July	2.35	2.67
August	2.35	2.6
September	2.35	2.44
October	2.14	2.3
November	2.14	2.07
December	2.14	1.98

Deemed Savings Fundamentals

A few important decisions and assumptions underlie this deemed savings analysis.

Weather Zones

This deemed savings analysis of HPWHs has been performed for 5 different areas of the state (weather zones) using weather data from specific cities to characterize those 5 zones. In the past, deemed savings in Texas have generally been presented for four weather zones: Amarillo (Zone 1), Dallas (Zone 2), Houston (Zone 3) and Corpus Christi (Zone 4). This formulation has required extending the Dallas results to El Paso, despite significant climatic differences between Dallas and El Paso. For these deemed savings, a fifth weather zone – El Paso (Zone 5) – has been included in the analysis.

Market Availability

Review of currently available heat pump water heaters that have been certified by ENERGY STAR®[13] reveals that HPWHs for the residential market come in four basic tank sizes: 40 gal, 50 gal, 60-65 gal, and 80 gal. For the tanks in the 60-65 gallon range, a 65-gallon tank was assumed in this analysis.

[13] Water Heater, Heat Pump for Consumers. DOE ENERGY STAR® Program. Online. Available: http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=WHH. Accessed July 2011. See link, Qualified Heat Pump Water Heaters.

Impact Estimates

Impacts are estimated by comparing the energy usage of HPWHs with that of electric storage water heaters in meeting the same levels of demand for hot water under the same conditions. However, for a HPWH installed inside conditioned space, estimating the total impact on household energy usage requires not only estimating the energy that a HPWH uses to heat water, but also estimating the heating penalty and cooling benefits from the extraction of heat from the conditioned air. Additionally, a number of factors affect the overall energy impacts of heating water with these two technologies, which must be taken into account.

Factors Affecting Water Heater Energy Usage

The key variables that affect the energy savings presented in this document are as follows:

- Hot water consumption (gallons per day)
- Climate city (e.g., average ambient temperature, ground water temperature)
- Water heater performance (i.e., Energy Factor)
- Hot water set point
- Inlet water temperature
- Space temperature

Additional Factors Affecting Home Energy Usage when Using an HPWH

The key factors that additionally affect the performance of a HPWH are as follows:

- Water heater location (in conditioned or unconditioned space);
    - Space heating/cooling demand (for units installed in conditioned space); and,
- Incidence of backup (resistance) heating element usage, a function of large draws of hot water during a single event, or closely spaced draws of hot water

A detailed description of the calculations performed to estimate total energy use in the baseline and efficient conditions, including how the above-listed factors affecting residential water heater energy use (electric storage and heat pump) are addressed, is provided in Appendix B.

Appendix B – Calculation Methodology

Deemed savings for this measure are taken by comparing the energy usage associated with the base technology – an electric storage water heater with resistance heating elements only – with that of a heat pump water heater (HPWH). Because HPWHs interact with their surroundings, the electric energy and peak demand savings opportunities they provide vary based on installation location and heating type. Deemed savings are therefore estimated by comparing the total energy use impacts of the two technologies.

The first section of this Appendix presents the general equations used to estimate energy usage in the base (electric resistance only) and change (HPWH) cases. Energy usage impacts of the HPWH are further modified by two factors discussed below:

- The extent to which backup resistance heat elements are employed, and
- Interactive heating and cooling effects (when the HPWH is installed in conditioned space).

Furthermore, the estimation of these deemed savings rely on a number of assumptions and the application of a number of calculations. These three key elements underlie the estimation of energy usage for heating water for domestic hot water use and are presented in the subsequent sections:

- Incoming Water Temperature (Mains temperature from piped water system)
- Household Demand for Hot Water (gallons per day)
- Hourly Profile of Hot Water Usage (for peak coincidence, demand impacts)
- Standby Heat Loss Coefficients

Energy Use Calculations - Baseline Technology

The basic equation used to estimate the energy usage of an electric storage water heater relates the volume of daily water use to a number of factors:

$$Q_{in}\left[\frac{Btu}{day}\right] = \frac{vol \times dens \times c_p \times (T_{tank} - T_{mains})}{EF}$$

Where,

Q_{in} = total water heater energy consumption [Btu/day],

vol = daily draw volume [gal/day],

dens = density of water [lb/gal]

c_p = specific heat of water [Btu/lb-°F],

T_{tank} = tank thermostat setpoint temperature [°F],

T_{mains} = inlet water temperature [°F], and

EF = energy factor.

The energy factor is a blended efficiency estimator: it is designed to account for losses in the conversion of input energy to heat (Recovery Efficiency, RE) as well as the energy required to make up for storage losses, which is a function of tank volume. Some of these inputs vary with time and are calculated; others are standard input values:

Input	Value	Source
vol	Varies by month	See Household Demand for Hot Water
den	8.294 lb/gal	Density of Water
c_p	1.0007 BTU/lb•°F	Specific Heat of Water
T_{tnk}	120 °F	Mfr-recommended (default) set point
T_{mains}	Varies by month	See Entering Water Temperature (T_{mains})
EF	Varies by tank size	Set by Federal Standard: see Definition of Baseline Condition

Efficient Technology – Heat Pump Water Heater

The total impact of an HPWH on residential energy consumption is calculated in two steps: first, the energy associated with heating and storing water is estimated, and second, the heating penalties and cooling benefits are estimated.

Energy Employed in Making and Storing Hot Water

The basic equation used to estimate the energy used by an HPWH is similar to that for baseline electric storage water heaters, with one modification:

$$Q_{in}\left[\frac{Btu}{day}\right] = \frac{vol \times dens \times c_p \times (T_{tank} - T_{mains})}{EF(1 + PA)}$$

Where,

Q_{in} = total water heater energy consumption [Btu/day],

vol = daily draw volume [gal/day],

den = density of water [lb/gal],

C_p = specific heat of water [Btu/lb-°F],

T_{tank} = tank thermostat set point temperature [°F],

T_{mains} = inlet water temperature [°F],

EF = energy factor, and

PA = performance adjustment.

The values and sources of information for all variables except the EF (set to 2.2 for HPWHs) and the performance adjustment factor (PA) are the same as described above for baseline electric storage water heaters. The PA is described in detail in deriving the Energy Factors for HPWHs in the main body of this document (see Definition of Efficient Condition). The values in Table 8 represent the different denominators in the equation for calculating the energy used by HPWHs in heating water.

Importantly, not all of the energy for making hot water in a HPWH comes from the heat pump. HPWHs have backup resistance elements, which are called upon in periods of high water draws. Analysis of field test data developed by TIAX, LLC in a 2004 study for the California Energy Commission[14] suggests that approximately 11 percent of the energy used to heat hot water in HPWHs is resistance heat. Accordingly, these deemed savings incorporate an assumption that 11 percent of input energy used to meet the demand for hot water in homes with HPWHs is from the backup resistance elements.

Cooling Benefits and Heating Penalties

Cooling benefits and heating penalties are estimated for HPWHs installed in conditioned space. Assuming that 11 percent of energy input into the HPWH goes to the backup resistance element, cooling benefits and heating penalties are estimated for the 89 percent of hot water that is made with the heat pump. These benefits and penalties are estimated by month, using average monthly ambient temperature by climate zone: in the heating season, a heating penalty is estimated, while in cooling season a cooling benefit is estimated.

In most months, HVAC systems are in either cooling mode or heating mode; however, in transition months there will be a mix of heating and cooling, or limited heating and cooling loads, such that the cooling benefits and/or heating penalties associated with the HPWH are likely offsetting, or negligible. 65 °F is generally considered the thermal balance point of residential buildings: the temperature above which homes are likely in cooling mode, and below which there will be a demand for heat. To control for these transitions and avoid over-application of either cooling benefits or heating penalties, a range was applied: for any month in which the average temperature was within 3 degrees of 65 °F, a home was considered to be in neither heating nor cooling mode. In these months, neither cooling benefits nor heating penalties were applied.

Heating penalties and cooling benefits are calculated by estimating the impact (in BTUs) of operating the heat pump inside the conditioned space and estimating (1) the amount of energy the air conditioner would have required to make that same amount of cool air when the home is in cooling mode, or (2) the amount of energy the electric heating system (electric resistance or heat pump) requires to make up for the heat extracted from the air when the home is in heating mode. Since duct systems are not perfect, a distribution system efficiency of 75% is applied.

[14] Design Refinement and Demonstration of a Market-Optimized Heat-Pump Water Heater. California Energy Commission, April 2004. Prepared by TIAX, LLC. Attachment 2, California Field Test Data and Analysis.

The effect of the HPWH on the ambient space load (cooling or heating) is estimated using the following series of equations from WAPTAC:

$$Q_{spaceload}[Btu] = Q_{reject/in} \times hour_{comp-on}$$

$$Q_{hwload}\left[\frac{10^6\,Btu}{yr}\right] = \frac{vol \times den \times c_p \times \left(T_{tnk} - T_{in}\right) \times 365}{10^6}$$

$$hour_{comp-on}[h] = Q_{hwload} \times 0.4623 + 2.2865$$

The first equation multiplies the rated capacity of the typical HPWH (3,500 Btu/h is used in this analysis) to the compressor runtime to develop the spaceload in Btu/day ($Q_{spaceload}$). The second equation estimates the hot water load in mmbtu/yr. The third equation is the result of a regression analysis relating the daily HPWH compressor runtime (in hrs) to the hot water load; it estimates the number of hours per day that the HPWH must operate to meet its load.

Entering Water Temperature (T_{mains})

The entering water temperature (T_{mains}) is adjusted for each climate zone. The following equation, developed by the National Renewable Energy Laboratory (NREL), is used to calculate the entering water temperature.

$$T_{mains}(°F) = \frac{\left(Avg\left(T_{air,month}\right) + offset\right) + ratio \times \left(\max\left(T_{air,month}\right) - \min\left(T_{air,month}\right)\right)}{2 \times \sin\left(0.986 \times \left((30 \times Month\,\#) - 15 - lag\right) - 90°\right)}$$

Where:

Avg ($T_{air,month}$)	= Annual average air temperature (°F), assumed to be ambient outdoor dry bulb temperature,
Max ($T_{air,month}$)	= Max of monthly mean air temperature (°F),
Min ($T_{air,month}$)	= Minimum monthly mean air temperature (°F),
offset (district water)	= 6°F,
ratio	= 0.4 + 0.01 x ($T_{amb,ave}$ – 44),
lag	= 35 – 1.0 x ($T_{amb,ave}$ – 44), and
$T_{amb,ave}$	= Average annual ambient temperature, by location.

Typical Meteorological Year (TMY) data are used to estimate monthly and annual average ambient temperatures for each of the five cities selected to represent five weather zones in Texas. Application of the NREL equation for T_{mains} to the TMY conditions for the five Texas weather cities provides the monthly estimates of inlet water temperature depicted in Figure 1.

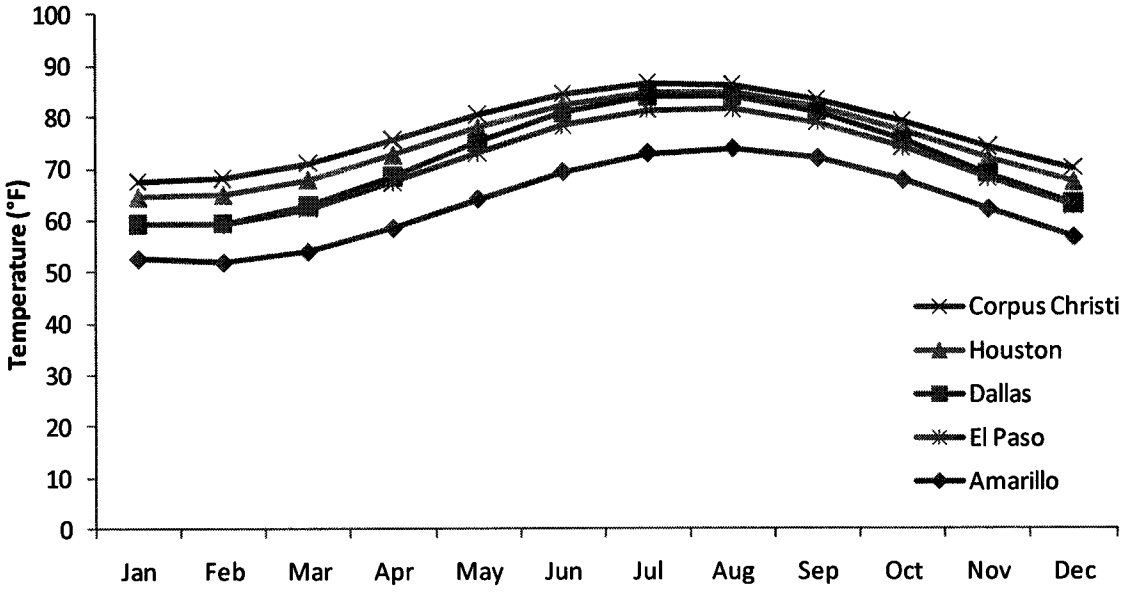

Figure 1. Monthly Mains Water Temperatures (T_{mains}), Representative Cities

The NREL equation provides mains water temperatures that fluctuate as a lagged function of ambient air temperature. Figure 2 illustrates the relationship between T_{mains} and T_{air} for climate zone 1 – Amarillo, TX.

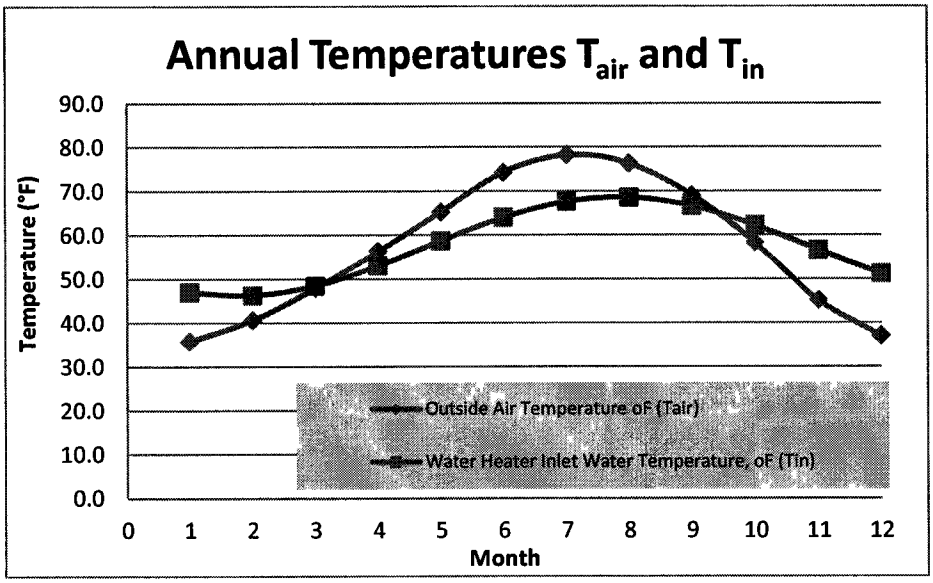

Figure 2. Annual Temperatures T_{air} and T_{in} for Climate Zone 1: Amarillo, TX

Household Demand for Hot Water

The number of people per household is a major driver of hot water consumption. In addition to showers and baths, clothes washers and dishwashers are large users of hot water. The remaining household hot water use is primarily attributed to kitchen and bathroom sinks. As part of the Building America Research Benchmark project, NREL produced the following table in 2004 summarizing residential hot water usage:

Table 9. Water Usage by Hot Water End-Use Point

End-Use	End-Use Water Temperature	Water Usage
Clothes Washer	N/A	$7.5 + 2.5 \times N_{br}$ gal/day (Hot Only)
Dishwasher	N/A	$2.5 + 0.833 \times N_{br}$ gal/day (Hot Only)
Showers and Baths	105 °F	$14 + 4.67 \times N_{br}$ gal/day (Hot + Cold)
Sinks	105 °F	$10 + 3.33 \times N_{br}$ gal/day (Hot + Cold)

Source: *Development of an Energy Savings Benchmark for All Residential End-Uses*. R. Hendron et al. Conference Paper, SIMBUILD 2004 Conference August 4-6, 2004. Online. Available: http://www.nrel.gov/docs/fy04osti/35917.pdf.

For showers and baths, as well as sinks, demand for hot water is determined through the additional step of estimating how much cold water must be mixed with hot water to achieve the desired usage temperature, which varies with T_{mains}.

Because the 2004 work underlying the Building America Benchmark predates changes to water use standards for both clothes washers and dishwashers, and assumes relatively inefficient appliances, the equations for clothes washers and dishwashers were multiplied by adjustment factors to reflect updates in water usage standards promulgated in 2009 (clothes washers) and 2010 (dishwashers). These adjustment factors are provided in Table 10.

Table 10. Water Usage Adjustment Factors, Clothes Washers, and Dishwashers

End-Use	Previous Baseline	Updated Standard	Adjustment Factor
Clothes Washer	39.2 gal/cycle	21.0 gal/cycle	0.54
Dishwasher	8.2 gal/cycle	6.5 gal/cycle	0.79

For the purposes of establishing deemed savings for heat pump water heaters with tanks of different sizes, use of the equations in Table 9 also requires developing a relationship between

tank size and the number of bedrooms in a given home. An underlying assumption of these deemed savings is that heat pump water heaters are sized appropriately for their loads. Standard practice is that water heaters be sized according to their first hour rating (FHR) – the amount of hot water the unit can supply in an hour of operation, starting with a full tank.[15] Review of the first hour rating of available, ENERGY STAR®-listed HPWHs shows that FHR, as expected, increases with tank size:

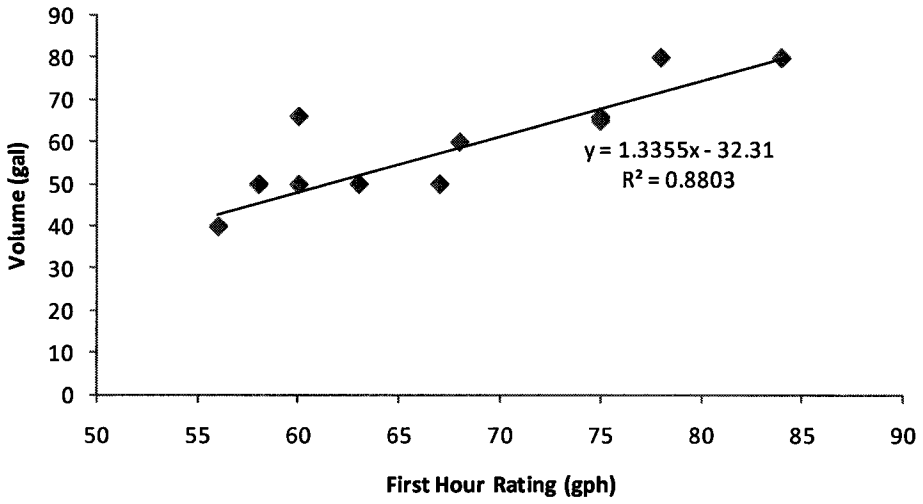

Figure 3. Tank Volume and First Hour Rating

Frontier ran permutations on the FHR tank sizing worksheet provided by DOE[16] to estimate the maximum amount of hot water needed in a given hour in homes with different numbers of bedrooms (based on occupancy assumptions tied to the number of bedrooms). Typical results of those permutations are presented in Figure 4.

[15] Sizing Storage and Heat Pump (with Tank) Water Heaters. USDOE, EERE. Online. Available: http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12990.

[16] Ibid.

2 Bedroom = 3 people			
Use	Average gallons of HW per usage	Times used per 1 hr	Gallons used per 1 hr
Shower	12	2	24
Bath	9	0	0
Shaving	2	0	0
Hands & face washing	4	1	4
Hair shampoo	4	0	0
Hand dishwashing	4	1	4
Automatic dishwasher	14	1	14
Food preparation	5	0	0
Wringer clothes washer	26		
Automatic clothes washer	32	0	0
	Total Peak Hour Demand:		46

3 Bedroom = 4 people			
Use	Average gallons of HW per usage	Times used per 1 hr	Gallons used per 1 hr
Shower	12	2	24
Bath	9	0	0
Shaving	2	1	2
Hands & face washing	4	2	8
Hair shampoo	4	0	0
Hand dishwashing	4	1	4
Automatic dishwasher	14	1	14
Food preparation	5	1	5
Wringer clothes washer	26		
Automatic clothes washer	32	0	0
	Total Peak Hour Demand:		57

4 Bedroom = 5 people			
Use	Average gallons of HW per usage	Times used per 1 hr	Gallons used per 1 hr
Shower	12	2	24
Bath	9	1	9
Shaving	2	1	2
Hands & face washing	4	3	12
Hair shampoo	4	0	0
Hand dishwashing	4	1	4
Automatic dishwasher	14	1	14
Food preparation	5	0	0
Wringer clothes washer	26		
Automatic clothes washer	32	0	0
	Total Peak Hour Demand:		65

5 Bedroom = 6 people			
Use	Average gallons of HW per usage	Times used per 1 hr	Gallons used per 1 hr
Shower	12	3	36
Bath	9	1	9
Shaving	2	1	2
Hands & face washing	4	3	12
Hair shampoo	4	0	0
Hand dishwashing	4	1	4
Automatic dishwasher	14	1	14
Food preparation	5	0	0
Wringer clothes washer	26		
Automatic clothes washer	32	0	0
	Total Peak Hour Demand:		77

Figure 4. Hot Water Tank Sizing Worksheets

Using the regression relationship derived in Figure 3 to estimate the required storage volume to meet the first hour demand for hot water and rounding up to the HPWH with the next highest storage tank size available in the market, a relationship between number of bedrooms and tank size was estimated.

Table 11. Number of Bedrooms, First Hour Demand, and Water Heater Storage Tank Size

Number of Bedrooms (N_{br})	First Hour Demand (gal/hr)	Req'd Storage Volume (gal)	Tank Size (gal)
2	42-46	29	40
3	51-57	44	50
4	59-65	55	65
5	69-77	71	80

Assembling the relationships between water heater tank size, the number of bedrooms in a home, end-point water usage, T_{mains}, and the temperature at which water is used at given endpoints, profiles of daily hot water usage by tank size were developed. Figure 5 shows the monthly usage profiles derived through this approach.

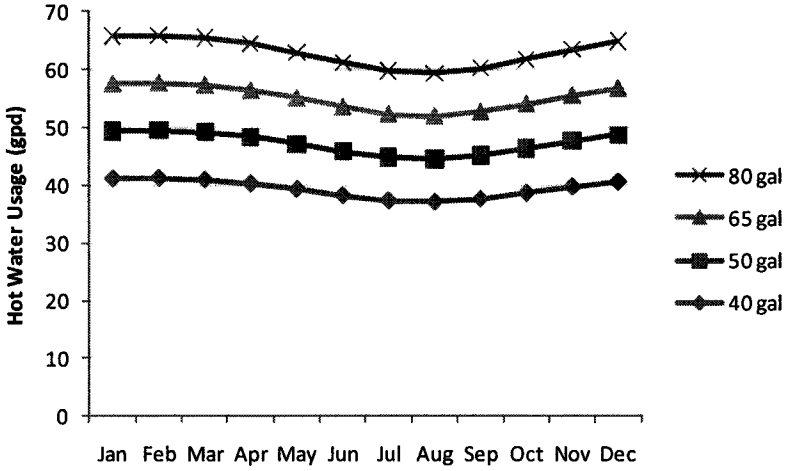

Figure 5. Hot Water Usage by Tank Size, Amarillo TX

Hourly Demand Profile

Figure 6 is the hourly hot water usage profile (gal/hr) for a residential home. This profile was used to develop the resultant peak kW and coincidence factor (CF) for this measure.

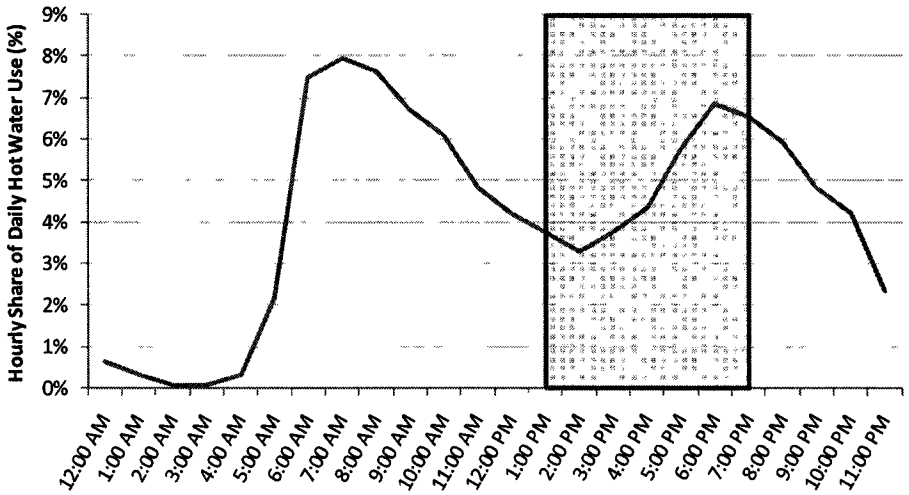

Figure 6. Daily Hot Water Use Profile[17]

Current PUC rules define the summer peak demand period as the hours between 1 PM and 7 PM from June through September. Based on this definition, the peak demand impacts of this measure are associated with the average demand during this window, which is approximately 4.6 percent of daily domestic hot water energy usage.

[17]Source: Building America Appliance and Plug Loads Calculation Tool. Underlying source is DOE 2.2.

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