DEER2015 Service and Domestic Water Heater Measures Update

Contents

October 1, 2014

Increase in Minimum Code Efficiency

The Code/Standard technology for most service and domestic water heater measures in DEER2014 are updated based on the "Code of Federal Regulations", part 430.32, section (d): "*Water heaters. The energy factor of water heaters shall not be less than the following for products manufactured on or after the indicated dates*." The table below summarizes the change in minimum energy factor (EF) associated with the federal regulations.

	Energy Factor	
Product class	As of Jan 20, 2004	As of April 16, 2015
Gas-fired Water Heater	0.67−(0.0019 × Rated Storage Volume in gallons)	For tanks with a Rated Storage Volume at or below 55 gallons: EF = 0.675 − (0.0015 × Rated Storage Volume in gallons).
		For tanks with a Rated Storage Volume above 55 gallons: EF = 0.8012 − (0.00078 × Rated Storage Volume in gallons).
Electric Water Heater	0.97−(0.00132 × Rated Storage Volume in gallons)	For tanks with a Rated Storage Volume at or below 55 gallons: EF = 0.960 − (0.0003 × Rated Storage Volume in gallons).
		For tanks with a Rated Storage Volume above 55 gallons: EF = 2.057 − (0.00113 × Rated Storage Volume in gallons).
Instantaneous Gas-fired Water Heater	0.62−(0.0019 × Rated Storage Volume in gallons)	EF = 0.82 − (0.0019 × Rated Storage Volume in gallons).

Table 1. New EF requirements for water heaters

For storage gas and electric water heaters less than 55 gallons the energy factor (EF) increases slightly while for larger water heaters the increase in EF is substantial. Note that the new minimum EF for electric water heaters over 55 gallons requires the use of a heat pump water heater.

Service and Domestic Water Heater Product class	Example EF values		
	Gallons	prior EF	new EF
Gas-fired Water Heater	30	0.61	0.63
	60	0.56	**0.75**
Electric Water Heater	30	0.93	0.95
	60	0.89	**1.98**
Instantaneous Gas-fired Water Heater	2	0.62	**0.82**

Table 2. Example of EF increase by water heater product class and size (gallons)

Updated DEER Measures

The worksheet "Measure Summary" of the attached workbook[1] lists all of the DEER2014 water heater measures that are updated for DEER2015. In many cases, additional measures are needed to capture increased efficiency tier levels. Overall, 42 DEER2014 measures are updated by 60 new DEER2015 water heater measures.

The efficiency levels included in the updated measures are based on the new minimum code levels and currently available high-efficiency technologies. The following table summarizes the efficiency levels for the various categories of water heater measures.

Water Heater Type		**Efficiency Tiers**			
Fuel	Size (gallons)	Min. Code	Tier 1	Tier 2	Tier 3
Electric	30	0.951 EF	2.00 EF	2.20 EF	2.40 EF
Electric	40	0.948 EF	2.00 EF	2.20 EF	2.40 EF
Electric	50	0.945 EF	2.00 EF	2.20 EF	2.40 EF
Electric	60	1.98 EF	2.20 EF	2.40 EF	
Electric	75	1.96 EF	2.20 EF	2.40 EF	
Gas	Instantaneous		0.82 EF	0.92 EF	
Gas	30	0.630 EF	0.65 EF	0.70 EF	0.72 EF
Gas	40	0.615 EF	0.65 EF	0.70 EF	0.82 EF
Gas	50	0.600 EF	0.67 EF	0.70 EF	0.82 EF
Gas	60	0.754 EF	0.78 EF	0.80 EF	0.82 EF
Gas	75	0.743 EF	0.78 EF	0.80 EF	0.82 EF

Table 3. DEER2015 Water Heater efficiency levels

Energy savings for alternative measure efficiency levels can be determined using the methodologies described for this update. Program administrators (PAs) are encouraged to provide program-specific measure technology data (i.e. incented efficiency levels) for evaluation and potential inclusion in the DEER2015 update.

Simulation Methodology

A calculation tool was developed for the DEER2015 water heater measures. The tool utilizes hourly output from the DEER2014 DOE2 building prototypes for hot water loads and ambient conditions along with new technology definitions to estimate the hourly energy use of gas, electric and heat pump water heaters. This new tool was developed to accommodate the modeling requirements of heat pump water heaters and to provide a relatively easy method to add new measures and technologies based on PA program requirements.

Assumptions for hot water usage for each building type are not changed for this update. The hot water schedule by building type are the same as was used for DEER2011 and DEER2014. The mains water temperatures are based on the 2013 Title-24 weather files and are the same as DEER2014.

The addition or heat-pump water heaters to all of the updated electric water heater measures, either as the code level or measure level technology, requires new simulation methods as previous DEER versions did not include this technology type. For consistency, all small storage and small intanteneous water

[1] 2015DEER-SmallStorageWaterHeaterUpdate-1Oct2014.xlsx

heater measures impacted by the code update utilize the water heater calculation tool developed for this update.

Standard Gas and Electric Water Heater Technologies

The small storage gas and electrc resistance water heaters are modeled consistent with the DEER2014 methodology. The water heater technologies are described with a rated energy factor (EF), rated volume in gallons, heating capacity, recovery efficiency (RE), and tank loss (UA_{tank}). The tank loss for a given water heater is determined based on the unit's Energy Factor, recovery efficiency and heating capacity using the following equation:

$$UA_{tank} = (RE/EF - 1) / (24/41092 - 1/(EF * RE * 1000)) / 67.5$$

Auxiliary electric energy use, ventilation energy use and pilot light gas consumption can also be specified for the DEER2015 water heater technologies. Technology definitions for all of the small storage water heaters are listed on the Technologies tab of the accompanying workbook.

Hourly ambient temperature

The ambient temperature (T_{amb}) of the water heater tank and heat pump evaporator is used to determine the heat loss from the tank as well as the hourly COP of a HP water heater. Hourly temperatures were extracted from the DEER prototypes for seven spaces types and for each climate zone. The water heater ambient space type assigned to each of the 28 prototypes is listed in the table below. For single-family homes, T_{amb} is assumed to be the hourly garage temperature, for mobile homes, T_{amb} is assumed to be the hourly outdoor temperature and multi-family homes use an interior hallway temperature for T_{amb}. Commercial building utilize a conditioned interior space, a conditioned storage space or an unconditioned storage space for T_{amb}.

Building Type	Water Heater Ambient Space Type
Assembly	Conditioned Interior space
Primary School	Conditioned Storage space
Secondary School	Conditioned Storage space
Community College	Conditioned Storage space
University	Conditioned Storage space
University Dormitory	Conditioned Storage space
Relocatable Classroom	Interior Hallway
Grocery	Conditioned Storage space
Hospital	Conditioned Interior space
Nursing Home	Conditioned Interior space
Hotel	Conditioned Interior space
Hotel Guest Room	Interior Hallway
Motel	Interior Hallway
Bio/Tech Manufacturing	Conditioned Interior space
Light Industrial Manuf.	Conditioned Storage space
Large Office	Conditioned Interior space
Small Office	Conditioned Interior space
Sit-Down Restaurant	Conditioned Storage space

Building Type	Water Heater Ambient Space Type
Fast-Food Restaurant	Conditioned Storage space
Department Store	Conditioned Storage space
Big Box Retail	Conditioned Storage space
Small Retail	Conditioned Storage space
Conditioned Storage	Conditioned Storage space
Unconditioned Storage	Unconditioned Storage space
Refrigerated Warehouse	Conditioned Interior space
Single Family Home	Attached Garage
Multifamily Home	Interior Hallway
Mobile Home	Outdoor Cabinet

Hourly hot water load

The DOE2 prototypes used for the development of DEER2014 were utilized to create hourly profiles of hot water load in gallons of water. These 8760 hourly profiles vary by building type (23 commercial buildings and 3 residential buildings). For the Univerity and Hotel prototypes, the residential type spaces (dorm room and guest room spaces, respectively) were separated from the other building spaces and analyzed separately.

Heat Pump Water Heaters

The minimum code-level efficiency for electric water heaters over 55 gallons in size requires a heat pump water heater with an EF of approximately 2.0. There are a number of issues involved with estimating energy use of heat pump water heaters that do not exist for the simpler electric resistance water heaters.

One issue with simulating heat pump water heaters is that manufacturers do not consistently publish data that can be used to accurately determine the energy performance of the water heaters. These data include:

- COP at standard operating conditions,
- COP at off-standard operating conditions ,
- heating capacity of heat pump under standard conditions,
- heating capacity of heat pump at off-standard operating conditions ,
- heating capacity of electric resistance elements,
- control strategy of electric resistance heating, and
- tank heat loss rate.

Another issue with simulating heat pump water heaters is that the introduction of relatively inexpensive heat pump water heaters in residential and commercial applications is relatively new, and there are only sparse data indicating how the units are used and perform in actual operation.

There are a number of studies that published rated and measured data for specific heat pump water heaters. These studies are summarized in the attached workbook and are used to derive the required heat pump performance characteristics.

The lack of reliable and accurate data describing heat pump water heater performance limits the accuracy of any simulation approach that attempts to capture typical energy savings of representative heat pump water heater efficiency measures. For this update, simulation input values for hot water load and environmental conditions consistent with the values used for DEER2014 are used in a custom tool to estimate annual energy and peak demand savings. Performance characteristics of the heat pump water heaters are derived from available research and published data, as described in the following section.

HP Water Heater Unit specification

Heat pump water heater COP

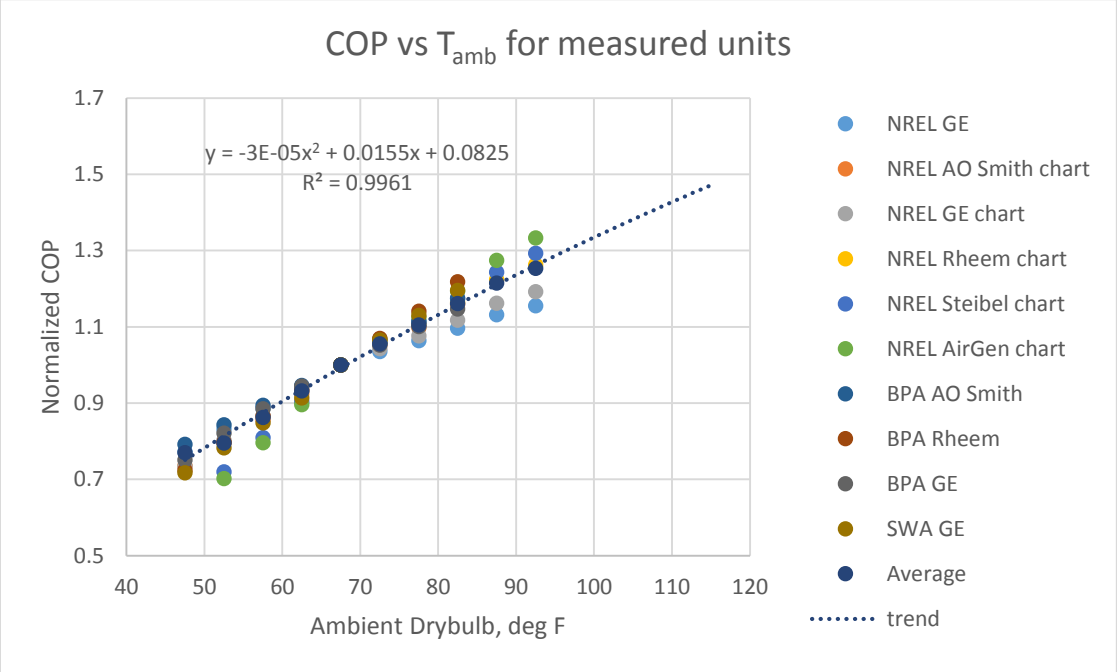
The COP of the unit has to be estimated based on the available published data from other studies. Based on the NREL data[2], the COP can be estimated for a tank temperature of 120 and 135 as 1.0 * EF and 0.8 * EF, respectively. Based on these two points, the equation for COP, within the limits of a tank temperature between 120 and 135 F can be written as:

$$COP = EF * (2.6 - 0.0133 * T_{tank})$$

Heat pump water heater COP as a function of ambient temperature

[2] NREL reference here

The performance of the heat pump water heater as a function of the ambient temperature relies upon measured data from the available studies. The following graphic shows the data points used to derive the equation for the COP adjustment factor.



$$COP_{adj} = 0.0825 + 0.0155 * T_{amb} - 0.00003 * T_{amb}^2$$

Tank loss rate (BTU/hr-°F)

The heat loss rate from the HP water heater is expected to be somewhat higher than the heat loss rate from a comparable electric resistance water heater due to the added piping and potential circulation of the heat pump plumbing. Unfortunately, the heat loss rate is typically not published for heat pump water heaters available on the market and the value cannot be "back calculated" based on the rated EF as it is for standard electric water heaters.

The few data points of tank loss rate available from the NREL data shows no trend with regard to tank size or rated EF. The average value of 4.2 BTU/hr-°F is used for all HP water heaters for this analysis.

Control Sequence for Electric Resistance "backup"

All heat pump water heaters have electric resistance heaters as well as the DX heating coils. These electric resistance elements are typically used under a number of situations:

- at start-up, when the tank is first filled,
- when the ambient temperature is low enough to degrade the DX performance and potentially cause ice buildup on the evaporator coils (typically < 45°F),
- when the ambient temperature exceeds a high temperature limit (typically > 115 °F), and
- when the tank temperature is below a setpoint temperature caused by a high-load situation.

The available research[3] indicates that the amount of electric resistance heating used due to high-load situations can vary from essentially zero to as much as 80% of the annual energy use. Larger volume water heaters tend to use less electric resistance heating than smaller tanks. Overall, the average measured electric resistance heating as a percentage of annual heating is 12%, though this value is highly influenced by one brand that often operates in electric resistance mode. Both the median and the mode for the fraction of annual energy that is from electric resistance mode are 6%.

Hourly data from the XXX study shows that electric resistance heating was used when the hourly hot water load in gallons exceeded 1/3 of the tank volume. This functional relationship along with target values of 6% of annual energy are used to simulate the number of hours that the heat pump water heater operates in electric resistance mode.

Number of water heaters required for building hot water load

The energy savings of both residential and commercial water heaters are reported on a "per hot water heater" basis. The number of water heaters needed to meet the building hot water load is determined based on the peak hot-water load of the building and capacity of the water heater technology to deliver hot water. The following equation is used to deteremine the number of units required:

NumHeaters = PeakGallons * dT * Gal2BTUF * SF / (CapBTUh * RE + Volgal * 0.5 * dT * Gal2BTUF)

Where:

PeakGallons	= the building peak gallons of hot water required per hour at the tank setpoiont temperature.\
dT	= the design heat rise of the make up water, 100 F
Gal2BTUF	= conversion of gallons of water to BTU/F at tank temperature
SF	= Sizing factor, varies based on water heater fuel and building type based on the diversity of the hot water load profile
CapBTUh	= heating capacity of the water heater in BTU/hr
RE	= Recovery efficiency of the water heater
Volgal	= volume of the water heater tank in gallons
0.5	= the fraction of the tank volume that can be depleted in one hour to meet the load

Simulation hourly calculations

The simulation tool developed for this update uses the water heater technology specifications, as described above, and hourly inputs for ambient temperature and hot water load to calculate the annual energy use and demand of a specific water heater technology. The hourly inputs and basic calculation method are described below.

Hourly calculation

[3] Reference here

For each hour:

1. $Load_{HW} = HrVol_{gal} * (T_{tank} – T_{mains}) * Gal2BTUF$
2. $Load_{UA} = TankUA * (T_{tank} – T_{amb})$
3. $Load_{tot} = Load_{HW} + Load_{UA} - AuxBTU * AuxEff$
4. $Load_{del} = Min(Load_{tot}, Capacity)$
5. If $(HrVol_{gal} > HrVol_{max})$ *or* $(T_{amb} < T_{amb,min})$ *or* $(T_{amb} > T_{amb,max})$
   then
   $kWh_{hr} = Load_{Tot} / 3412\ BTU/kWh$
   else
   $kWh_{hr} = Load_{Tot} / 3412\ BTU/kWh / (COP_{hr} * COP_{adj})$

Where:

kWh_{hr}	= the hourly kWh electric use of the HP water heater
$HrVol_{gal}$	= the hourly hot water load in gallons at the tank setpoint temperature
$HrVol_{max}$	= the hourly hot water load in gallons above which electric resistance heating is used
$Load_{HW}$	= the hourly load in BTUs due to water use
$Load_{UA}$	= the hourly load in BTUs due to loss from the hot water tank
$Load_{Tot}$	= the total hourly load in BTUs to maintain tank temperature
AuxBTU	= Auxiliary (pilot light) BTU/hr rate
AuxEff	= fraction of Auxiliary BTU energy that is transferred to the water storage
COP	= rated COP of HP at standard conditions, or the recovery efficiency for non-HP water heaters
COP_{adj}	= COP adjustment factor based on current hourly ambient temperature for heat pumps, 1.0 for non-HP water heaters.
T_{tank}	= setpoint temperature of water heater (°F)
T_{mains}	= current hour mains water (cold water inlet) temperature (°F)
T_{amb}	= hourly ambient temperature of the HP water heater (°F)
$T_{amb.min}$	= ambient temperature below which the HP operates in electric resistance mode (°F)
$T_{amb.max}$	= ambient temperature above which the HP operates in electric resistance mode (°F)
Gal2BTUF	= conversion of gallons of water to BTU/F at tank temperature = 61.73 lb/ft^3 / 7.48 gal/ft^3 * 0.997 BTU/lb-F = 8.23 BTU/F @ 120°F = 61.46 lb/ft^3 / 7.48 gal/ft^3 * 0.998 BTU/lb-F = 8.20 BTU/F @ 135°F

The annual energy use is the sum of all kWh_{hr} values for the year and the peak demand value is the average hourly savings during the standard 9-hour peak demand window for the climate zone. Energy savings for a measure is determined by comparing annual values for the various technologies included in

a measure definition. For a more detailed description of the water heater calculations, see the "Calculation" tab of the water heater calculator workbook.

Simulation Results

The simulation tool developed for this update uses the technology definitions to determine the hot water energy use for each climate zone, building type and building vintage that are part of the standard DEER applicability parameters. Measure savings are determined by comparing the energy use associated with the technologies defined in the measure definition. The water heater tool formats the energy impacts for each defined measure in the ex ante format such that the data can be directly uploaded to the ex ante database.

Limitations of the HP water heater simulation

The simulation results are limited by the accuracy of the input values describing the performance of the heat pump water heaters. As more reliable data are published these simulations can be updated to reflect the best-available information.

The limited measured data available at this time indicate that the energy use of individual heat pump water heaters varies significantly from brand-to-brand and from model-to-model. A brief survey of units available on the market indicates that some of the worst-performing heat pump models receive popular reviews because they reliably heat water, albeit primarily in electric resistance mode. The energy savings based on these simulation results are designed to be typical for the measures and applications described, but users of the data should be aware of the large potential variation of actual installation savings.

The cooling impacts of the heat pump water heaters on their immediate environment are not accounted for in these simulations. Some decrease in cooling energy along with increased heating energy requirements can be expected in some situations. In commercial situations, the HVAC interaction can be expected to be relatively small, as the hot water heaters are likely location in maintenance rooms or closets that not directly connected to the HVAC contol zone. In residential situations, there is potential for HVAC interaction if the water heater is located in a conditioned space, as opposed to a garage or outdoor closet (as with mobile homes). Further research will be needed to quantifiy the typical HVAC interactive effects of heat pump water heaters.