SAFER, SMARTER, GREENER

DEER Water Heater Calculator Documentation

v4.2 for DEER2021

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1 Water Heater Calculator

1.1 General background

The calculation tool was initially developed for DEER2015 water heater measures. The tool utilizes hourly output from the DEER2014 DOE2 building prototypes for hot water loads (in gallons per minute, by building type) and ambient conditions (incoming "mains" water temperature, ambient indoor space temperature) to estimate hourly energy use for a variety of water heaters. It was originally developed to accommodate the modeling requirements of heat pump water heaters (HPWHs) and to provide a relatively easy method to add new measures and technologies based on program administrator (PA) requirements.

The tool utilizes a calculation methodology that accounts for the water heater's recovery or thermal efficiency (i.e., effectiveness of converting fuel energy into hot water) and other supplemental energy uses (tank loss, auxiliary ventilation, pilot-light gas, supplemental/backup electric resistance heat) to estimate the water heater's total energy use. The ambient indoor-air temperature of the water heater tank and/or heat pump (HP) evaporator is used to determine the heat loss from the tank as well as the hourly coefficient of performance (COP) of a HPWH.

The calculator currently accounts for the following:

- Incoming cold-water temperature ("mains" temperature), by climate zone and month[1]
- Hourly hot water load: energy needed to deliver the hot-water load (gallons of water between 110 °F and 135 °F) for a given hour[2]
- Quantity of hot water heaters necessary to satisfy the peak hot-water volume of the building type's hourly hot water load profile. The calculator multiplies the required heating capacity for the peak hot water load (in Btu/h) by a sizing factor (similar to DEER building prototype equipment sizing, with values between 1.2 and 2.0) to determine the quantity of water heaters (rounded to a whole integer) necessary to satisfy a given building type's hot-water load profile.
- Tank loss (if applicable): stored hot water energy lost to the ambient air
- Location of the water heater depends on the building type. Single family homes assume garage (unconditioned) space, multi-family buildings assume an interior hallways temperature, and mobile homes assume an outdoor (e.g., outdoor cabinet) temperature. Commercial buildings mostly utilize conditioned interior space.
- Auxiliary load: energy consumed by pilot lights, condensing ventilation fan, etc.
- HPWH COP adjustments due to ambient air temperature.
- Heat pump supplemental (i.e., backup) electric resistance heating element
- Heat pump compressor cut-off temperatures i.e., minimum and maximum ambient temperatures[3] at which the heat pump will disable the compressor and only use electric resistance to heat water

[1] CZ2010 weather files for 2013 Title 24

[2] Water temperature is assumed to be 110 °F for hotel guest room, and university dorm room building types. It is 135 °F for all other building types.

- Heat pump supplemental electric resistance load when hot water load exceeds water heater's maximum hourly heating flowrate, in gallons/hour (gph)[4]

There are notable limitations to the calculator. It *does not* currently account for:

- Interactive effects between the water heater and the HVAC system serving the corresponding conditioned space
- Split-system heat pump water heaters
- Variable hot-water temperature set points[5] (i.e., to simulate effects of load shifting)
  - Interactive effects of standby (i.e., tank) losses and changes in tank temperature
- Hourly changes in fractional, supplemental electric-resistance heating supplied by HP water heaters: if the hourly hot-water load (in gallons) exceeds what can be supplied by the HP compressor alone, a fraction (assumed to be 10%) of heating for that hourly load is provided by the backup electric resistance heater. This assumed fraction does not change regardless of the estimated excess hourly hot-water load.
- Heat pump defrost-cycle energy (e.g., heat pump evaporator is in a cold ambient environment) and allowed to operate at ambient temperatures that might cause frosting
- While the calculator uses 8,760 hot-water load profiles and estimates hourly water heater energy use, it sums hourly energy use into an annual usage estimate and does not retain hourly impacts.

The calculator determines how much energy is required to meet hot-water loads using water heater performance characteristics derived from Air Conditioning, Heating, & Refrigeration Institute (AHRI), U.S. Department of Energy (DOE), and/or the California Energy Commission (CEC) databases. These characteristics that are commonly found in the databases are listed as follows:

- Water heater type
- Recovery efficiency (%), for residential water heaters
- Thermal efficiency (%), for commercial water heaters
- Standby loss (Btu/h or %/hour), for commercial water heaters
- Rated input capacity (kBtu/h or kW)
- Rated storage volume (gallons)
- Uniform Energy Factor (UEF), for residential water heaters (used to determine COP for HP water heaters)
- Usage or draw pattern bin, for residential water heaters
- First-hour rating (FHR), for residential water heaters

[3] Assumed for all HPWHs to be 37 °F minimum and 145 °F maximum
[4] Assumed by all HPWHs to be 10%. Derived from NREL study
[5] The simulated hot water temperature set point is 135 °F

1.2 Hot water load profiles

The calculator contains 8,760-hour hot water load profiles (in gallons hot water) extracted from DEER DOE2 building prototypes. There are 23 commercial load profiles and 3 residential load profiles. The university and hotel prototypes use the dorm room and guest room space profiles, respectively. All hot water loads for the various building prototypes are converted to gallons of water at the hot water tank temperature (135 °F).

1.1.1 Residential NREL peak demand event profiles

For residential buildings, a more detailed "Event" schedule is used to better capture peak loads. See http://www.nrel.gov/docs/fy10osti/47685.pdf for more information on the event schedule. This schedule is used specifically for estimating peak demand (kW) and peak demand reduction. DEER DOE2 building prototype hot water load profiles are used for annual energy (kWh and therm) usage and savings.

1.3 Ambient air temperature profiles

Hourly ambient air temperature profiles of the hot water tank and heat pump evaporator is used to determine the heat loss from the tank and the adjusted COP of a HPWH. The ambient temperature profiles were extracted from DEER DOE prototypes for seven space types and for each climate zone. See Table 1-1 for each building type's designated ambient temperature space type. HPWH COP adjustment due to ambient air temperature is discussed in Section 1.1.5.

Table 1-1. Water heater ambient space type by building type

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 Manufacturing	Conditioned Storage space
Large Office	Conditioned Interior space
Small Office	Conditioned Interior space
Sit-Down Restaurant	Conditioned Storage space
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

Building Type	Water heater ambient space type
Refrigerated Warehouse	Conditioned Interior space
Single Family Home	Attached Garage
Multifamily Home	Interior Hallway
Mobile Home	Outdoor Cabinet

1.4 Temperatures of water mains

The calculator also accounts for variation in incoming ("mains") water temperature. Ground water temperature is extracted from the DEER DOE2 prototypes using CZ2010 weather files. The water temperature is listed by month and climate zone.

1.5 Water heater load

Water heater measures historically have used DOE performance metrics (EF, UEF, TE, FHR, standby loss) as criteria for measure qualification. EF and UEF represent the efficiency of the water heater's heating elements and tank losses under a specific 24-hour test procedure. While EF used a single draw pattern for the 24-hour test procedure, UEF uses different draw patterns (very small, low, medium, high) for the test procedure.

The water heater calculator does not directly use UEF—or Energy Factor (EF)—to calculate water heating energy usage. UEF and EF values are used as a comparison metric among water heater types. The derivation of the UEF/EF metric relies on specific hot water draw patterns that are not used by the calculator (the calculator uses hot water load profiles as mentioned in 1.2). The calculator uses recovery efficiency (RE), thermal efficiency, COP, and tank UA (i.e., tank heat loss) as key efficiency parameters.

The calculator categorizes three separate loads water heaters must satisfy as described below.

1.1.2 Hot water load

Hot water load is the calculated hourly hot water load in Btu/hr due to hot water use. This load uses the building-specific hot water load profiles (in gallons water), assumed main water temperature, and assumed tank temperature.

Equation 1-1. Hourly hot water load

$$HW_{load} = HW_{gal} \times (T_{tank} - T_{mains}) \times 8.2$$

where,

HW_{load} = hourly hot water load in Btu/hr

HW_{gal} = hourly hot water volume, in gallons

T_{tank} = water heater temperature, 135 °F

T_{mains} = water mains (ground water) temperature

8.2 = specific heat and density conversion factor for water

1.1.3 Tank loss load

Tank loss represents the hourly hot water load in Btu/hr due to heat lost through the tank walls/insulation. This load is calculated using the water heaters tank loss factor (tank UA). They are described in greater detail in Section 1.6.

1.1.4 Auxiliary load

Auxiliary load represents the hourly hot water load due to pilot light heating the water tank6. Gas storage water heaters have a constant hourly load; instantaneous gas heaters only use pilot light energy while the heater is operating.

1.6 Tank losses (Tank UA)

Standby losses are not reported in AHRI for residential water heaters. The calculator uses the following formula to estimate standby losses (Btu/hr-°F) for storage water heaters that are not HPWHs. Instantaneous water heaters are assumed to have no tank loss.

Equation 1-2. Tank UA of residential (storage) water heaters[7]

$$UA_{tank} = \frac{\left(\frac{RE}{UEF} - 1\right)}{\left(\frac{24}{41{,}092} - \frac{1}{(UEF \times Cap \times 1{,}000)}\right)} \times 67.5$$

Where,

UA_{tank} = tank heat losses to ambient air, Btu/hr-°F

RE = recovery efficiency, %

UEF = uniform energy factor or energy factor

Cap = input capacity of water heater, in kBtu/hr

Commercial water heaters have published standby losses in Btu/hr or %/hr (% of input capacity). The TechID tank UA values (Btu/hr-°F) for commercial water heaters are calculated using the following formula.

Equation 1-3. Tank UA of commercial (storage) water heaters

$$UA_{tank} = \frac{loss_{standby}}{70}$$

Where,

UA_{tank} = tank heat losses to ambient air, Btu/hr-°F

$loss_{standby}$ = published (AHRI, CEC) standby loss in Btu/hr

70 = assumed temperature difference between tank and ambient air, °F

Tank loss rates of HPWHs are discussed in Section 1.1.6.

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[6] Assumed to be 350 Btu/hr and 67% efficient

[7] The equation is based on the estimate of water heater energy consumption proposed in WHAM: A Simplified Energy Consumption Equation for Water Heaters (Lutz, 1998). The WHAM model is also utilized in the DOE UEF conversion procedure

1.7 HPWH performance

There is limited data that supports actual heat pump performance. The HPWHs utilize EF values to predict corresponding COP values.[8] The COP values are used in the calculator to estimate water heating energy usage and are utilized in the calculator like RE and TE. This EF-COP correlation is based on an NREL study[9] that investigated heat pump water heater performance.

1.1.5 HPWH COP

The HPWH COP is estimated as a fraction of the rated EF for a tank temperature range between 120 and 135 °F. The COP is also adjusted as a function of ambient temperature. The updated version of the water heater calculator uses the same assumptions and equations that predict heat pump water heater performance as the previous calculator versions. The equation for HPWH COP is shown below. See Figure 1-1 for the relationship between COP and ambient temperature.

Equation 1-4. HPWH COP as a function of EF and tank temperature

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

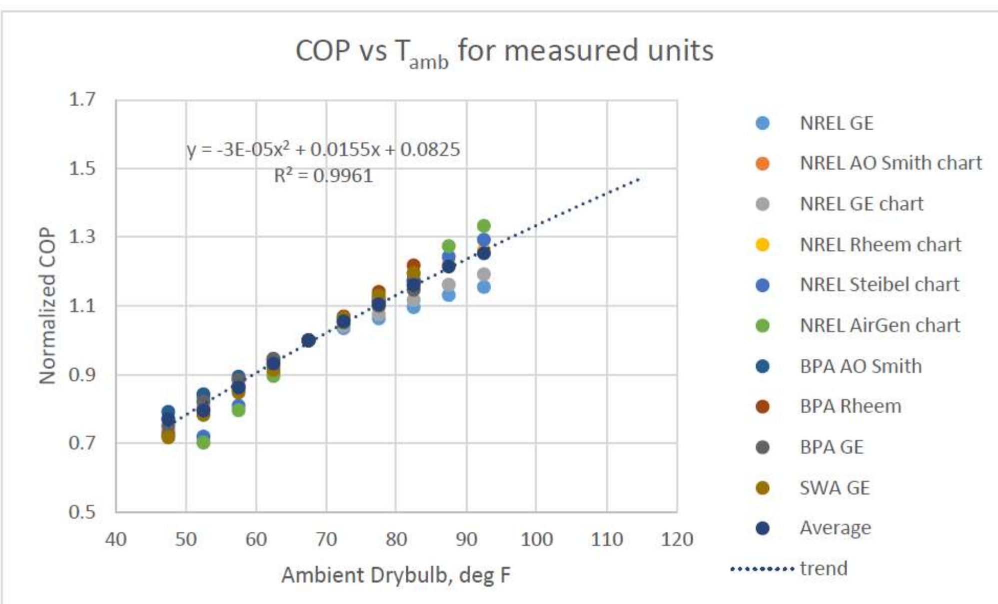
Where,

COP = coefficient of performance

EF = energy factor

T_{tank} = tank temperature, °F

Figure 1-1. HPWH COP adjusted for ambient temperature



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

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[8] The calculator coverts the published UEF values into EF values (using DOE conversion formulae), then uses EF values to predict COP values.

[9] https://www.nrel.gov/docs/fy16osti/64904.pdf

1.1.6 HPWH tank loss (Tank UA) rate

Standby losses are not published for HPWHs and are dependent on characteristics that are different from traditional storage water heaters. The Deemed Ex Ante Review team decided to retain the same assumption used in previous version of the WH calculator, which uses a value of 4.2 Btu/hr-°F for all HPWHs.[10]

[10] The value is the average of standby loss rates of HPWHs in the NREL study (https://www.nrel.gov/docs/fy16osti/64904.pdf)

2 DEER2021 Updates

In 2019, the Deemed Ex Ante Review team was assigned with updating the domestic water heater calculator. Some of the specific tasks included:

1. Utilize UEF values within calculations
2. Update "Technology" definitions (e.g., recovery efficiency, burner capacity, standby losses) with current CEC, DOE, and AHRI database findings
3. Correct calculations that previously resulted in negative savings
4. Reduce number of measures to one draw pattern per water heater size
5. Include measure savings for electric HP water heaters
6. Include measure savings for commercial tankless water heaters
    a. Accommodate commercial water heaters rated with thermal efficiency rating similar to the following example measure IDs:
        i. NG-WtrHt-LrgInst-Gas-gt200kBtuh-0p80Et
        ii. NG-WtrHt-LrgInst-Gas-gt200kBtuh-0p90Et
        iii. NG-WtrHt-LrgStrg-Gas-gte75kBtuh-0p83Et
        iv. NG-WtrHt-LrgStrg-Gas-gte75kBtuh-0p90Et
        v. NG-WtrHt-MedInst-Gas-76to200kBtuh-0p90Et
    b. Accommodate commercial water heaters that have residential-level input capacities (e.g., instantaneous gas water heaters with an input capacity < 200 kBtu/h)
7. Include "Com" building type savings for all climate zones
8. Remove PA-specific savings and apply "ANY" for the PA designation within a given climate zone
9. For the commercial TechType = "Stor_UEF", change "NormUnits" to "Cap-kBTUh"
    a. Provide transparency for the conversion (from "Each" to "Cap-kBTUh")
10. Other updates and discrepancy fixes

The sub-sections that follow will describe the listed updates in greater detail.

2.1 Utilize UEF values within calculations

UEF values are not used directly by the calculator to estimate energy consumption of water heaters. RE/TE values and tank loss rates are the primary equipment parameters for water heater energy usage. See Section 1.5 for more information on EF and UEF definitions and the calculator's savings methodology.

2.2 Update "Technology" definitions with current offerings

Measure IDs and measure savings are based on the comparison of two technology IDs (TechIDs). The first TechID represents the baseline water heater and the second TechID represents the efficient water heater. Each TechID is simulated to be installed in the DEER building types and climates zones. Annual energy usage for each combination of TechID, building type, and climate zone is simulated within the calculator.

The water heater calculator TechIDs representing code/standard and measure case water heaters were updated using the following residential and commercial water heater sources[11]:

- AHRI database, February 2020
- CEC database, March 2020
- DOE Compliance Certification database (CCDB), March 2020

The water heater data sources are used to determine calculator simulation parameters regarding the efficiency, input capacity, and thermal transmittance (UA) of the storage tank for the variety of TechIDs. The source data (hereafter referred to as *the AHRI/CEC database*) are categorized into water heater technology types (e.g., gas storage, electric heat pump, etc.), sector types (residential or commercial), storage volume bins, input capacity bins, and efficiency tier bins.

For the majority of TechIDs, the simulation parameters that ultimately are used for a specific TechID are calculated by averaging the water-heater performance and efficiency data that fall within each category bin. Some exceptions are made for categories containing insufficient data or without building code standards (e.g., heat pump water heaters). However, the intent of utilizing manufacturer data whenever possible is to develop TechIDs with parameters that are the average representative of water heaters in the California water-heater market.

The following sub-sections describe in detail how the AHRI/CEC database and binning workbook[12] are used to develop TechIDs.

2.2.1 TechID naming conventions

This update attempted to follow precedent established from previous versions of the water heater calculator. The Deemed Ex Ante Review team wanted to make clear some specific conventions for the TechID name and input parameter values (e.g., UEF, RE, input capacity, etc.) of those TechIDs.

- Efficiency value in pre-existing TechID names match the efficiency input parameter value
- Efficiency value in standard/code TechID names match the corresponding minimum code value; however, the efficiency input parameter value of the TechID can be the same or higher than what is in the name. This is because of the average binning method discussed in section 2.2.3.
- Efficiency values in measure TechID names match workpaper efficiency tier efficiency values; however, the efficiency input parameter value of the TechID can be the same or higher than what is in the name. This is because of the averaging method discussed in the section 2.2.4.

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[11] These databases overlap with each other and the aggregate database ultimately has duplicates. Duplicates are not removed from the aggregate database, but are also accounted for in the binning workbook

[12] The binning workbook shall be included with releases of updated water heater calculator workbook files.

2.2.2 Pre-existing TechIDs

TechIDs that are used to simulate vintage water heaters did not have their TechID input parameters or descriptions converted in to UEF. Part of the reason not to convert the name was to distinguish pre-existing TechIDs from standard/code-level or measure-level TechIDs. Standard/code-level and measure-level TechIDs all use UEF or TE in their names, but pre-existing TechIDs do not.[13]

2.2.3 Standard/code TechIDs

The TechIDs that represent standard/code base case water heaters were developed using a combination of minimum efficiency standards defined in the U.S. Code of Federal Regulations and percentage ranges above the minimums.[14] This method is intended to approximate typical entry-level water heaters on the market that are usually slightly above code. There are UEF standards for residential consumer (and residential-duty commercial) products and TE standards for commercial products. The minimum efficiency values used by the binning workbook are shown in the figures that follow (Figure 2-1, Figure 2-2, and Figure 2-3).

[13] Exceptions are made for the commercial sector where pre-existing TechIDs did not previously exist for 80, 100, and 120-gallon water heaters. Future updates of the calculator may include a research component that incorporates more findings from commercial building stock studies (e.g., California Commercial End-Use Survey).

[14] Residential consumer products: Title 10 → Chapter II → Subchapter D → Part 430 → Subpart C → § 430.32
Commercial products: Title 10 → Chapter II → Subchapter D → Part 431 → Subpart G → § 431.110

Figure 2-1. UEF minimum efficiency standards for residential consumer water heater products

Product class	Rated storage volume and input rating (if applicable)	Draw pattern	Uniform energy factor
Gas-fired Storage Water Heater	≥20 gal and ≤55 gal	Very Small	$0.3456 - (0.0020 \times V_r)$
		Low	$0.5982 - (0.0019 \times V_r)$
		Medium	$0.6483 - (0.0017 \times V_r)$
		High	$0.6920 - (0.0013 \times V_r)$
	>55 gal and ≤100 gal	Very Small	$0.6470 - (0.0006 \times V_r)$
		Low	$0.7689 - (0.0005 \times V_r)$
		Medium	$0.7897 - (0.0004 \times V_r)$
		High	$0.8072 - (0.0003 \times V_r)$
Oil-fired Storage Water Heater	≤50 gal	Very Small	$0.2509 - (0.0012 \times V_r)$
		Low	$0.5330 - (0.0016 \times V_r)$
		Medium	$0.6078 - (0.0016 \times V_r)$
		High	$0.6815 - (0.0014 \times V_r)$
Electric Storage Water Heaters	≥20 gal and ≤55 gal	Very Small	$0.8808 - (0.0008 \times V_r)$
		Low	$0.9254 - (0.0003 \times V_r)$
		Medium	$0.9307 - (0.0002 \times V_r)$
		High	$0.9349 - (0.0001 \times V_r)$
	>55 gal and ≤120 gal	Very Small	$1.9236 - (0.0011 \times V_r)$
		Low	$2.0440 - (0.0011 \times V_r)$
		Medium	$2.1171 - (0.0011 \times V_r)$
		High	$2.2418 - (0.0011 \times V_r)$
Tabletop Water Heater	≥20 gal and ≤120 gal	Very Small	$0.6323 - (0.0058 \times V_r)$
		Low	$0.9188 - (0.0031 \times V_r)$
		Medium	$0.9577 - (0.0023 \times V_r)$
		High	$0.9884 - (0.0016 \times V_r)$
Instantaneous Gas-fired Water Heater	<2 gal and >50,000 Btu/h	Very Small Low	0.80 0.81
		Medium	0.81
		High	0.81
Instantaneous Electric Water Heater	<2 gal	Very Small	0.91
		Low	0.91
		Medium	0.91
		High	0.92
Grid-Enabled Water Heater	>75 gal	Very Small	$1.0136 - (0.0028 \times V_r)$
		Low	$0.9984 - (0.0014 \times V_r)$
		Medium	$0.9853 - (0.0010 \times V_r)$
		High	$0.9720 - (0.0007 \times V_r)$

*V_r is the Rated Storage Volume (in gallons), as determined pursuant to 10 CFR 429.17.

Figure 2-2. UEF minimum efficiency standards for residential-duty commercial water heaters

Product class	Specifications[a]	Draw pattern	Uniform energy factor[b]
Gas-fired Storage	>75 kBtu/hr and ≤105 kBtu/hr and ≤120 gal	Very Small Low	0.2674 − (0.0009 × Vr) 0.5362 − (0.0012 × Vr)
		Medium	0.6002 − (0.0011 × Vr)
		High	0.6597 − (0.0009 × Vr)
Oil-fired Storage	>105 kBtu/hr and ≤140 kBtu/hr and ≤120 gal	Very Small Low	0.2932 − (0.0015 × Vr) 0.5596 − (0.0018 × Vr)
		Medium	0.6194 − (0.0016 × Vr)
		High	0.6740 − (0.0013 × Vr)
Electric Instantaneous	>12 kW and ≤58.6 kW and ≤2 gal	Very Small	0.80
		Low	0.80
		Medium	0.80
		High	0.80

[a]Additionally, to be classified as a residential-duty commercial water heater, a commercial water heater must meet the following conditions: (1) if the water heater requires electricity, it must use a single-phase external power supply; and (2) the water heater must not be designed to heat water to temperatures greater than 180 °F.

[b]Vr is the rated storage volume (in gallons), as determined pursuant to 10 CFR 429.44.

Figure 2-3. TE minimum efficiency standards for commercial water heater products

Equipment category	Size	Energy conservation standard[a]		
		Maximum standby loss[c] (equipment manufactured on and after October 29, 2003)[b]	Minimum thermal efficiency (equipment manufactured on and after October 29, 2003 and before October 9, 2015)[b] (%)	Minimum thermal efficiency (equipment manufactured on and after October 9, 2015)[b] (%)
Electric storage water heaters	All	0.30 + 27/Vm (%/hr)	N/A	N/A
Gas-fired storage water heaters	≤155,000 Btu/hr	Q/800 + 110(Vr) ½ (Btu/hr)	80	80
	>155,000 Btu/hr	Q/800 + 110(Vr) ½ (Btu/hr)	80	80
Oil-fired storage water heaters	≤155,000 Btu/hr	Q/800 + 110(Vr) ½ (Btu/hr)	78	80
	>155,000 Btu/hr	Q/800 + 110(Vr) ½ (Btu/hr)	78	80
Gas-fired instantaneous water heaters and hot water supply boilers	<10 gal ≥10 gal	N/A Q/800 + 110(Vr) ½ (Btu/hr)	80 80	80 80
Oil-fired instantaneous water heaters and hot water supply boilers	<10 gal ≥10 gal	N/A Q/800 + 110(Vr) ½ (Btu/hr)	80 78	80 78
Equipment category		Size	Minimum thermal insulation	
Unfired hot water storage tank		All	R-12.5	

[a]Vm is the measured storage volume (in gallons), and Vr is the rated volume (in gallons). Q is the nameplate input rate in Btu/hr.

As with the code/standard TechIDs of previous versions of the calculator, this update defines the code/standard TechID minimum efficiency as a range equal to and a percentage above the code minimum requirement. For example, the TechID that represents a gas-fueled 50-gallon storage water heater with a medium draw pattern would have a minimum code UEF of 0.56 (see Figure 2-1; 0.6483-0.0017*50). However, an 5.0% tolerance above the minimum code requirement is added so the range of water heaters in the database representing this TechID have an allowable UEF from 0.56 up to 0.59. The representative UEF for this code-level TechID (Stor_UEF-Gas-050gal-MD-0.56UEF) turned out to be 0.57. Based on the UEF range (code level + some % above code), the TechID input capacity and RE are also averaged using the binning workbook. Table 2-1 shows the percentage range above code applied to the various volume and draw pattern bins.

Table 2-1. Code minimum UEF percentage range, code UEF to code UEF*(1+%)

Water Heater Type	Capacity (gal.)	Low Draw	Medium Draw	High Draw
Instantaneous (gal)	2	1.0%	1.0%	1.0%
Storage (gal)	30	5.0%	5.0%	5.0%
Storage (gal)	40	5.0%	5.0%	5.0%
Storage (gal)	50	5.0%	5.0%	5.0%
Storage (gal)	55	1.0%	1.0%	1.0%
Storage (gal)	60	5.0%	1.0%	5.0%
Storage (gal)	75	1.0%	1.0%	5.0%
Storage (gal)	80	1.0%	1.0%	15.0%
Storage (gal)	100	1.0%	1.0%	5.0%
Storage (gal)	120	1.0%	1.0%	5.0%

The percentage ranges were generally determined through visual analysis of database entries. There are categories of water heaters where the available water heaters in the market significantly exceed the code minimum. The percentage ranges allow the standard TechID to represent those water heaters in the market that are closest to code minimum. Table 2-2 and Table 2-3 show the updated UEF values for the standard/code electric and gas storage water heaters. These tables represent standard/code water heaters that meet residential application requirements; however, they can be implemented in non-residential buildings. **Error! Reference source not found.** contains standard/code TechID thermal efficiency values for gas storage water heaters with input capacity greater than 105 kBtu/h (non-residential).

Table 2-2. Standard/code TechID UEFs for electric storage water heaters (< 12 kW)[15]

Fuel – Volume - Draw	Previous EF	Current UEF
Elec – 30 - Low	0.951	0.92
Elec – 30 - Medium	0.951	0.92
Elec – 40 - Low	0.948	0.91
Elec – 40 - Medium	0.948	0.93
Elec – 50 – Low	0.945	0.91
Elec – 50 - Medium	0.945	0.93
Elec – 50 - High	0.945	0.94

Table 2-3. Standard/code TechID UEFs for gas-fueled storage water heaters (< 105 kBtu/h)

Fuel – Volume - Draw	Previous UEF	Current UEF
Gas – 30 - Medium	0.60	0.60
Gas – 30 - High	0.65	0.65
Gas – 40 - Low	0.52	0.52

[15] Previous standard/code TechIDs for electric storage did not have draw patterns; they just categorized by EF and storage volume.

Fuel – Volume - Draw	Previous UEF	Current UEF
Gas – 40 - Medium	0.58	0.59
Gas – 40 - High	0.64	0.65
Gas – 50 - Medium	0.56	0.57
Gas – 50 - High	0.63	0.64
Gas – 75 – High[16]	N/A	0.60

A similar method was employed to develop standard/code TechIDs for "large" storage water heaters (> 75 kBtuh input capacity) utilizing the TE efficiency metric. The code/standard TE for a large storage water heater is 0.8 (TechID = Stor_TE-Gas-gt75kBtuh-0.80Et).

2.2.3.1 Heat pump water heaters

There are no specific code requirements for (residential/consumer) HPWHs; they are technically covered under electric storage water heaters. All HPWHs on the market significantly exceed the electric storage water heater UEF code requirements; therefore, UEF values (Table 2-4) were selected by the Deemed Ex Ante Team to match the SWWH014 workpaper minimum standard efficiency for HPWHs, based on storage volume. The Table 2-4 values represent standard/code UEF values when the HPWH is defined in the measure as the base case water heater.

Table 2-4. Standard TechID UEF requirement for HPWHs

Volume (gallons)	UEF
65	2.91
80	3.00

2.2.4 Measure TechIDs

TechIDs that represent measure-level water heaters are developed similarly to code/standard TechIDs except that the qualifying criteria (e.g., UEF, standby loss) are, generally speaking, modified to meet or exceed ENERGY STAR® requirements. There are some TechIDs where the qualifying criteria do not exceed ENERGY STAR. These TechIDs match qualifying criteria according to the statewide workpapers describing the measure.

The residential ENERGY STAR criteria (enacted April 2015) give qualification pathways for EF or UEF ratings; however, only the UEF pathways were used. Commercial ENERGY STAR criteria (enacted October 2018) give qualification pathways for TE, COP, and standby loss. ENERGY STAR criteria are shown in Table 2-5 and Table 2-6 that follow.

[16] This volume size uses residential-duty commercial code criteria to define standard UEF

Table 2-5. ENERGY STAR criteria for residential water heaters

Residential water heater type	Capacity, ≤55 gallons	Capacity, >55 gallons	All
Electric storage (UEF)	2.00	2.20	—
Gas storage, medium draw (UEF)	0.64	0.78	—
Gas storage, high draw (UEF)	0.68	0.80	—
Gas instantaneous (UEF)	—	—	0.87
Residential-duty gas storage (UEF)	—	—	0.80

Table 2-6. ENERGY STAR criteria for commercial water heaters

Commercial water heater type	Thermal efficiency	Standby loss (Btu/h)	COP
Gas storage	0.94	0.84 x [(Input rate / 800) + 110 x $(\text{Volume})^{1/2}$]	—
Gas storage-type instantaneous	0.94	0.84 x [(Input rate / 800) + 110 x $(\text{Volume})^{1/2}$]	—
Gas instantaneous	0.94	0.80	—
Electric heat pump	—	—	3.0

Unlike the code/standard binning range discussed above and UEF percentage range outlined in Table 2-6, the input parameter values for the measure TechIDs are developed using a pivot table averaging method in order to accommodate for multiple efficiency tier levels. This method allows specific efficiency ranges to be included in the category (e.g., 40-gallon storage gas with medium draw pattern) average. From this pivot table method, category averages are calculated for key input parameters like input capacity, UEF, RE, TE, and storage volume. The pivot table(s) used for developing input parameters for the measure TechIDs are included in the binning workbook. Cell notes are also included in the water heater calculator on the "Technologies" worksheet. Some of these notes explain exceptions made for some measure TechIDs, mostly due to a lack of water heaters in specific categories (e.g., there are no low draw pattern tankless water heaters with a UEF greater than 0.95 but a work paper measure exists for this category).

2.2.4.1 Heat pump water heaters

Within the ENERGY STAR definitions, HPWHs are considered to be electric storage water heaters. Current HPWHs on the market commonly exceed the ENERGY STAR specifications with UEF ratings typically exceeding 3.0. Measure TechIDs representing HPWHs were assigned qualifying requirements that match current statewide water heater workpapers (SWWH014 and SWWH025) defining HPWH measures. The qualifying measure efficiencies for HPWHs are shown in Table 2-7.

Table 2-7. Measure TechID UEF requirement for HPWHs

Volume (gallons)	Tier 1 UEF	Tier 2 UEF
50	3.09	3.31
65	3.33	N/A
80	3.42	N/A

Table 2-8 lists the previous HPWH measures developed and defined in the calculator. Table 2-9 lists the current residential HPWH measures defined in the calculator.

Table 2-8. Previous residential electric water heater definitions

Measure	Tier	Previous Code/Std.	Previous Measure
RE-WtrHt-SmlStrg-HP-lte12kW-rep30G-3p24EF	1	30gal – Elec – 0.95 EF	50gal – HP – 3.24 EF
RE-WtrHt-SmlStrg-HP-lte12kW-rep40G-3p24EF	1	40gal – Elec – 0.95 EF	50gal – HP – 3.24 EF
RE-WtrHt-SmlStrg-HP-lte12kW-rep50G-3p24EF	1	50gal – Elec – 0.95 EF	50gal – HP – 3.24 EF
RE-WtrHt-SmlStrg-HP-lte12kW-rep60G-3p17EF	1	65gal – HP – 3.00 EF	60gal – HP – 3.17 EF
RE-WtrHt-SmlStrg-HP-lte12kW-rep75G-3p06EF	1	80gal – HP – 3.00 EF	80gal – HP – 3.06 EF
RE-WtrHt-SmlStrg-HP-lte12kW-rep30G-3p50EF	2	30gal – Elec – 0.95 EF	50gal – HP – 3.50 EF
RE-WtrHt-SmlStrg-HP-lte12kW-rep40G-3p50EF	2	40gal – Elec – 0.95 EF	50gal – HP – 3.50 EF
RE-WtrHt-SmlStrg-HP-lte12kW-rep50G-3p50EF	2	50gal – Elec – 0.95 EF	50gal – HP – 3.50 EF
RE-WtrHt-SmlStrg-HP-lte12kW-rep60G-3p50EF	2	65gal – HP – 3.00 EF	60gal – HP – 3.50 EF
RE-WtrHt-SmlStrg-HP-lte12kW-rep75G-3p50EF	2	80gal – HP – 3.00 EF	80gal – HP – 3.50 EF

Table 2-9. Current residential electric measures (HPWHs)

Measure	Tier	Code/Std.	Measure
RE-WtrHt-SmlStrg-HP-lte6kW-rep30G-MD-3p09UEF-50g	1	30gal – Elec – MD - 0.92 UEF	50gal – HP – 3.09 UEF
RE-WtrHt-SmlStrg-HP-lte6kW-rep30G-MD-3p31UEF-50g	2	30gal – Elec – MD - 0.92 UEF	50gal – HP – 3.31 UEF
RE-WtrHt-SmlStrg-HP-lte6kW-rep40G-MD-3p09UEF-50g	1	40gal – Elec – MD - 0.92 UEF	50gal – HP – 3.09 UEF
RE-WtrHt-SmlStrg-HP-lte6kW-rep40G-MD-3p31UEF-50g	2	40gal – Elec – MD - 0.92 UEF	50gal – HP – 3.31 UEF
RE-WtrHt-SmlStrg-HP-lte6kW-rep50G-MD-3p09UEF-50g	1	50gal – Elec – MD - 0.92 UEF	50gal – HP – 3.09 UEF
RE-WtrHt-SmlStrg-HP-lte6kW-rep50G-MD-3p31UEF-50g	2	50gal – Elec – MD - 0.92 UEF	50gal – HP – 3.31 UEF
RE-WtrHt-SmlStrg-HP-lte6kW-65G-3p33UEF	1	65gal – HP – 2.91 UEF	65gal – HP – 3.33 UEF
RE-WtrHt-SmlStrg-HP-lte6kW-80G-3p42UEF	1	80gal – HP – 3.00 UEF	80gal – HP – 3.42 UEF
RE-WtrHt-FuelSub-SmlStrg-HP-lte6kW-rep30G-MD-3.09UEF-50g	1	30gal – Gas – MD - 0.60 UEF	50gal – HP – 3.09 UEF
RE-WtrHt-FuelSub-SmlStrg-HP-lte6kW-rep30G-MD-3p31UEF-50g	2	30gal – Gas – MD - 0.60 UEF	50gal – HP – 3.31 UEF
RE-WtrHt-FuelSub-SmlStrg-HP-lte6kW-rep40G-MD-3.09UEF-50g	1	40gal – Gas – MD - 0.58 UEF	50gal – HP – 3.09 UEF
RE-WtrHt-FuelSub-SmlStrg-HP-lte6kW-rep40G-MD-3p31UEF-50g	2	40gal – Gas – MD - 0.58 UEF	50gal – HP – 3.31 UEF
RE-WtrHt-FuelSub-SmlStrg-HP-lte6kW-rep40G-HI-3.09UEF-50g	1	40gal – Gas – HI - 0.64 UEF	50gal – HP – 3.09 UEF
RE-WtrHt-FuelSub-SmlStrg-HP-lte6kW-rep40G-HI-3p31UEF-50g	2	40gal – Gas – HI - 0.64 UEF	50gal – HP – 3.31 UEF
RE-WtrHt-FuelSub-SmlStrg-HP-lte6kW-rep50G-MD-3.09UEF-50g	1	50gal – Gas – MD - 0.56 UEF	50gal – HP – 3.09 UEF

Measure	Tier	Code/Std.	Measure
RE-WtrHt-FuelSub-SmlStrg-HP-lte6kW-rep50G-MD-3p31UEF-50g	2	50gal – Gas – MD - 0.56 UEF	50gal – HP – 3.31 UEF
RE-WtrHt-FuelSub-SmlStrg-HP-lte6kW-rep50G-HI-3.09UEF-50g	1	50gal – Gas – HI - 0.63 UEF	50gal – HP – 3.09 UEF
RE-WtrHt-FuelSub-SmlStrg-HP-lte6kW-rep50G-HI-3p31UEF-50g	2	50gal – Gas – HI - 0.63 UEF	50gal – HP – 3.31 UEF
RE-WtrHt-FuelSub-SmlStrg-HP-lte6kW-rep60G-HI-3p33UEF-80g	1	60gal – Gas – HI - 0.61 UEF	65gal – HP – 3.33 UEF
RE-WtrHt-FuelSub-SmlStrg-HP-lte6kW-rep75G-HI-3p42UEF-80g	1	75gal – Gas – HI - 0.59 UEF	80gal – HP – 3.42 UEF
RE-WtrHt-FuelSub-SmlInst-HP-lte6kW-replt200kBtuh-LW-3.09UEF	1	Inst – Gas – LW – 0.81 UEF	50gal – HP – 3.09 UEF
RE-WtrHt-FuelSub-SmlInst-HP-lte6kW-replt200kBtuh-LW-3.31UEF	2	Inst – Gas – LW – 0.81 UEF	50gal – HP – 3.31 UEF
RE-WtrHt-FuelSub-SmlInst-HP-lte6kW-replt200kBtuh-MD-3.09UEF	1	Inst – Gas – MD – 0.81 UEF	50gal – HP – 3.09 UEF
RE-WtrHt-FuelSub-SmlInst-HP-lte6kW-replt200kBtuh-MD-3.31UEF	2	Inst – Gas – MD – 0.81 UEF	50gal – HP – 3.31 UEF
RE-WtrHt-FuelSub-SmlInst-HP-lte6kW-replt200kBtuh-HI-3.09UEF	1	Inst – Gas – HI – 0.81 UEF	50gal – HP – 3.09 UEF
RE-WtrHt-FuelSub-SmlInst-HP-lte6kW-replt200kBtuh-HI-3.31UEF	2	Inst – Gas – HI – 0.81 UEF	50gal – HP – 3.31 UEF

There are also updates to the commercial water heater measures. These updates can be found on the "Measure" worksheet in the updated calculator workbook. There are measures utilizing "residential" TechIDs but are designated for the commercial sector (use measure ID prefix "NG" or "NE"). There are also commercial-specific TechIDs that utilize TE (or COP for the commercial HPWH). Some of these commercial measures will be further explained in Section 2.6.

One of the original intents of the water heater calculator was to provide PAs a basis for defining and developing new measures using the savings methodology of the calculator. The measures presented in this document and in the updated calculator reflect the Deemed Ex Ante Team's attempt to:

- Update the current offerings,
- Add commercial measures using TE performance ratings
- Provide a fuel substitution offering that can be leveraged by the PAs to expand fuel substitution offerings.

The Deemed Ex Ante Review team intends to collaborate with the PAs for future additions to the calculator and water heater measure offerings.

2.3 Correct calculations for negative savings

Negative savings occur because UEF is not always a clear indicator of absolute efficiency improvement over a water heater with a smaller UEF. UEF (and EF) efficiency metrics are estimated using a specific testing procedure that assumes specific draw patterns or daily water volume. The calculator does not utilize these same draw patterns. Rather, it uses hot water load profiles (i.e., "patterns") derived from DEER building prototypes. Therefore, the difference in annual energy usage between a "base case" water heater with a UEF rating lower than the “measure case” water heater is dependent on the water heaters’ RE, Tank UA, and ambient air temperature (i.e., building type and tank loss to ambient air).

For this update, there were two water heater measures that estimated negative savings[17]. The measures were “NG-WtrHt-SmlStrg-Gas-lte75kBtuh-40G-MD-0p64UEF” and “NG-WtrHt-LrgStrg-Gas-gt75kBtuh-0p83Et”. Each measure presented unique combinations of building types (i.e., hot water load profiles) and climate zones (i.e., ground water and, potentially, ambient temperatures) where savings were negative.

The large storage water heater measure estimated negative savings in small office and small retail buildings because the hot water load profiles of these buildings were very small compared to the size of the water heater. This caused the impact of the difference in tank losses between the standard and measure TechIDs to outweigh the difference in TE.

The 40-gallon medium draw water heater measure estimated negative savings for the refrigerated warehouse building type in climate zone 16. While tank loss loads were greater for the standard water heater, so were delayed loads that, when unmet, do not get accounted for as delivered loads. In other words, in this specific case, the standard water heater had greater unmet hours but also consumed less fuel than the measure water heater because of those unmet hours.

The typical cause of negative savings in measures is the aggregate of recovery efficiency and tank loss differences when applied to a specific hot-water load profile. Depending on the how the AHRI database entries are averaged together, there is a chance that Measure ID combinations can produce negative savings.

While measure case UEF and tank UA are more efficient than the standard case metrics, the measure case RE can be less efficient than the standard case RE. A comparison of all medium-draw, 40-gallon gas storage water heaters in the AHRI/CEC database with a UEF of 0.65 show that the RE ratings range from 0.73 to 0.75. A comparison of the same subset of water heaters but with a rated UEF of 0.58 show that the RE ratings range from 0.73 to 0.78. This comparison shows that water heaters with higher UEF can have lower RE than water heaters with a lower UEF. Using this example, under particular circumstances (e.g., heavy hot water load profiles), the comparison of a 0.65 UEF water heater to a 0.58 UEF water heater can yield negative savings.

Under typical circumstances, most of the water heater energy usage is expended to meet the hourly hot water load (which the calculator estimates using the RE value)—with a fraction of total energy usage spent re-heating tank water due to tank loss to ambient air—the calculator estimates that some combinations of water heater measures do not save energy.

While the Deemed Ex Ante Review team considered culling the measures available in the calculator so that only those offerings that yield substantial savings are presented, this was not pursued.

2.4 Reduce number of measures to one draw pattern per water heater size

Simplifying the offerings by reducing the number of measures to one draw pattern per water heater size was a recommendation proposed by SCG in a memo submitted to ED on March 6, 2019. While this recommendation would reduce the number of combinations of measures for a given water heater size (e.g.,

[17] For non-fuel switching measures. Fuel switching measures (gas to electric fuel) all have positive fuel savings and negative electric savings

storage volume or input heating capacity), draw patterns are an important aspect of the new efficiency metric (UEF). It is commonly part of a customer's selection criteria for an appropriate water heater meeting their needs. This metric will also be readily available when submitting program rebate applications, so measure selection should not be complicated. For this update, the Deemed Ex Ante Review Team has decided to retain draw patterns in TechIDs; measures are the comparison of TechIDs with the same draw pattern, among other matching criteria (like storage volume or input capacity). New TechIDs dissociated from specific draw patterns and corresponding measures could be developed in future updates.

2.5 Include measure savings for electric heat pump water heaters

TechIDs that account for electric heat pump water heaters were added to the water heater calculator. These updates were based on statewide work papers SWWH014 and SWWH025, and new CEC/AHRI database entries collected in March 2020. Several heat pump water heater measures were developed to cover residential and commercial sectors as well as fuel substitution.

2.6 Include measure savings for commercial tankless water heaters

Commercial tankless water heaters (TE-rated) technologies were added to the calculator as shown in Table 2-10. They were divided in to two size groups – (1) 76 to 200 kBtu/h and (2) greater than or equal to 200 kBtu/h.

Table 2-10. Commercial instantaneous gas measures

Measure ID	Tier	Code/Std.	Measure
NG-WtrHt-MedInst-Gas-76to200kBtuh-lt2G-0p80Et	1	Large Gas Storage – 0.80 TE	Med Inst – Gas – 0.80 TE
NG-WtrHt-MedInst-Gas-76to200kBtuh-lt2G-0p90Et	2	Large Gas Storage – 0.80 TE	Med Inst – Gas – 0.90 TE
NG-WtrHt-MedInst-Gas-76to200kBtuh-lt2G-0p96Et	3	Large Gas Storage – 0.80 TE	Med Inst – Gas – 0.96 TE
NG-WtrHt-LrgInst-Gas-gte200kBtuh-lt2G-0p80Et	1	Large Gas Storage – 0.80 TE	Large Inst – Gas – 0.80 TE
NG-WtrHt-LrgInst-Gas-gte200kBtuh-lt2G-0p90Et	2	Large Gas Storage – 0.80 TE	Large Inst – Gas – 0.90 TE
NG-WtrHt-LrgInst-Gas-gte200kBtuh-lt2G-0p96Et	3	Large Gas Storage – 0.80 TE	Large Inst – Gas – 0.96 TE

2.7 Include "Com" building type savings for all climate zones

"Com" building-weighted results for PA = "Any" and vintage = "Ex" are included in the calculator for all climate zones

2.8 Remove "PA"-specific savings and apply "ANY" for the PA designation

The calculator provides statewide-specific (PA = "Any") savings. The savings designated with "Any" are dependent on climate zone.

2.9 Adding "Cap-kBtuh" as "NormUnit"

The water heater calculator workbook had been developed to produce an "Each" normalized unit ("NormUnit") meaning savings outputs generated by the calculator were for a single water heater. The calculator uses DEER prototype models to estimate building-specific hot water loads. When the calculator selects water heater TechIDs, it estimates given the water heater's input capacity how many water heaters are necessary to meet the peak hot water load[18].

This estimate of the number of water heaters needed ("NumUnits") to meet peak hot water load is passed along in the water heater calculator to normalize savings to "Each". The DEER team adjusted the equation that estimates "NumUnits" to round up to the nearest integer. Note that "NumUnits" is equal to "1" for all residential building types.

"Cap-kBtuh" was added as a "NormUnit" for commercial TechIDs. A parameter called "Cap*NumUnits", equal to "NumUnits" multiplied by the input capacity of the TechID, is passed along in the "TechResults" processing. Depending on the "NormUnit" defined for the MeasureID (on the "Measure" worksheet), the "NormUnit" is per water heater ("Each") or per kBtuh of water heater input capacity ("Cap-kBtuh").

2.10 Other updates

Other updates that are not included or addressed in the DEER2021 updates described in Section 2.1 through Section 2.9 are noted in this section.

- Updated climate zone 5 peak period hours. The "Peak Period" worksheet that has 8,760-hour peak hour flag columns for each climate zone had hours for 4 p.m. to 8 p.m. for climate zone 5. It was updated to include 9 p.m. for the three consecutive days.
- "Volume per unit" – column H on "TechCalc" worksheet. The equation was modified from "=$G/$T$9" to "=IF($T$9<1,$G##,$G##/$T$9)". The change restricts the volume per unit to be equal to the hourly water volume (column G) if the "number of units used" is less than 1. This logic becomes moot because the "number of units used" (Cell T9 on the "TechCalc" worksheet) equation was adjusted so that the number is always a whole integer of at least 1 or greater.
- "number of units used" – cell T9 on "TechCalc" worksheet. The cell equation sets the number of units equal to 1 if the building type = "Res". If the building type is "Com", the cell equation was updated to round up the number of units used to a whole integer. The logic behind this update was to have a realistic quantity of water heaters of a specific type serving the building type's hot water load. The adjustment essentially increases the sizing factor that the simulation uses to estimate the quantity of water heaters necessary to satisfy peak hot water load. Normalized per unit savings are computed as:

Equation 2-1. Per-unit savings

$$savings_{unit} = \frac{\left(usage_{unit,base} \times NumUnits_{base} - usage_{unit,measure} \times NumUnits_{measure}\right)}{NumUnits_{measure}}$$

- Added default RE = 0.98 for back up electric resistance heating element for HPWH. This default value is in cell K8 on the "TechCalc" worksheet
- Updated the "kWh_bu" (backup kWh – column U) variable on the "TechCalc" worksheet. This column is intended to estimate the hourly electric energy a HPWH uses when the hour calls for back up electric resistance heat ("resist frac" – column S). Previously, the calculator used the RE linked from

[18] The calculator incorporates sizing factors for required capacity to meet peak hot water load and uses assumptions for stored capacity (from the storage tank if applicable) to estimate equivalent capacity of a single water heater

the “Technologies” worksheet. Previous HPWH TechIDs all had a RE of 0.98. With TechID updates, HPWHs have RE values based on AHRI entries (and are >0.98). In order to isolate the RE of the backup electric element of the HPWH, this column needed to be updated to point to cell K8 for the RE value (see above bullet).

- Added entry columns on “Technologies” worksheet. Added “COP” (column I) and columns S through W (“Version”, “Calc_tankUA”, “Pre-existing flag”, TechLevel”, and “Draw pattern”) to add supplementary details on each TechID entry.
- Column F “Uniform_Energy_Factor (or Energy_Factor)” on the “Technologies” worksheet accepts both UEF or EF values
- Column H (RecovEff (or TE for Commercial WHs) on the “Technologies” worksheet accepts both RE and TE values.
- “Technologies” worksheet has all previous version TechIDs and associated calculator version documented for record.
- Added vintage records for “large storage” (greater than 75 kBtu/h) commercial pre-existing TechIDs. They are equivalent to standard/code TechIDs. Records are added on the “VintageUpdate” worksheet, in columns AB to AG. The addition allows pre-existing savings to be estimated in the calculator; however, the pre-existing savings are equivalent to the standard/code savings. Future updates may incorporate research in to building stock assessment studies to determine reasonable efficiency levels to estimate pre-existing savings for “large storage” commercial measures.
- Building weights. The previous version of the water heater calculator used building weights last updated for DEER 2017. DEER 2020 residential and commercial building weights were added to the calculator to remain consistent with building weights used by MASControl 3. They are located on the “wts_res_location” and “wts_com_vintage” worksheets. The residential weights are categorized by PA, climate zone, and building type. The commercial weights (normalized to PA = “Any” and building vintage = “Ex”) are categorized by climate zone and building type. *Version 4.1 of the water heater calculator was updated (to version 4.2) to fix a calculation error*[19]*. The building weights were not properly applied to the “Com” building type.*
- Renamed an output column header on “TechResults” and “TechCalc” worksheets. “Btu_aux” was renamed to “therm_aux” because the output unit was therms.
- Added “Com” and “Res” weighted building types for PA = “Any”. Energy impact outputs are now delivered by: (1) building type and climate zone (1 to 16) for PA = ”Any” i.e., unweighted; and (2) weighted results for building type = “Com” and “Res” for PA = “Any” and climate zone (1 to 16).
- Added message box in TechCalc macro to report elapsed time running macro to produce “TechResults” output.
- Removed standing pilot “pilotBTU” burner input capacity for instantaneous/tankless water heater (TWH) TechIDs. The original author of the water heater calculator had given the option to include a standing pilot input capacity for TWHs that may have utilized them. This option was assumed

[19] http://deeresources.com/index.php/deer-versions/deer2021

present for all TWHs. After discussion with PAs, it can be shown that TWHs use electric ignition systems and not standing pilot burners.

3 Future considerations

The Deemed Ex Ante Review Team considers the following points and/or limitations of the water heater calculator to be priority candidates to improve the quality of the calculator:

1. HPWH performance dependencies e.g., ambient air temperature, supplemental heating ratio
2. Interactive effects, specifically for HPWH
3. Location of HPWHs e.g., accommodating for split-system HPWHs
4. Variable tank temperature
5. Load shifting and 8,760-hour load shapes
6. Tank loss changes from ambient and tank temperature
7. COP entries for residential HPWHs in AHRI
8. Continuing improvement of hot water load profiles

Specific to the first item on the list, simulating the energy performance of HPWHs requires more data and input than traditional water heaters. Manufacturers of HPWHs and influencers like ENERGY STAR are still settling on consistent performance data to publish for HPWHs. Important data to more accurately simulate energy performance of HPWHs include:

- COP at standard and variable conditions
- Heating capacity at standard and variable conditions
- Control strategy of heating elements (heat pump and electric resistance)
- Tank heat loss rate
- Control strategy for load shifting

With guidance from the CPUC, the Deemed Ex Ante Review Team will prioritize the considerations listed above for future updates.

4 Using the water heater calculator

4.1 General function of the water heater calculator

The calculator estimates the annual energy usage of each "TechID". TechIDs represent types of water heaters on the market or pre-existing water heaters that are currently installed in buildings. The "Technologies" worksheet contains all the combinations of water heaters offered in DEER measures. The worksheet can be amended to offer new types of water heaters. There are currently three water heater technology types:

- Standard ("Std"). This type represents storage-type water heaters that are not heat pumps. These storage type water heaters generally have storage volumes greater than 20 gallons and have an input rating of less than 4,000 Btu per hour of input per gallon of storage.
- Instantaneous ("Inst"). This type represents instantaneous water heaters that, in general, have a storage volume less than 2 gallons and an input rating of more than 4,000 Btu per hour of input per gallon of storage.
- Heat pump ("HP"). This type represents *packaged* heat pump water heaters.

Standard and instantaneous water heaters use recovery efficiency or thermal efficiency as the primary efficiency metric for calculating how much energy (gas or electric) is required to heat incoming cold water to the hot water temperature. Heat pump water heaters use COP[20]. The calculator accounts for two fuel types – electricity and natural gas.

DEER measures (MeasureIDs) are the comparison of two TechIDs. One TechID represents the base case and one TechID represents the measure case. These comparisons, the MeasureIDs, are defined on the "Measure" sheet. The measure entries on this sheet specify the measure technology, the standard/code-compliant technology and the pre-existing technology. It also specifies the building sector (residential or commercial) and the measure's savings unit ("Each" or "Cap-kBtuh").

The general procedure for adding new measures to the water heater calculator involve the following steps:

1. Add TechIDs to the Technologies worksheet
2. Add Measure IDs to the Measure worksheet
3. Execute "Calculate All Results" button macro on the TechCalc worksheet
4. Execute "Create All Impacts" button macro on the EnImpacts-Res and EnImpacts-Com worksheets
5. Execute "Export" button macro on the EnergyImpact worksheet

The following sections describe in more detail how to add new TechIDs on the "Technologies" worksheet, add new MeasureIDs on the "Measure" worksheet, and execute the macros.

4.2 Adding TechIDs to the water heater calculator

[20] COP values are estimated using EF or UEF values and the tank temperature

4.2.1 Using the "binning workbook"

Adding TechIDs should generally be performed using the average binning method performed in the "CEC-AHRI-binning" workbook (referenced hereafter as the binning workbook). The binning workbook contains the latest consumer water heater databases released by the CEC, AHRI, and DOE. There are examples of TechIDs that do not follow exactly the binning workbook; the primary reasons being lack of data in the AHRI/CEC database or lack of efficiency standards by which to bin database entries by. For those TechIDs, addition into the calculator should include documentation on how the TechID parameters were generated. The binning workbook categorizes the database entries by:

- Residential or nonresidential
- Residential water heater types
  - Heat pump
  - Gas instantaneous
  - Gas storage
  - Residential-duty gas storage
  - Electric instantaneous
  - Residential-duty electric instantaneous
  - Electric storage
- Nonresidential water heater types
  - Heat pump
  - Gas instantaneous
  - Storage type gas instantaneous
  - Gas storage
  - Electric instantaneous
  - Electric storage
- Draw pattern (residential only) – very small, low, medium, high
- Storage volume – 2, 30, 40, 50, 55, 60, 75, 80, 100, and 120 gallons
- Meets code requirements (Yes or no)[21]
- Meets measure requirements (Yes or no)[22]

[21] Different code requirements for residential and nonresidential are defined in the binning workbook

[22] Different measure requirements for residential and nonresidential are defined in the binning workbook

The example below illustrates how the TechID "Stor_UEF-Gas-050gal-HI-0.70UEF" was developed using the binning workbook. This TechID has the following parameter values entered in to the "Technologies" worksheet.

Figure 4-1. Technologies worksheet, Stor_UEF-Gas-050gal-HI-0.70UEF

TechID	TechTy	Fuel_	Nom_Gallon	Uniform_Energy_F	BurnCa	Recov
Stor_UEF-Gas-050gal-HI-0.70UEF	Std	Gas	50	0.70	44.0	0.79

Since this TechID was created to represent a measure, the binning workbook filter drop-down list on the Summary worksheet was selected as "Meas" for measure.

Figure 4-2. Binning workbook, Summary worksheet, filter dropdown

C	D	E	F
	Filters:		
	Code/Meas	Meas	

This filter causes the binning tables on the Summary worksheet to calculate average values for the several water heater parameters like quantity, UEF, RE, TE, capacity, and standby loss. They are averaged by volume category, water heater type, and draw pattern. For the example, 50-gallon gas storage water heaters with a high draw pattern show the following table information for UEF, RE, and capacity.

Figure 4-3. Binning workbook, Summary worksheet, recovery efficiency table

	Recovery or Thermal Efficiency (bin average), %	Gas Instantaneous			Gas Storage		
	CATEGORY	LOW DRAW	MEDIUM DRAW	HIGH DRAW	LOW DRAW	MEDIUM DRAW	HIGH DRAW
2	2	#N/A	95%	94%	#N/A	#N/A	#N/A
0	30	#N/A	#N/A	96%	#N/A	#N/A	84%
0	40				#N/A	76%	78%
0	50				#N/A	77%	79%
5	55				#N/A	#N/A	#N/A
0	60				#N/A	#N/A	#N/A
5	75				#N/A	#N/A	#N/A
0	80				#N/A	#N/A	#N/A
5	100				#N/A	#N/A	#N/A
0	120				#N/A	#N/A	#N/A

Figure 4-4. Binning workbook, Summary worksheet, UEF table

	Uniform Energy Factor (bin average)	Gas Instantaneous			Gas Storage		
MAX VOL (GAL)	CATEGORY	LOW DRAW	MEDIUM DRAW	HIGH DRAW	LOW DRAW	MEDIUM DRAW	HIGH DRAW
2	2	#N/A	0.90	0.90	#N/A	#N/A	#N/A
30	30	#N/A	#N/A	0.92	#N/A	#N/A	0.76
40	40				#N/A	0.65	0.71
50	50				#N/A	0.65	0.70
55	55				#N/A	#N/A	#N/A
60	60				#N/A	#N/A	#N/A
75	75				#N/A	#N/A	#N/A
80	80				#N/A	#N/A	#N/A
105	100				#N/A	#N/A	#N/A
120	120				#N/A	#N/A	#N/A

Figure 4-5. Binning workbook, Summary worksheet, Input capacity table

Input (bin average), kBtu/h (gas), kW (electric)	Gas Instantaneous			Gas Storage		
CATEGORY	LOW DRAW	MEDIUM DRAW	HIGH DRAW	LOW DRAW	MEDIUM DRAW	HIGH DRAW
2	#N/A	120	179	#N/A	#N/A	#N/A
30	#N/A	#N/A	199	#N/A	#N/A	65
40				#N/A	39	42
50				#N/A	40	44
55				#N/A	#N/A	#N/A
60				#N/A	#N/A	#N/A
75				#N/A	#N/A	#N/A
80				#N/A	#N/A	#N/A
100						
120						

As the example shows, the binning values in Figure 4-3, Figure 4-4, and Figure 4-5 for a 50-gallon high draw gas storage heater are entered in to the corresponding columns for the TechID row in Figure 4-1. "TankUA" and "auxVent" are auto-calculated based on other cells (see equations in cell columns K through W on the Technologies sheet). "pilotBtu", and "pilotHtgEff" are assumed values (see other examples of storage gas heaters) that can be copied in to the TechID row.

Code/standard TechIDs created for this calculator update were developed by selecting "Code" filter on the "summary" worksheet in the binning workbook. The same procedure as shown in the measure example above was used for other TechID entries. TechIDs that did not follow the procedure typically have cell comments entered on the calculator's Technologies worksheet. The comments explain how the parameter values were sourced (e.g., "measure low draw UEF same as measure medium draw UEF").

4.2.2 Heat pump water heaters

HPWHs were handled differently from other technologies because there are limited HPWHs in the AHRI database. Instead, a separate analysis was performed on HPWH database entries to develop representative performance parameters for code/standard and measure TechIDs. The derivation of the HPWH TechID entries can be found on the "HP analysis" sheet in the binning workbook.

4.2.3 Final notes for adding TechIDs

Each TechID row much be completed for the workbook's lookup equations to function correctly. It is not necessary to remove TechIDs from the Technologies worksheet; rather, add new TechIDs at the bottom of the list, filling down existing column equations. Column R ("Update") is set to TRUE or FALSE to signal the calculator to perform the calculation process when the macro "Calculate All Results" is executed on the "TechCalc" worksheet.

4.3 Adding Measure IDs

Measure IDs are entered and defined on the "Measure" spreadsheet. The general procedure and rules for adding new measures are as listed below:

- Fill down the index on column B
- Designate "Res" or "Com" sector on column D
- Adjust the "Res" and "Com" upper and lower bounds (Cells I2:J3) according to the measure list entries. These upper and lower bounds can be sub-sets of the total list, the "Create Impacts" macros on the "EnImpacts-Res" and "EnImpacts-Com" use these bounds to determine which measures to create.
- For "Res" measures, NumUnits = 1, NormUnit = Each
- For "Com" measures, NumUnits = N/A, NormUnit = Cap-kBtuh
- Column G "Code/Standard" is the baseline TechID for the Measure ID. Column H "Measure" is the measure TechID for the Measure ID
- Columns K through R are informational and use lookup equations to populate the cells

4.4 Executing the calculator macros

Once new TechIDs and Measure IDs are entered macros must be executed to generate results.

4.4.1 TechCalc "Calculate All Results" macro

This macro cycles through all TechIDs with column R = TRUE and calculates annual results for that water heater by *every* building type and climate zone. The macro copies annual results (located in cells J14:AA14) from the TechCalc worksheet in to the TechResults worksheet.

Notes on the macro:

- The TechResults worksheet should have only one unique combination of TechID + building type + climate zone. In other words, once a TechID is calculated using the macro, its UPDATE cell can be changed to FALSE. If the TechID parameters are for some reason updated (but the TechID name remains the same), the rows of that TechID should be removed from the TechResults sheet.

- The macro is very time intensive. Allows at least 10 minutes per TechID

4.4.2 EnImpacts-Res and EnImpacts-Com "Create Impacts" macros

These macros cycle through all the measureIDs included in the bounds defined on the Measure worksheet. The pre-defined cells on the EnImpacts-Res and EnImpacts-Com worksheets are updated based on which Measure ID is selected and the results are copied over to the EnergyImpact worksheet.

4.4.3 Notes on the macros

Here are some cautionary notes from our experience with the calculator:

- These macros perform their operations quickly. Allow 1-2 minutes per macro.
- The EnergyImpacts worksheet should only have one unique combination of MeasureID + PA (Any, PGE, SCE, SCG, SDG) + building type + building vintage + climate zone. If the EnImpacts-Res and EnImpacts-Com macros are executed again, it may create duplicate entries on the EnergyImpacts sheet.
- There may be enterprise- or company-level safety-related restrictions for executing macros within workbooks. The calculator workbook may need to be added to a set of "Trusted Documents" or the calculator user may need to request assistance from their IT department in order to enable and execute macros.