



BSR/ASHRAE Standard 118.2-2006R

Public Review Draft

Method of Testing for Rating Residential Water Heaters and Residential-Duty Commercial Water Heaters

**Second Public Review (March 2019)
(Complete Draft for Full Review)**

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FOREWORD

This second public review draft is a substantive revision of the first public review draft issued April 2016. Major differences from the first public review draft include clarifications on how to determine the standby loss coefficient and the recovery efficiency. The values for test variables and definitions of the draw patterns to be used have been moved to an informative annex.

1. PURPOSE

The purpose of this standard is to provide test procedures for rating the efficiency and hot water delivery capabilities of directly heated residential water heaters and residential-duty commercial water heaters.

2. SCOPE

This standard applies to the following:

2.1 Electric heat pump storage water heaters that:

- a) use electricity as the energy source,
- b) have a nameplate input rating of 12 kW (40,956 Btu/h) or less,
- c) have a rated storage capacity of 120 gallons (450 liters) or less,
- d) are designed to transfer thermal energy from one temperature level to a higher temperature level for the purpose of heating water, and
- e) are designed to heat and store water at a thermostatically-controlled temperature less than or equal to 180 °F (82 °C).

2.2 Electric instantaneous water heaters that:

- a) use electricity as the energy source,
- b) have a nameplate input rating of 58.6 kW (200,000 Btu/h) or less,
- c) contain no more than one gallon of water per 4,000 Btu per hour of input, and
- d) are designed to provide outlet water at a controlled temperature less than or equal to 180°F (82°C).

2.3 Electric storage water heaters that:

- a) use electricity as the energy source,

- b) have a nameplate input rating of 12 kW (40,956 Btu/h) or less,
- c) have a rated storage capacity of 120 gallons (450 liters) or less,
- d) contain more than one gallon of water per 4,000 Btu per hour of input, and
- e) are designed to heat and store water at a thermostatically-controlled temperature less than or equal to 180°F (82°C).

2.4 Gas-fired heat pump storage water heaters that:

- a) use gas as the main energy source,
- b) have a nameplate input rating of 20,000 Btu/h (26.4 MJ/h) or less,
- c) have a maximum current rating of 24 amperes (including all auxiliary equipment such as fans, pumps, controls, and, if on the same circuit, any resistive elements) at an input voltage of no greater than 250 volts,
- d) have a rated storage volume not more than 120 gallons (450 liters), and
- e) are designed to transfer thermal energy from one temperature level to a higher temperature level to deliver water at a thermostatically controlled temperature less than or equal to 180°F (82°C).

2.5 Gas-fired instantaneous water heaters that:

- a) use gas as the main energy source,
- b) have a nameplate input rating less than 200,000 Btu/h (210 MJ/h),
- c) contain no more than one gallon of water per 4,000 Btu per hour of input, and
- d) are designed to provide outlet water at a controlled temperature less than or equal to 180°F (82°C).

2.6 Gas-fired storage water heaters that:

- a) use gas as the main energy source,
- b) have a nameplate input rating of 105,000 Btu/h (110 MJ/h) or less,
- c) have a rated storage capacity of 120 gallons (450 liters) or less,
- d) contain more than one gallon of water per 4,000 Btu per hour of input, and
- e) are designed to heat and store water at a thermostatically-controlled temperature less than

or equal to 180°F (82°C).

2.7 Oil-fired instantaneous water heaters that:

- a) use oil as the main energy source,
- b) have a nameplate input rating of 210,000 Btu/h (220 MJ/h) or less,
- c) contain no more than one gallon of water per 4,000 Btu per hour of input, and
- d) are designed to provide outlet water at a controlled temperature less than or equal to 180°F (82°C).

2.8 Oil-fired storage water heaters that:

- a) use oil as the main energy source,
- b) have a nameplate input rating of 140,000 Btu/h (148 MJ/h) or less,
- c) have a rated storage capacity of 120 gallons (450 liters) or less,
- d) contain more than one gallon of water per 4,000 Btu per hour of input, and
- e) are designed to heat and store water at a thermostatically-controlled temperature less than or equal to 180°F (82°C).

3. DEFINITIONS

cut-in: the time when or water temperature at which a water heater control or thermostat acts to increase the energy or fuel input to the heating elements, compressor, or burner.

cut-out: the time when or water temperature at which a water heater control or thermostat acts to reduce to a minimum the energy or fuel input to the heating elements, compressor, or burner.

design power rating: the nominal power rating that a water heater manufacturer assigns to a particular design of water heater, expressed in kilowatts or Btu (kJ) per hour as appropriate.

draw cluster: a collection of water draws initiated during the simulated-use test during which no successive draws are separated by more than 2 hours.

first-hour rating: the maximum volume of “hot” water that a storage-type water heater can supply within an hour that begins with the water heater fully heated (*i.e.*, with all thermostats satisfied). It is a function of both the storage volume and the recovery rate.

flow-activated: an operational scheme in which a water heater initiates and terminates heating based on sensing flow.

heat trap: a device that can be integrally connected or independently attached to the hot and/or cold water pipe connections of a water heater such that the device will develop a thermal or mechanical seal to minimize the recirculation of water due to thermal convection between the water heater tank and its connecting pipes.

maximum GPM (L/min) rating: the maximum gallons per minute (liters per minute) of hot water that can be supplied by an instantaneous water heater during steady-state operation, as determined by testing in accordance with Section 7.3.2.

rated storage volume: the water storage capacity of a water heater, in gallons (liters), as certified by the manufacturer.

recovery efficiency: the ratio of energy delivered to the water to the energy content of the fuel consumed by the water heater.

recovery period: the time when the heating elements, compressor, or burner of a storage water heater is raising the temperature of the stored water.

standby: the time, in hours, during which water is not being withdrawn from the water heater. There are two standby time intervals used within this test procedure: $\tau_{\text{stby},1}$ represents the elapsed time between the time at which the maximum mean tank temperature is observed after the first draw cluster and the minute prior to the start of the first draw following the end of the first draw cluster of the 24-hour simulated-use test; $\tau_{\text{stby},2}$ represents the total time during the 24-hour simulated-use test when water is not being withdrawn from the water heater.

temperature controller: a device that is available to the user to adjust the temperature of the water inside a storage-type water heater or the outlet water temperature.

uniform energy factor: the measure of water heater overall efficiency.

3.1 Symbol Usage. The following identity relationships are provided to help clarify the symbology used throughout this procedure:

C_p	specific heat of water
E_{annual}	annual energy consumption of a water heater
$E_{\text{annual},e}$	annual electrical energy consumption of a water heater
$E_{\text{annual},f}$	annual fossil-fuel energy consumption of a water heater
FHR _j	First Hour Rating threshold j, gal (L), see Annex A for U.S. values
FHR	First Hour Rating of a storage-type water heater
F_{max}	maximum GPM (L/min) rating of an instantaneous water

i	a subscript to indicate the draw number during a test
j	a subscript indicating the first hour rating threshold to determine which draw pattern is to be used in the simulated use test
MaxGPM _{j}	Flow rate threshold j , GPM (L/min), see annex A for U.S. values
M_i	mass of water removed during the i th draw of the 24-hour simulated-use test
M^*_i	for storage-type water heaters, mass of water removed during the i th draw during the first-hour rating test
M_{10m}	for instantaneous water heaters, mass of water removed continuously during a 10-minute interval in the maximum GPM (L/min) rating test
n	for storage-type water heaters, total number of draws during the first-hour rating test
N	total number of draws during the 24-hour simulated-use test
Q	total fossil fuel and/or electric energy consumed during the entire 24-hour simulated-use test
Q_{24^*}	total energy used by the water heater from the start of the 24-hour simulated-use test until the minute prior to the recovery that occurs between hour 23 and 24 when tank UA value is determined at end of test
Q_d	daily water heating energy consumption adjusted for net change in internal energy
Q_{da}	means Q_d with adjustment for variation of tank to ambient air temperature difference from nominal value
Q_{dm}	overall adjusted daily water heating energy consumption, including Q_{da} and Q_{HWD}
Q_e	total electrical energy used by the water heater during the 24-hour simulated-use test
Q_f	total fossil fuel energy used by the water heater during the 24-hour simulated-use test
Q_{hr}	hourly standby losses
Q_{HW}	daily energy consumption to heat water at the measured average temperature rise across the water heater

- $Q_{HW,nom}$ daily energy consumption to heat quantity of water removed during test over the specified temperature rise
- Q_{HWD} adjustment to daily energy consumption, Q_{HW} , due to variation of the temperature rise across the water heater not equal to the specified nominal value
- Q_r energy consumption of water heater from the beginning of the test to the end of the first recovery period following the first draw, which may extend beyond subsequent draws
- Q_{stby} total energy consumed by the water heater during the standby time interval $\tau_{stby,1}$
- $Q_{su,0}$ total fossil fuel and/or electric energy consumed from the beginning of the test to the end of the cutout following the first draw cluster
- $Q_{su,f}$ total fossil fuel and/or electric energy consumed from the beginning of the test to the initiation of the first draw following the first draw cluster
- $RH_{a,nom}$ the nominal relative humidity, %. See Annex A for U.S. value
- t_{24*} elapsed time from start of test until minute prior to the start of the recovery that occurs between hours 23 and 24 of the simulated-use test when determining UA at end of test, h.
- $T_{a,nom}$ the nominal ambient temperature, °F (°C). See Annex A for U.S. value
- \bar{T}_0 mean tank temperature at the beginning of the 24-hour simulated-use test
- \bar{T}_{24} mean tank temperature at the end of the 24-hour simulated-use test
- \bar{T}_{24*} mean tank temperature at the minute prior to a recovery that occurs during hours 23 to 24 of the 24-hour simulated-use test when UA value is determined at end of test
- $\bar{T}_{a,stby}$ average ambient air temperature during standby periods of the 24-hour simulated-use test
- \bar{T}_{del} for flow-activated water heaters, average outlet water temperature during a 10-minute continuous draw interval in the maximum GPM (L/min) rating test
- $\bar{T}_{del,nom}$ the nominal outlet water temperature, °F (°C). See Annex A for U.S. value
- $\bar{T}_{del,i}$ average outlet water temperature during the i th draw of the 24-hour simulated-use testing
- \bar{T}_{in} for flow-activated water heaters, average inlet water temperature during a 10-

	minute continuous draw interval in the maximum GPM (L/min) rating test
$\bar{T}_{in,nom}$	the nominal inlet temperature, °F (°C). See Annex A for U.S. value
$\bar{T}_{in,i}$	average inlet water temperature during the <i>i</i> th draw of the 24-hour simulated-use test
$\bar{T}_{max,1}$	maximum measured mean tank temperature after cut-out following the first draw of the 24-hour simulated-use test
$\bar{T}_{su,0}$	maximum measured mean tank temperature at the beginning of the standby period which occurs after cut-out following the final draw of the first draw cluster
$\bar{T}_{su,f}$	measured mean tank temperature at the end of the standby period which occurs at the minute prior to commencement of the first draw that follows the end of the first draw cluster
$\bar{T}_{del,i}^*$	for storage-type water heaters, average outlet water temperature during the <i>i</i> th draw (<i>i</i> = 1 to <i>n</i>) of the first-hour rating test
$T_{max,i}^*$	for storage-type water heaters, maximum outlet water temperature observed during the <i>i</i> th draw (<i>i</i> = 1 to <i>n</i>) of the first-hour rating test
$T_{min,i}^*$	for storage-type water heaters, minimum outlet water temperature to terminate the <i>i</i> th draw (<i>i</i> = 1 to <i>n</i>) of the first-hour rating test
UA	standby loss coefficient of a storage-type water heater
UEF	uniform energy factor of a water heater
V_i	volume of water removed during the <i>i</i> th draw (<i>i</i> = 1 to <i>N</i>) of the 24-hour simulated-use test
V_i^*	volume of water removed during the <i>i</i> th draw (<i>i</i> = 1 to <i>n</i>) of the first-hour rating test
V_{10m}	for flow-activated water heaters, volume of water removed continuously during a 10-minute interval in the maximum GPM (L/min) rating test
V_{st}	measured storage volume of the storage tank
W_f	weight of storage tank when completely filled with water
W_t	tare weight of storage tank when completely empty of water
η_r	recovery efficiency
ρ	density of water

- $\tau_{stby,1}$ elapsed time during the portion of the test during which the standby coefficient is determined as described in Section 7.4.2
- $\tau_{stby,2}$ overall time of standby periods when no water is withdrawn during the 24-hour simulated-use test

4. TEST CONDITIONS

4.1 Installation Requirements. Tests shall be performed with the water heater and instrumentation installed in accordance with Section 6 of this document.

4.2 Ambient Air Temperature. The ambient air temperature shall be maintained at the nominal ambient air temperature $\pm 2.5^{\circ}\text{F}$ ($\pm 1.4^{\circ}\text{C}$) on a continuous basis. For heat pump water heaters, the dry bulb temperature shall be maintained at the nominal ambient air temperature $\pm 1^{\circ}\text{F}$ ($\pm 0.6^{\circ}\text{C}$), and the relative humidity shall be maintained at the nominal relative humidity $\pm 2\%$ throughout the test.

4.3 Supply Water Temperature. The temperature of the water being supplied to the water heater shall be maintained at nominal inlet temperature $\pm 2^{\circ}\text{F}$ ($\pm 1.1^{\circ}\text{C}$) throughout the test.

4.4 Outlet Water Temperature. The temperature controllers of a storage-type water heater shall be set so that water is delivered at the nominal outlet temperature $\pm 5^{\circ}\text{F}$ ($\pm 2.8^{\circ}\text{C}$).

4.5 Set Point Temperature. The temperature controller of instantaneous water heaters shall be set to deliver water at the nominal outlet temperature $\pm 5^{\circ}\text{F}$ ($\pm 2.8^{\circ}\text{C}$).

4.6 Supply Water Pressure. During the test when water is not being withdrawn, the supply pressure shall be maintained between 40 psig (275 kPa) and the maximum allowable pressure specified by the water heater manufacturer.

4.7 Electrical and/or Fossil Fuel Supply

4.7.1 Electrical. Maintain the electrical supply voltage to within $\pm 1\%$ of the center of the voltage range specified by the water heater and/or heat pump manufacturer.

4.7.2 Natural Gas. Maintain the supply pressure in accordance with the manufacturer's specifications. If the supply pressure is not specified, maintain a supply pressure of 7-10 inches of water column (1.7-2.5 kPa). If the water heater is equipped with a gas appliance pressure regulator, the regulator outlet pressure shall be within $\pm 10\%$ of the manufacturer's specified manifold pressure. For all tests, use natural gas having a heating value of approximately 1,025 Btu per standard cubic foot (38,190 kJ per standard cubic meter).

4.7.3 Propane Gas. Maintain the supply pressure in accordance with the manufacturer's specifications. If the supply pressure is not specified, maintain a supply pressure of 11-13 inches of water column (2.7-3.2 kPa). If the water heater is equipped with a gas appliance pressure regulator, the regulator outlet pressure shall be within $\pm 10\%$ of the manufacturer's specified

manifold pressure. For all tests, use propane gas with a heating value of approximately 2,500 Btu per standard cubic foot (93,147 kJ per standard cubic meter).

4.7.4 Fuel Oil. Maintain an uninterrupted supply of fuel oil. Use fuel oil having a heating value of approximately 138,700 Btu per gallon (38,660 kJ per liter).

5. INSTRUMENTATION

5.1 Pressure Measurements.

5.1.1 Measurement. Pressure measurements shall be made in accordance with the Standard Methods for Pressure Measurement, ASHRAE 41.3-2014.

5.1.2 Instrument Accuracy and Precision Pressure-measuring instruments shall have an error no greater than the following values:

Item measured	Instrument accuracy	Instrument precision
Gas pressure	±0.1 inch of water column (±0.025 kPa)	±0.05 inch of water column (±0.012 kPa).
Atmospheric pressure	±0.1 inch of mercury column (±0.34 kPa)	±0.05 inch of mercury column (±0.17 kPa).
Water pressure	±1.0 pounds per square inch (±6.9 kPa)	±0.50 pounds per square inch (±3.45 kPa).

5.2 Temperature Measurement

5.2.1 Measurement. Temperature measurements shall be made in accordance with the Standard Method for Temperature Measurement, ASHRAE 41.1-2013.

5.2.2 Accuracy and Precision. The accuracy and precision of the instruments, including their associated readout devices, shall be within the following limits:

Item measured	Instrument accuracy	Instrument precision
Air dry bulb temperature	±0.2°F (±0.1°C)	±0.1°F (±0.06°C).
Air wet bulb temperature	±0.2°F (±0.1°C)	±0.1°F (±0.06°C).
Inlet and outlet water temperatures	±0.2°F (±0.1°C)	±0.1°F (±0.06°C).
Storage tank temperatures	±0.5°F (±0.3°C)	±0.25°F (±0.14°C).

5.2.3 Scale Division. In no case shall the smallest scale division of the instrument or instrument system exceed 2 times the specified precision.

5.2.6 Time Constant. The time constant of the instruments used to measure the inlet and outlet water temperatures shall be no greater than 2 seconds.

5.3 Liquid Flow Rate Measurement.

5.3.1 Measurement. Liquid flow measurements shall be made in accordance with Standard Methods for Liquid Flow Rate Measurement, ASHRAE Standard 41.8-2016.

5.3.2 Accuracy. The accuracy of the liquid flow rate measurement, using the calibration if furnished, shall be equal to or less than $\pm 1\%$ of the measured value in mass units per unit time.

5.4 Electrical Energy.

5.4.1 Measurement. Electrical energy measurements shall be made in accordance with the ASHRAE Standard 41.11-2014 – Standard Methods for Power Measurement

5.4.2 Accuracy and Precision. The electrical energy used shall be measured with an instrument and associated readout device that is accurate within $\pm 0.5\%$ of the reading. Any current less than 0.1 amps the accuracy of the reading shall be within $\pm 2\%$.

5.5 Fossil Fuels. The quantity of fuel used by the water heater shall be measured with an instrument and associated readout device that is accurate within $\pm 1\%$ of the reading.

5.6 Mass Measurements. For mass measurements greater than or equal to 10 pounds (4.5 kg), a scale that is accurate within $\pm 0.5\%$ of the reading shall be used to make the measurement. For mass measurements less than 10 pounds (4.5 kg), the scale shall provide a measurement that is accurate within ± 0.1 pound (0.045 kg).

5.7 Heating Value. The higher heating value of the natural gas, propane, or fuel oil shall be measured with an instrument and associated readout device that is accurate within $\pm 1\%$ of the reading. The heating values of natural gas and propane must be corrected from those reported at standard temperature and pressure conditions to provide the heating value at the temperature and pressure measured at the fuel meter.

5.8 Time. The elapsed time measurements shall be measured with an instrument that is accurate within ± 0.5 seconds per hour.

5.9 Volume. Volume measurements shall be measured with an accuracy of $\pm 2\%$ of the total volume.

5.10 Relative Humidity.

5.10.1 Measurement. Relative humidity measurements shall be made in accordance with the Standards Methods for Humidity Measurement, ASHRAE 41.6-2014.

5.10.2 The relative humidity shall be measured with an accuracy of $\pm 1.5\%$ RH.

6. INSTALLATION

6.1 Water Heater Mounting. A water heater designed to be freestanding shall be placed on a $3/4$

inch (2 cm) thick plywood platform supported by three 2 × 4 inch (5 cm × 10 cm) runners. If the water heater is not approved for installation on combustible flooring, suitable non-combustible material shall be placed between the water heater and the platform. Counter-top water heaters shall be placed against a simulated wall section. Wall-mounted water heaters shall be supported on a simulated wall in accordance with the manufacturer-published installation instructions. When a simulated wall is used, the construction shall be 2 × 4 inch (5 cm × 10 cm) studs, faced with 3/4 inch (2 cm) plywood. For heat pump water heaters not delivered as a single package, the units shall be connected in accordance with the manufacturer-published installation instructions, and the overall system shall be placed on the above-described plywood platform. If installation instructions are not provided by the heat pump manufacturer, uninsulated 8 foot (2.4 m) long connecting hoses having an inside diameter of 5/8 inch (1.6 cm) shall be used to connect the storage tank and the heat pump water heater. The testing of the water heater shall occur in an area that is protected from drafts of more than 50 ft/min (0.25 m/s) from room ventilation registers, windows, or other external sources of air movement.

6.2 Water Supply. Connect the water heater to a water supply capable of delivering water at conditions as specified in Sections 4.3 and 4.6 and at flow rates specified in Section 7.5.

6.3 Water Inlet and Outlet Configuration. For freestanding water heaters that are taller than 36 inches (91.4 cm), inlet and outlet piping connections shall be configured in a manner consistent with Figures 1 and 2. Inlet and outlet piping connections for wall-mounted water heaters shall be consistent with Figure 3. For freestanding water heaters that are 36 inches or less in height and not supplied as part of a counter-top enclosure (commonly referred to as an under-the-counter model), inlet and outlet piping shall be installed in a manner consistent with Figures 4, 5, or 6. For water heaters that are supplied with a counter-top enclosure, inlet and outlet piping shall be made in a manner consistent with Figures 7a and 7b, respectively. The vertical piping noted in Figures 7a and 7b shall be located (whether inside the enclosure or along the outside in a recessed channel) in accordance with the manufacturer-published installation instructions.

All dimensions noted in Figures 1 through 7 must be achieved. All piping between the water heater and inlet and outlet water temperature sensors, noted as T-in and T-out in the figures, shall be Type “L” hard copper having the same diameter as the connections on the water heater. Install a pressure gauge and diaphragm expansion tank in the supply water piping at a location upstream of the inlet temperature sensor. Install an appropriately rated pressure and temperature relief valve on all water heaters at the port specified by the manufacturer. Discharge piping for the relief valve must be non-metallic. If heat traps, piping insulation, or pressure relief valve insulation are supplied with the water heater, they must be installed for testing. Except when using a simulated wall, provide sufficient clearance such that none of the piping contacts other surfaces in the test room.

6.4 Fuel and/or Electrical Power and Energy Consumption. Install one or more instruments that measure, as appropriate, the quantity and rate of electrical energy and/or fossil fuel consumption in accordance with Section 5.

6.5 Internal Storage Tank Temperature Measurements. For water heaters with rated storage volumes greater than or equal to 20 gallons, install six temperature measurement sensors inside the water heater tank with a vertical distance of at least 4 inches (100 mm) between successive

sensors. For water heaters with rated storage volumes between 2 and 20 gallons, install three temperature measurement sensors inside the water heater tank. Position a temperature sensor at the vertical midpoint of each of the six equal volume nodes within a tank larger than 20 gallons or the three equal volume nodes within a tank between 2 and 20 gallons. Nodes designate the equal volumes used to evenly partition the total volume of the tank. As much as is possible, the temperature sensor shall be positioned away from any heating elements, anodic protective devices, tank walls, and flue pipe walls. If the tank cannot accommodate six temperature sensors and meet the installation requirements specified above, install the maximum number of sensors that comply with the installation requirements. Install the temperature sensors through: (1) The anodic device opening; (2) the hot water outlet; and (3) the relief valve opening. If installed through the hot water outlet or the relief valve opening, a tee fitting or outlet piping, as applicable, must be installed as close as possible to its original location. If the relief valve temperature sensor is relocated, and it no longer extends into the top of the tank, install a substitute relief valve that has a sensing element that can reach into the tank. If the hot water outlet includes a heat trap, install the heat trap on top of the tee fitting. Cover any added fittings with thermal insulation having an R value at a minimum of $8 \text{ h} \cdot \text{ft}^2 \cdot ^\circ\text{F}/\text{Btu}$ ($1.4 \text{ m}^2 \cdot ^\circ\text{C}/\text{W}$).

6.6 Ambient Air Temperature Measurement. Install an ambient air temperature sensor at the vertical mid-point of the water heater and approximately 2 feet (610 mm) from the surface of the water heater. Shield the sensor against radiation.

6.7 Inlet and Outlet Water Temperature Measurements. Install temperature sensors in the cold-water inlet pipe and hot-water outlet pipe as shown in Figures 1, 2, 3, 4, 5, 6, 7a, and 7b, as applicable.

6.8 Flow Control. Install a valve or valves to provide flow as specified in Sections 7.3 and 7.4.

6.9 Flue Requirements

6.9.1 Gas-Fired Water Heaters. Establish a natural draft in the following manner. For gas-fired water heaters with a vertically discharging draft hood outlet, connect to the draft hood outlet a 5-foot (1.5-meter) vertical vent pipe extension with a diameter equal to the largest flue collar size of the draft hood. For gas-fired water heaters with a horizontally discharging draft hood outlet, connect to the draft hood outlet a 90-degree elbow with a diameter equal to the largest flue collar size of the draft hood, connect a 5-foot (1.5-meter) length of vent pipe to that elbow, and orient the vent pipe to discharge vertically upward.

Install direct-vent or power vent gas-fired water heaters with venting equipment specified in the manufacturer's instructions using the minimum horizontal lengths of vent pipe recommended by the manufacturer. If no minimum horizontal is specified, then use minimum vertical as specified by manufacturer.

6.9.2 Oil-Fired Water Heaters. Establish a draft at the flue collar at the value specified in the manufacturer's instructions. Establish the draft by using a sufficient length of vent pipe connected to the water heater flue outlet and directed vertically upward. For an oil-fired water heater with a horizontally discharging draft hood outlet, connect to the draft hood outlet a 90-degree elbow with

a diameter equal to the largest flue collar size of the draft hood, connect to the elbow fitting a length of vent pipe sufficient to establish the draft, and orient the vent pipe to discharge vertically upward. Direct-vent oil-fired water heaters shall be installed with venting equipment as specified in the manufacturer's instructions, using the minimum vertical and horizontal lengths of vent pipe recommended by the manufacturer.

Figure 1.

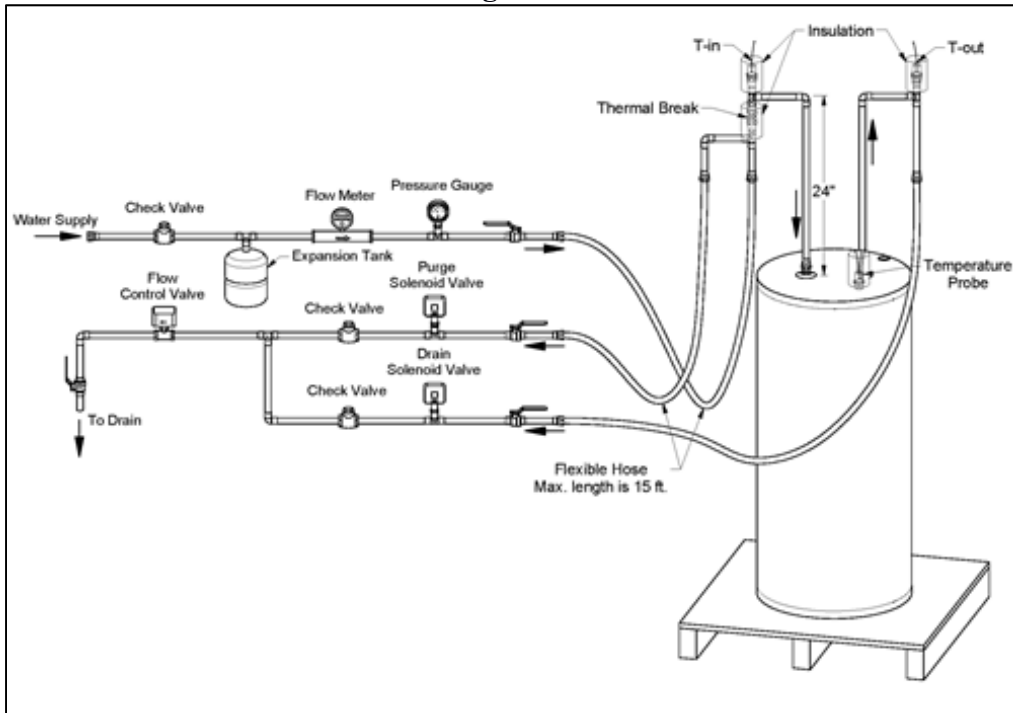


Figure 2A.

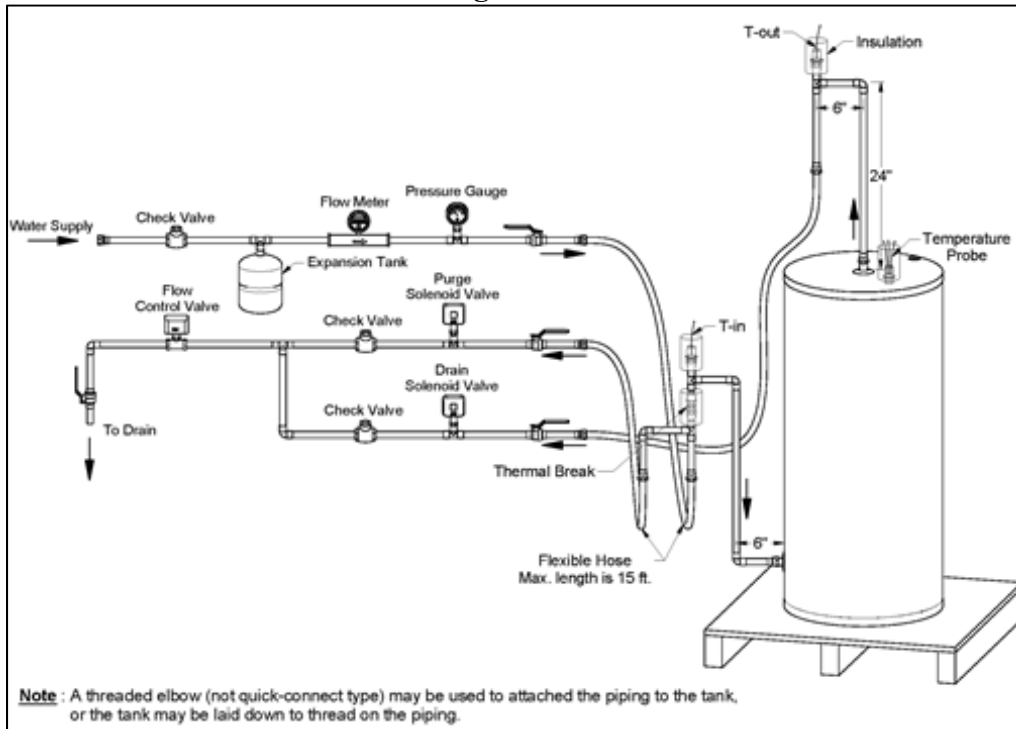


Figure 2B.

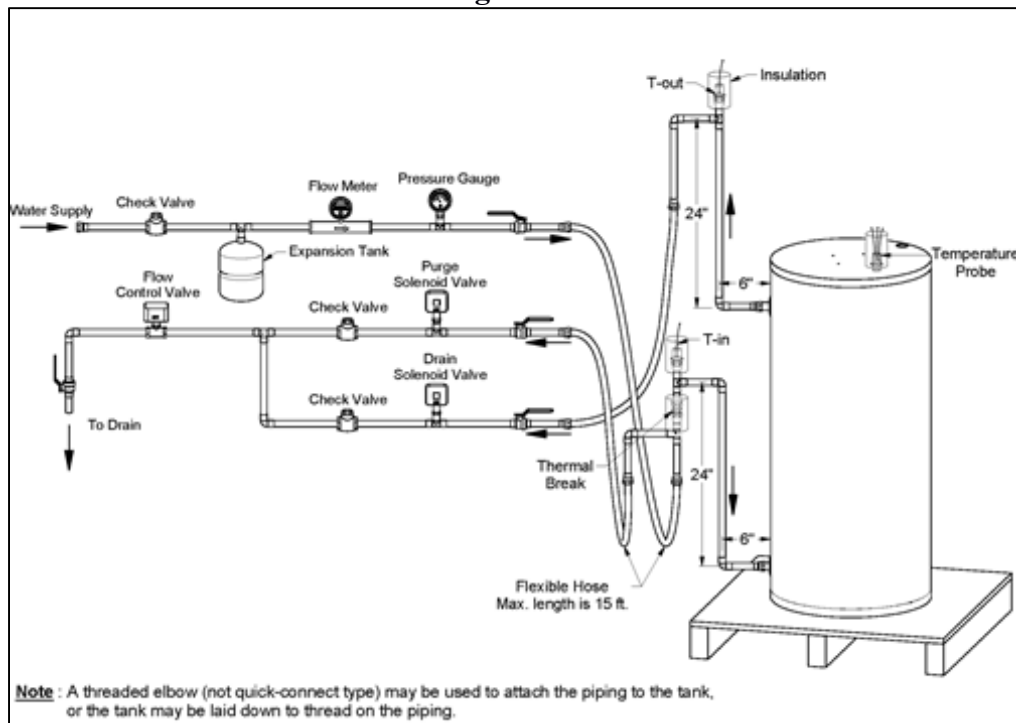


Figure 3.

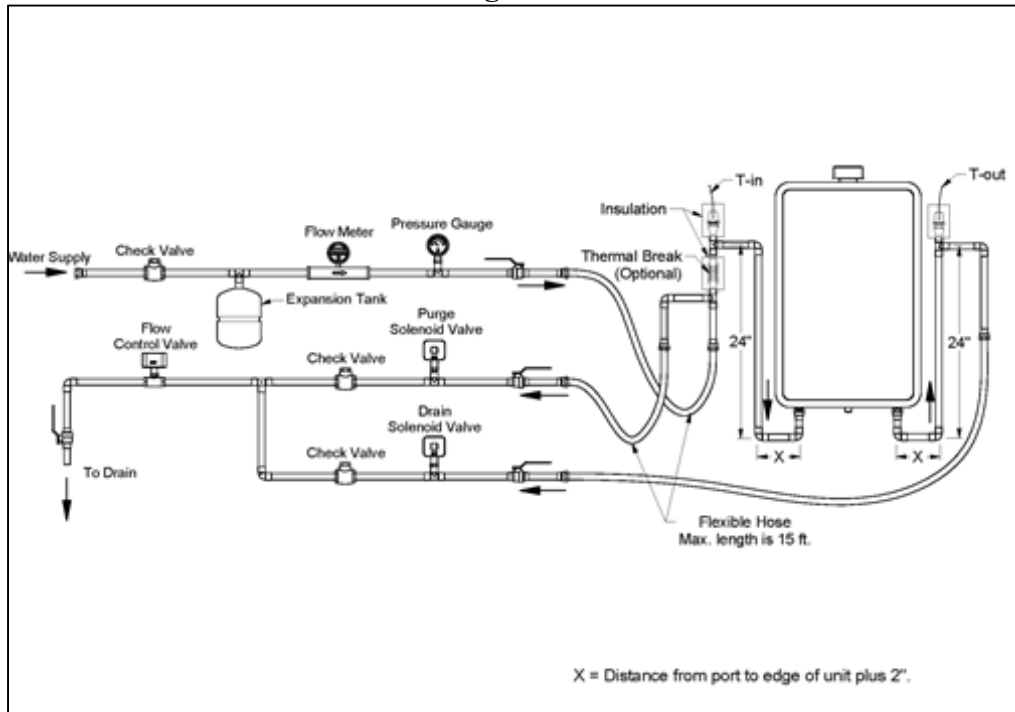


Figure 4.

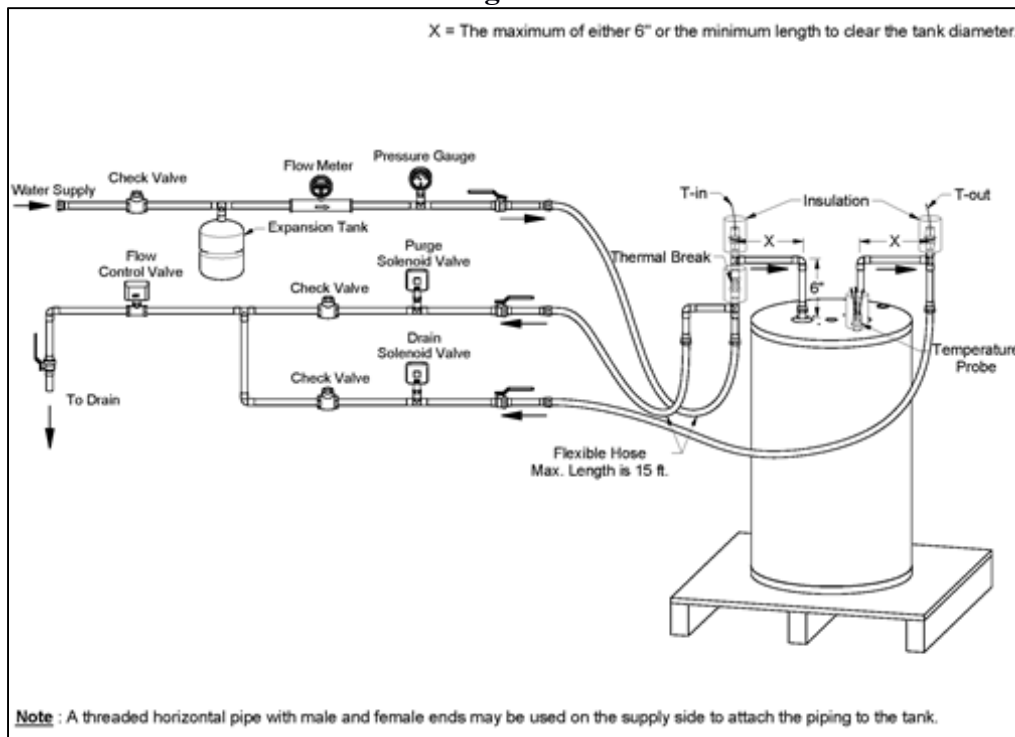


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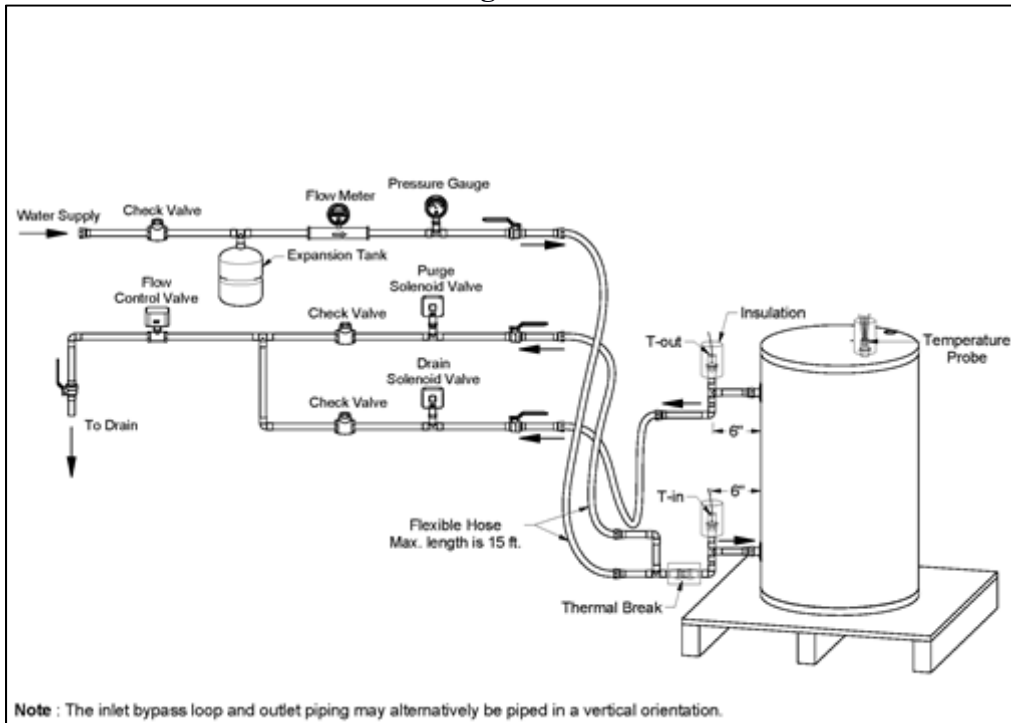


Figure 6.

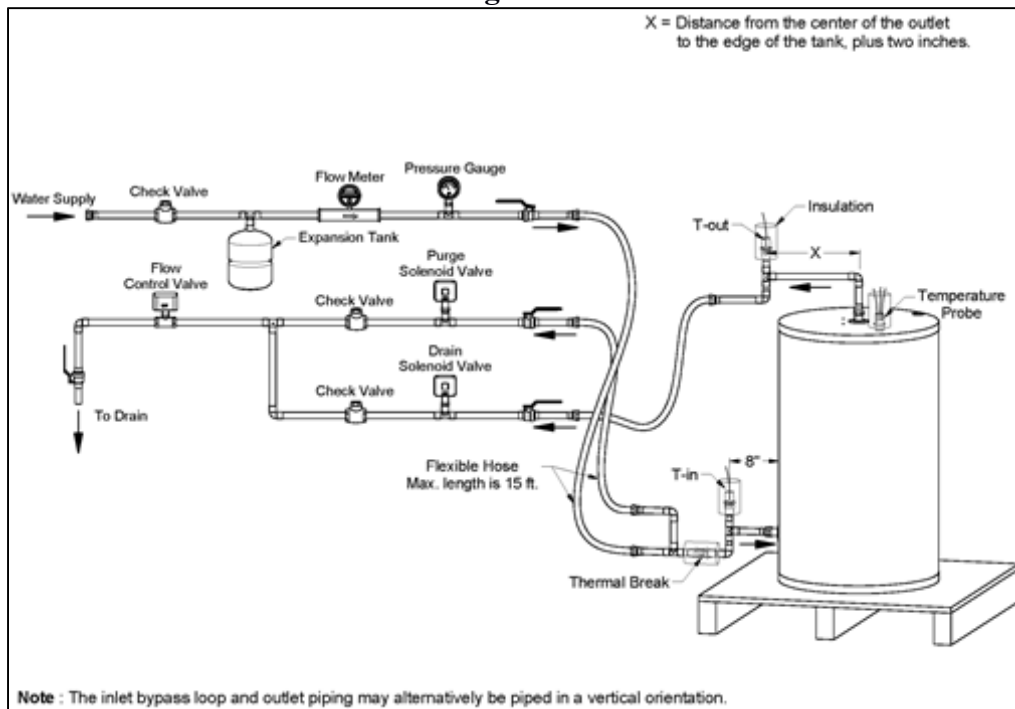


Figure 7A.

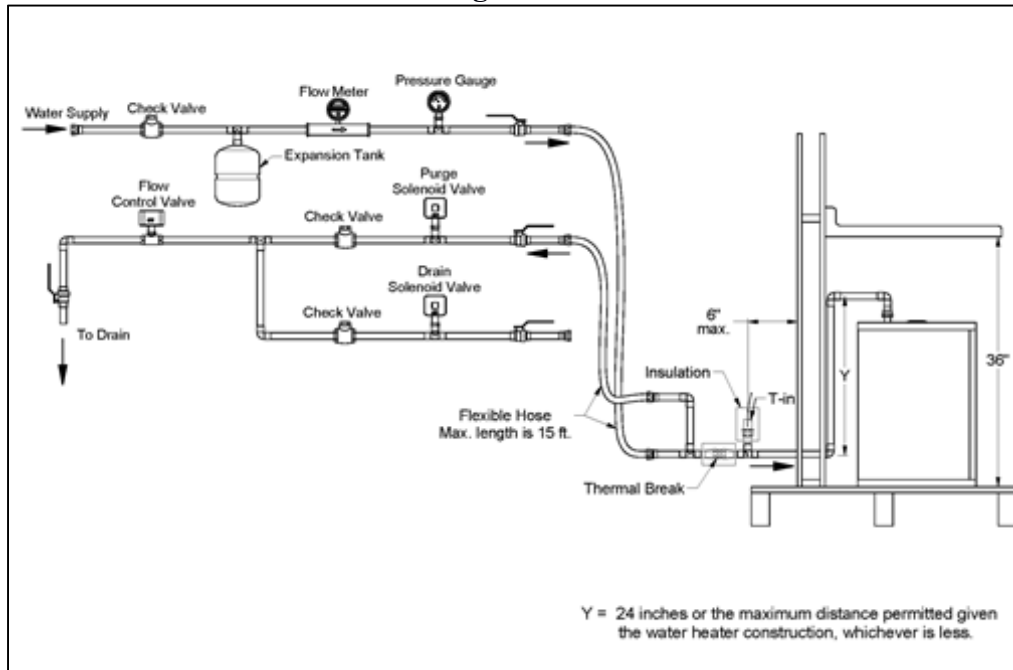


Figure 7B.

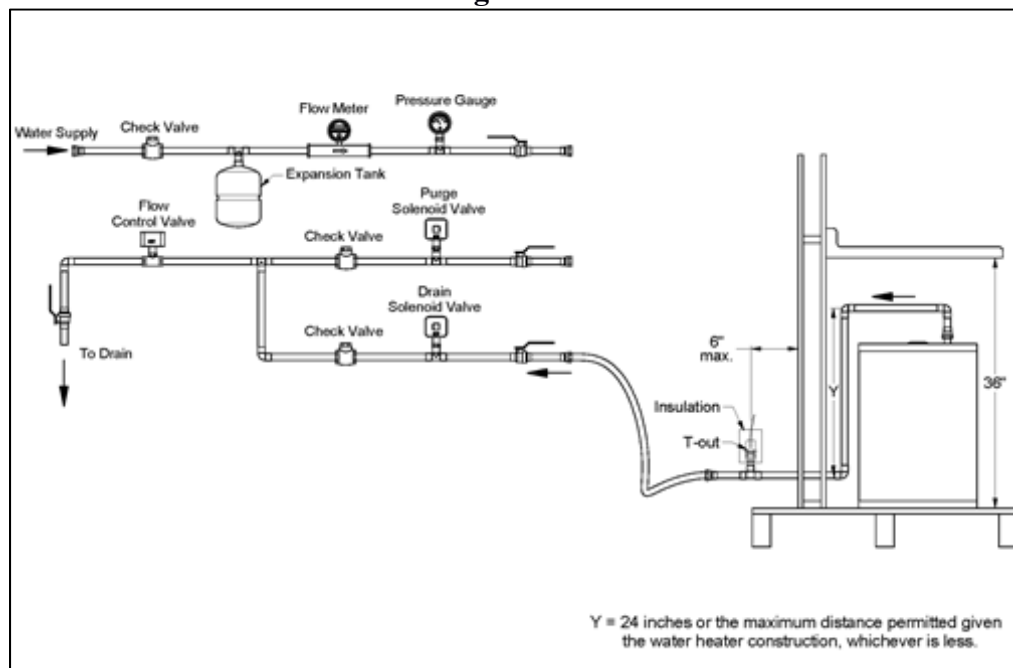


Figure 8.

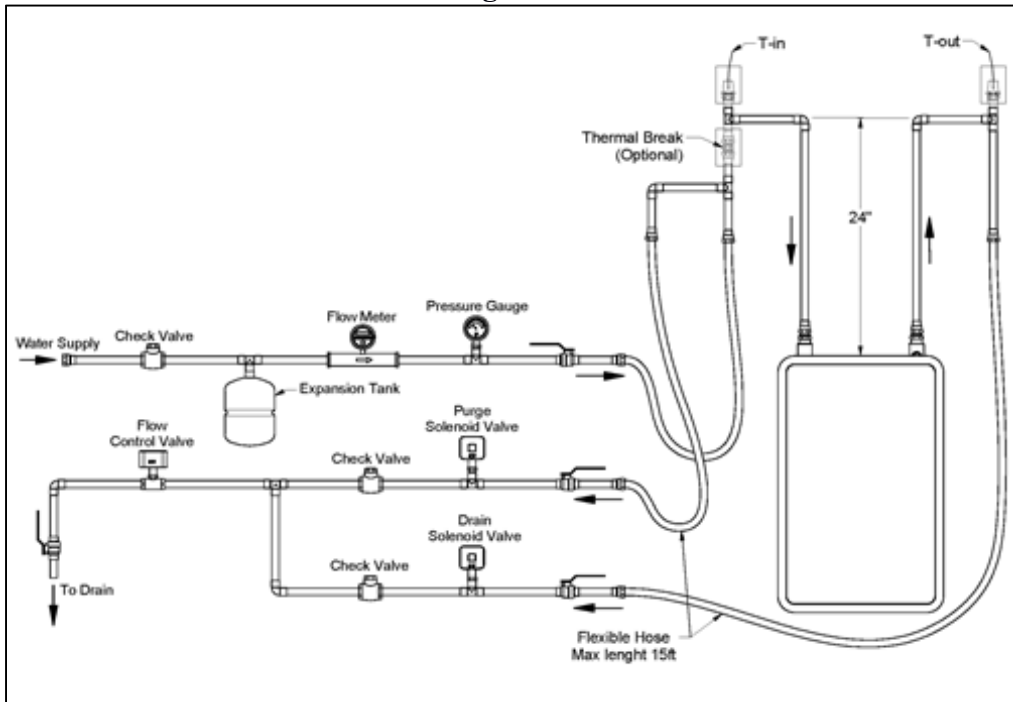


Figure 9.

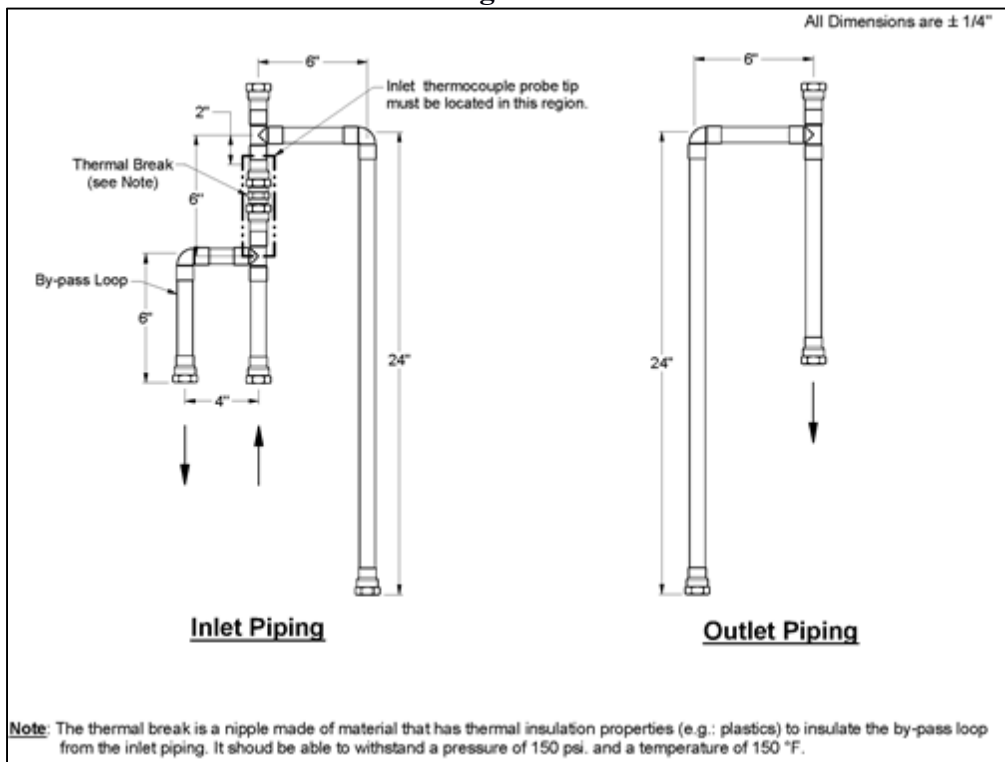


Figure 10.

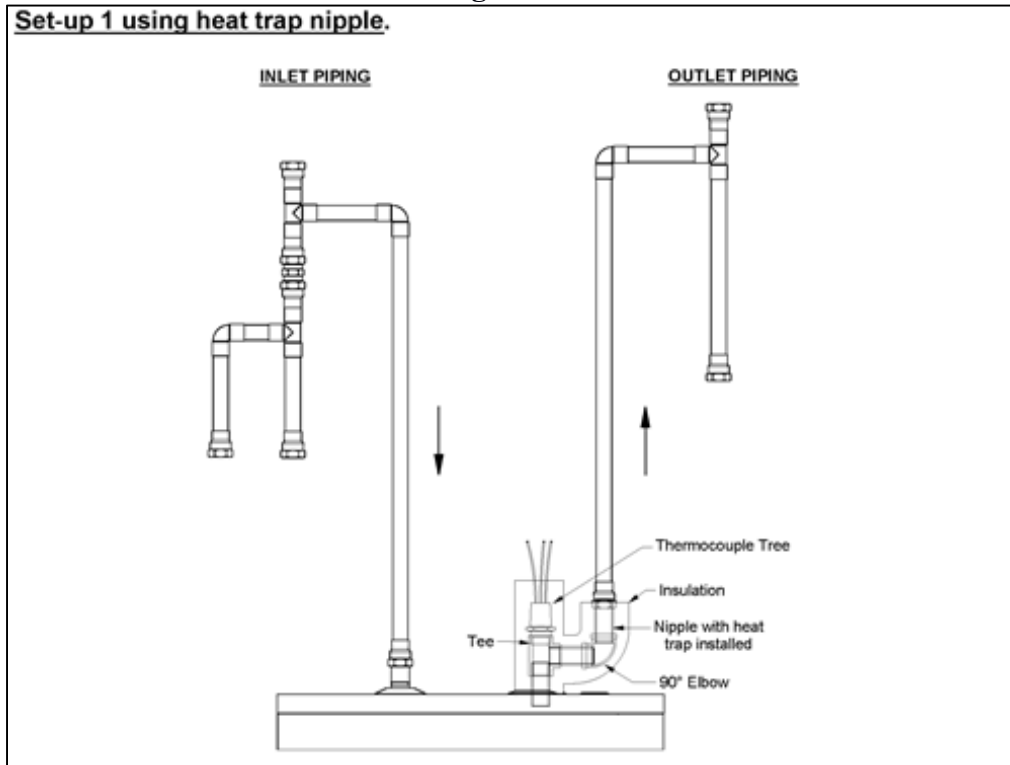
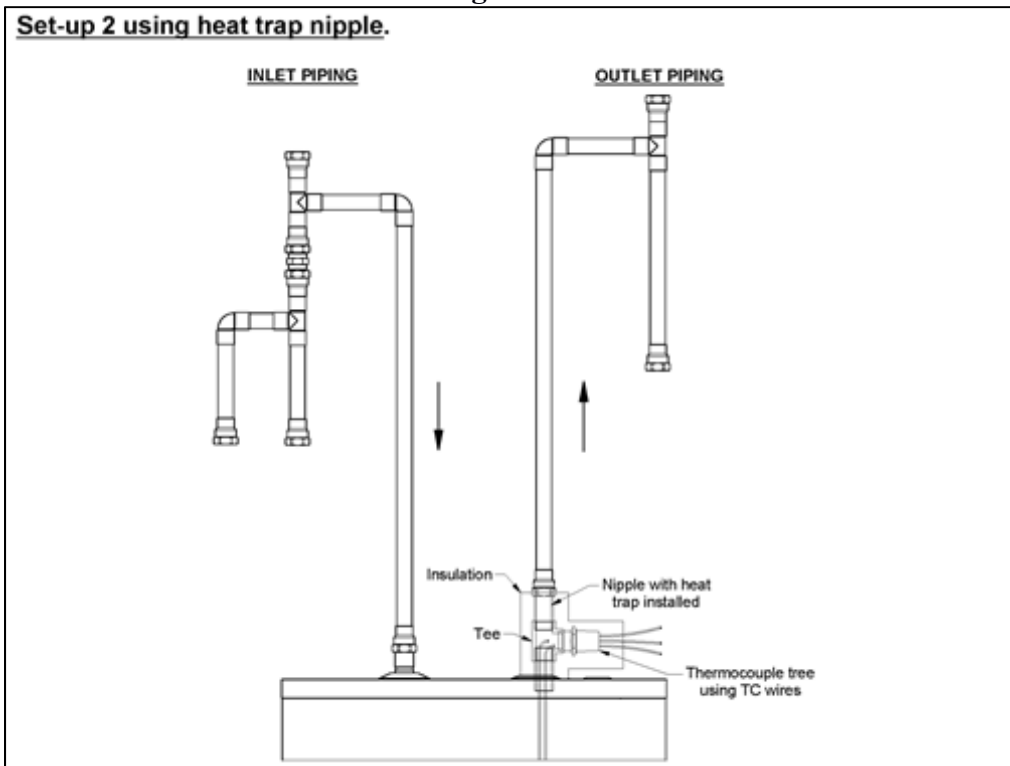


Figure 11.



7. TEST PROCEDURES

7.1 Operational Mode Selection. For water heaters that allow for multiple user-selected operational modes, all procedures specified in this test method shall be carried out with the water heater in the same operational mode (*i.e.*, only one mode). This operational mode shall be the default mode (or similarly-named, suggested mode for normal operation) as defined by the manufacturer in its product literature for giving selection guidance to the consumer. For heat pump water heaters, if a default mode is not defined in the product literature, each test shall be conducted under an operational mode in which both the heat pump and any electric resistance backup heating element(s) are activated by the unit's control scheme, and which can achieve the internal storage tank temperature specified in this test procedure; if multiple operational modes meet these criteria, the water heater shall be tested under the most energy-intensive mode. If no default mode is specified and the unit does not offer an operational mode that utilizes both the heat pump and the electric resistance backup heating element(s), the first-hour rating test and the simulated-use test shall be tested in heat-pump-only mode. For other types of water heaters where a default mode is not specified, test the unit in all modes and rate the unit using the results of the most energy-intensive mode.

7.2 Water Heater Preparation

7.2.1 Determination of Storage Tank Volume. For water heaters with a rated storage volume greater than or equal to 2 gallons, determine the storage capacity, V_{st} , of the water heater under test, in gallons (liters), by subtracting the tare weight—measured while the tank is empty—from the gross weight of the storage tank when completely filled with water (with all air eliminated and line pressure applied as described in Section 4.6 of this test method) and dividing the resulting net weight by the density of water at the measured temperature.

7.2.2 Setting the Outlet Water Temperature

7.2.2.1 Flow-Activated Water Heaters, including certain instantaneous water heaters and certain storage-type water heaters. Initiate normal operation of the water heater at the full input rating for electric water heaters and at the maximum firing rate specified by the manufacturer for gas or oil water heaters. Monitor the outlet water temperature and set to the nominal outlet temperature $\pm 5^{\circ}\text{F}$ ($\pm 2.8^{\circ}\text{C}$) in accordance with the manufacturer's instructions. If the water heater is not capable of providing this outlet water temperature when the flow rate is 1.7 gallons ± 0.25 gallons per minute (6.4 liters ± 0.95 liters per minute), then adjust the flow rate as necessary to achieve the specified outlet water temperature. Once the proper temperature control setting is achieved, the temperature setting must remain fixed for the duration of the maximum GPM test and the simulated-use test.

7.2.2.2 Storage-Type Water Heaters that Are Not Flow-Activated.

7.2.2.2.1 Tanks with a Single Temperature Controller.

7.2.2.2.1.1 Water Heaters with Rated Volumes Less than 20 Gallons. Starting with a tank at the supply water temperature, initiate normal operation of the water heater. After cut-out, initiate

a draw from the water heater at a flow rate of 1.0 gallon \pm 0.25 gallons per minute (3.8 liters \pm 0.95 liters per minute) for 2 minutes. Starting 15 seconds after commencement of draw, record the outlet water temperature at 15-second intervals until the end of the 2-minute period. Determine whether the maximum outlet temperature is at the nominal outlet temperature \pm 5°F (\pm 2.8°C). If not, turn off the water heater, adjust the temperature controller, and then drain and refill the tank with supply water. Then, once again, initiate normal operation of the water heater and repeat the 2-minute outlet temperature test following cut-out. Repeat this sequence until the maximum outlet temperature during the 2-minute test is at the nominal outlet temperature \pm 5°F (\pm 2.8°C). Once the proper temperature control setting is achieved, the setting must remain fixed for the duration of the first-hour rating test and the simulated-use test such that a second identical simulated-use test run immediately following the one specified in Section 7.4 would result in average delivered water temperatures that are within the bounds specified in Section 4.4 of this test method.

7.2.2.2.1.2 Water Heaters with Rated Volumes Greater than or Equal to 20 Gallons. Starting with a tank at the supply water temperature, initiate normal operation of the water heater. After cut-out, initiate a draw from the water heater at a flow rate of 1.7 gallons \pm 0.25 gallons per minute (6.4 liters \pm 0.95 liters per minute) for 5 minutes. Starting 15 seconds after commencement of draw, record the outlet temperature at 15-second intervals until the end of the 5-minute period. Determine whether the maximum outlet temperature is at the nominal outlet temperature \pm 5°F (\pm 2.8°C). If not, turn off the water heater, adjust the temperature controller, and then drain and refill the tank with supply water. Then, once again, initiate normal operation of the water heater and repeat the 5-minute outlet temperature test following cut-out. Repeat this sequence until the maximum outlet temperature during the 5-minute test is at the nominal outlet temperature \pm 5°F (\pm 2.8°C). Once the proper temperature control setting is achieved, the setting must remain fixed for the duration of the first-hour rating test and the simulated-use test such that a second identical simulated-use test run immediately following the one specified in Section 7.4 would result in average delivered water temperatures that are within the bounds specified in Section 4.4 of this test method.

7.2.2.2.2 Tanks with Two or More Temperature Controllers. Verify the temperature controller set-point while removing water in accordance with the procedure set forth for the first-hour rating test in Section 7.3.3 of this test method. The following criteria must be met to ensure that all temperature controllers are set to deliver water at the nominal outlet temperature \pm 5°F (\pm 2.8°C):

- a) At least 50 percent of the water drawn during the first draw of the first-hour rating test procedure shall be delivered at the nominal outlet temperature \pm 5°F (\pm 2.8°C).
- b) No water is delivered above the nominal outlet temperature +5°F (2.8°C) during first-hour rating test.
- c) The outlet temperature measured 15 seconds after commencement of each draw begun prior to an elapsed time of 60 minutes from the start of the test shall be at the nominal outlet temperature \pm 5°F (\pm 2.8°C).

If these conditions are not met, turn off the water heater, adjust the temperature controllers, and then drain and refill the tank with supply water. Repeat the procedure described at the start of Section 7.2.2.2.2 until the criteria for setting the temperature controllers is met.

If the conditions stated above are met, the data obtained during the process of verifying the temperature control set-points may be used in determining the first-hour rating provided that all other conditions and methods required in Sections 4 and 7.2.4 in preparing the water heater were followed.

7.2.3 Adjust Power Input. For all water heaters except electric types, initiate normal operation (as described in Section 7.1) and determine the power input, P, to the main burners (including pilot light power, if any) after 15 minutes of operation. If the water heater is equipped with a gas appliance pressure regulator, the regulator outlet pressure shall be set within $\pm 10\%$ of that recommended by the manufacturer. For oil-fired water heaters, the fuel pump pressure shall be within $\pm 10\%$ of the manufacturer's specified pump pressure. Adjust all burners to achieve an hourly Btu (kJ) rating that is within $\pm 2\%$ of the value specified by the manufacturer. For an oil-fired water heater, adjust the burner to give a CO₂ reading recommended by the manufacturer and an hourly Btu (kJ) rating that is within $\pm 2\%$ of that specified by the manufacturer. Smoke in the flue may not exceed No. 1 smoke as measured by the procedure in ASTM D2156.

7.2.4 Soak-In Period for Water Heaters with Rated Storage Volumes Greater than or Equal to 2 Gallons. For storage-type water heaters and instantaneous water heaters having greater than 2 gallons (7.6 liters) of storage (including heat pump water heaters having greater than 2 gallons of storage), the water heater must sit filled with water and without any draws taking place for at least 12 hours after first cut-out so as to achieve the nominal temperature set-point within the tank and with the unit connected to a power source.

7.3 Delivery Capacity Tests.

7.3.1 General. For flow-activated water heaters, conduct the maximum GPM test, as described in Section 7.3.2, Maximum GPM Rating Test for Flow-Activated Water Heaters. For all other water heaters, conduct the first-hour rating test as described in Section 7.3.3.

7.3.2 Maximum GPM Rating Test for Flow-Activated Water Heaters. Establish normal water heater operation at the full input rate for electric water heaters and at the maximum firing rate for gas or oil water heaters with the outlet water temperature set in accordance with Section 7.2.2.1. For this 10-minute test, either collect the withdrawn water for later measurement of the total mass removed or use a water meter to directly measure the water volume removed. Initiate water flow through the water heater and record the inlet and outlet water temperatures beginning 15 seconds after the start of the test and at subsequent 5-second intervals throughout the duration of the test. At the end of 10 minutes, turn off the water. Determine and record the mass of water collected, M_{10m} , in pounds (kilograms), or the volume of water, V_{10m} , in gallons (liters).

7.3.3 First-Hour Rating Test

7.3.3.1 General. During hot water draws for water heaters with rated storage volumes greater than or equal to 20 gallons, remove water at a rate of 3.0 ± 0.25 gallons per minute (11.4 ± 0.95 liters per minute). During hot water draws for storage-type water heaters with rated storage volumes below 20 gallons, remove water at a rate of 1.0 ± 0.25 gallon per minute (3.8 ± 0.95 liters per minute). Collect the water in a container that is large enough to hold the volume removed during

an individual draw and is suitable for weighing at the termination of each draw to determine the total volume of water withdrawn. As an alternative to collecting the water, a water meter may be used to directly measure the water volume(s) withdrawn.

7.3.3.2 Draw Initiation Criteria. Begin the first-hour rating test by starting a draw on the storage-type water heater. After completion of this first draw, initiate successive draws based on the following criteria. For gas-fired and oil-fired water heaters, initiate successive draws when the temperature controller acts to reduce the supply of fuel to the main burner. For electric water heaters having a single element or multiple elements that all operate simultaneously, initiate successive draws when the temperature controller acts to reduce the electrical input supplied to the element(s). For electric water heaters having two or more elements that do not operate simultaneously, initiate successive draws when the applicable temperature controller acts to reduce the electrical input to the energized element located vertically highest in the storage tank. For heat pump water heaters that do not use supplemental, resistive heating, initiate successive draws immediately after the electrical input to the compressor is reduced by the action of the water heater's temperature controller. For heat pump water heaters that use supplemental resistive heating, initiate successive draws immediately after the electrical input to the first of either the compressor or the vertically highest resistive element is reduced by the action of the applicable water heater temperature controller. This draw initiation criterion for heat pump water heaters that use supplemental resistive heating, however, shall only apply when the water located above the thermostat at cut-out is heated to nominal outlet temperature $\pm 5^{\circ}\text{F}$ ($\pm 2.8^{\circ}\text{C}$) as indicated by the upper most internal storage tank temperature sensor. If this criterion is not met, then the next draw shall be initiated once the heat pump compressor cuts out.

7.3.3.3 Test Sequence. Establish normal water heater operation, if necessary. If the water heater is not presently heating, initiate a draw. The draw shall be terminated when the outlet temperature drops 15°F below the maximum recorded outlet temperature or when cut-in occurs, whichever is longer. If the water heater is heating, wait for the maximum mean tank temperature after cut-out, then initiate a draw. Terminate the draw when the outlet temperature drops 15°F below the maximum recorded outlet temperature or when cut-in occurs, whichever is longer. After cut-out occurs (i.e., all temperature controllers are satisfied), record the internal storage tank temperature at each sensor described in Section 6.5 every one minute, and determine the mean tank temperature by averaging the values from these sensors. Initiate a draw after a maximum mean tank temperature (the maximum of the mean temperatures of the individual sensors) has been observed following a cut-out. Record the time when the draw is initiated and designate it as an elapsed time of zero ($\tau^* = 0$). (The superscript * is used to denote variables pertaining to the first-hour rating test). Record the outlet and inlet water temperature beginning 15 seconds after the draw is initiated and at 5-second intervals thereafter until the draw is terminated. Determine the maximum outlet temperature that occurs during this first draw and record it as $T_{\text{max},1}^*$. For the duration of this first draw and all successive draws, in addition, monitor the inlet temperature to the water heater to ensure that the required nominal inlet temperature $\pm 2^{\circ}\text{F}$ ($\pm 1.1^{\circ}\text{C}$) test condition is met. Terminate the hot water draw when the outlet temperature decreases to $T_{\text{max},1}^* - (T_{\text{del,nom}} - 110)^{\circ}\text{F}$ [$T_{\text{max},1}^* - (T_{\text{del,nom}} - 43.3)^{\circ}\text{C}$]. (Note, if the outlet temperature does not decrease to $T_{\text{max},1}^* - (T_{\text{del,nom}} - 110)^{\circ}\text{F}$ [$T_{\text{max},1}^* - (T_{\text{del,nom}} - 43.3)^{\circ}\text{C}$] during the draw, then hot water would be drawn continuously for the duration of the test. In this instance, the test would end when the temperature decreases to $T_{\text{max},1}^* - (T_{\text{del,nom}} - 110)^{\circ}\text{F}$ [$T_{\text{max},1}^* - (T_{\text{del,nom}} - 43.3)^{\circ}\text{C}$] after the electrical power

and/or fuel supplied to the water heater is shut off, as described in the following paragraphs.) Record this temperature as $T^*_{\min,1}$. Following draw termination, determine the average outlet water temperature and the mass or volume removed during this first draw and record them as $T^*_{\text{del},i}$ and M^*_1 or V^*_1 , respectively.

Initiate a second and, if applicable, successive draw(s) each time the applicable draw initiation criteria described in Section 7.3.3.2 are satisfied. As required for the first draw, record the outlet water temperature 15 seconds after initiating each draw and at 5-second intervals thereafter until the draw is terminated. Determine the maximum outlet temperature that occurs during each draw and record it as $T^*_{\max,i}$, where the subscript i refers to the draw number. Terminate each hot water draw when the outlet temperature decreases to $T^*_{\max,i} - (T_{\text{del,nom}} - 110) \text{ }^\circ\text{F}$ [$T^*_{\max,i} - (T_{\text{del,nom}} - 43.3) \text{ }^\circ\text{C}$] or 105°F (40.6°C), whichever is higher. Record this temperature as $T^*_{\min,i}$. Calculate and record the average outlet temperature and the mass or volume removed during each draw ($T^*_{\text{del},i}$ and M^*_i or V^*_i , respectively). Continue this sequence of draw and recovery until one hour after the start of the test, then shut off the electrical power and/or fuel supplied to the water heater.

If a draw is occurring at one hour from the start of the test, continue this draw until the outlet temperature decreases to $T^*_{\max,n} - (T_{\text{del,nom}} - 110) \text{ }^\circ\text{F}$ [$T^*_{\max,n} - (T_{\text{del,nom}} - 43.3) \text{ }^\circ\text{C}$], at which time the draw shall be immediately terminated. (The subscript n shall be used to denote measurements associated with the final draw.) If a draw is not occurring one hour after the start of the test, initiate a final draw at one hour, regardless of whether the criteria described in Section 7.3.3.2 are satisfied. This draw shall proceed for a minimum of 30 seconds and shall terminate when the outlet temperature first indicates a value less than or equal to the cut-off temperature used for the previous draw ($T^*_{\min,n-1}$) or 105°F (40.6°C), whichever is higher. If an outlet temperature greater than $T^*_{\min,n-1}$ is not measured within 30 seconds of initiation of the draw, zero additional credit shall be given towards first-hour rating (i.e., $M^*_n = 0$ or $V^*_n = 0$) based on the final draw. After the final draw is terminated, calculate and record the average outlet temperature and the mass or volume removed during the final draw ($T^*_{\text{del},n}$ and M^*_n or V^*_n , respectively).

7.4 24-Hour Simulated Use Test

7.4.1 Selection of Draw Pattern. The water heater will be tested under a draw profile that depends upon the first-hour rating obtained following the test prescribed in Section 7.3.3 of this test procedure, or the maximum GPM rating obtained following the test prescribed in Section 7.3.2 of this test procedure, whichever is applicable.

7.4.2 Test Sequence for Water Heaters with Rated Storage Volumes Greater Than or Equal to 2 gallons (7.6 L). If the water heater is turned off, fill the water heater with supply water and maintain supply water pressure as described in Section 4.6. Turn on the water heater and associated heat pump unit, if present. If turned on in this fashion, the soak-in period described in Section 7.2.4 shall be implemented. If the water heater has undergone a first-hour rating test or maximum GPM test prior to conduct of the simulated-use test, allow the water heater to fully recover after completion of that test such that the main burner, heating elements, or heat pump compressor of the water heater are no longer raising the temperature of the stored water. In all cases, the water heater shall sit idle for 1 hour prior to the start of the 24-hour test; during which time no water is drawn from the unit and there is no energy input to the main heating elements,

heat pump compressor, and/or burners. At the end of this period, the 24-hour simulated-use test will begin.

At the start of the 24-hour test, record the mean tank temperature (\bar{T}_0), and the electrical and/or fuel measurement readings, as appropriate. Begin the 24-hour simulated use test by withdrawing the volume specified in the applicable draw pattern table for the first draw at the flow rate specified in the applicable draw pattern table. Record the time when this first draw is initiated and assign it as the test elapsed time (τ) of zero (0). Record the average storage tank and ambient temperature every minute throughout the 24-hour simulated-use test. At the elapsed times specified in the applicable draw pattern table initiate additional draws pursuant to the applicable draw pattern, removing the volume of hot water at the prescribed flow rate specified by the applicable draw pattern table. The maximum allowable deviation from the specified volume of water removed for any single draw taken at a nominal flow rate less than or equal to 2 GPM (7.6 liters per minute) is ± 0.1 gallon (± 0.4 liters). The maximum allowable deviation from the specified volume of water removed for any single draw taken at a nominal flow rate greater than or equal to 2.0 GPM (7.6 liters per minute) is ± 0.25 gallons (± 0.9 liters). The quantity of water withdrawn during the last draw shall be increased or decreased as necessary such that the total volume of water withdrawn equals the prescribed daily amount for that draw pattern ± 1.0 gallons (± 3.8 liters). If this adjustment to the volume drawn during the last draw results in no draw taking place, the test is considered invalid.

All draws during the 24-hour simulated-use test shall be made at the flow rates specified in the applicable draw pattern table, within a tolerance of ± 0.25 gallons per minute (± 0.9 liters per minute). Measurements of the inlet and outlet temperatures shall be made 5 seconds after the draw is initiated and at every subsequent 3-second interval throughout the duration of each draw. Calculate and record the mean of the hot water outlet temperature and the cold water inlet temperature for each draw ($\bar{T}_{del,i}$ and $\bar{T}_{in,i}$). Determine and record the net mass or volume removed (M_i or V_i), as appropriate, after each draw.

At the end of the first recovery period following the first draw, which may extend beyond subsequent draws, record the maximum mean tank temperature observed after cut-out, $\bar{T}_{max,1}$, and the energy consumed by an electric resistance, gas, or oil-fired water heater (including electrical energy), from the beginning of the test, Q_r . For heat pump water heaters, the total energy consumed during the first recovery by the heat pump (including compressor, fan, controls, pump, etc.), and, if applicable, by the resistive element(s) shall be recorded as Q_r .

The start of the portion of the test during which the standby loss coefficient is determined depends upon whether the unit has fully recovered from the first draw cluster. If a recovery is occurring at or within five minutes of the end of the final draw in the first draw cluster, as identified in the applicable draw pattern table in Section 7.5 of this test procedure, then the standby period starts when a maximum average tank temperature is observed starting five minutes after the end of the recovery period that follows that draw. If a recovery does not occur at or within five minutes of the end of the final draw in the first draw cluster, as identified in the applicable draw pattern table in Section 7.5 of this appendix, then the standby period starts five minutes after the end of that draw. In these cases, proceed to Section 7.4.2.1 to complete the test. In the event that the recovery period continues from the end of the last draw of the first draw cluster until the subsequent draw,

or the time from the observed maximum mean tank temperature after cut-out to the start of the next draw following the first draw cluster is less than 6 hrs, the standby period shall start after the end of the first recovery period after the last draw of the simulated-use test. For this case, proceed to Section 7.4.2.2 to complete the test.

7.4.2.1 Completion of Test when Standby Period Occurs Between Draw Cluster 1 and Draw Cluster 2

In preparation for determining the energy consumed during standby, record the reading given on the electrical energy (watt-hour) meter, the gas meter, and/or the scale used to determine oil consumption, as appropriate. Determine and record the total electrical energy and/or fossil fuel consumed from the beginning of the test to the start of the standby period, $Q_{su,0}$. Record the mean tank temperature at the start of the standby period as $\bar{T}_{su,0}$. At 1-minute intervals, record the mean tank temperature and the electric and/or fuel instrument readings until the next draw is initiated. Just prior to initiation of the next draw, record the mean tank temperature as $\bar{T}_{su,f}$. If the water heater is undergoing recovery when the next draw is initiated, record the mean tank temperature $\bar{T}_{su,f}$ at the minute prior to the start of the recovery. The time at which this value occurs is the end of the standby period. Determine the total electrical energy and/or fossil fuel energy consumption from the beginning of the test to this time and record as $Q_{su,f}$. Record the time interval between the start of the standby period and the end of the standby period as $\tau_{sby,1}$. Record the time during which water is not being withdrawn from the water heater during the entire 24-hour period as $\tau_{sby,2}$. Following the final draw of the prescribed draw pattern and subsequent recovery, allow the water heater to remain in the standby mode until exactly 24 hours have elapsed since the start of the simulated-use test (i.e., since $\tau = 0$). During the last hour of the simulated-use test, power to the main burner, heating element, or compressor shall be disabled. At 24 hours, record the reading given by the gas meter, oil meter, and/or the electrical energy meter as appropriate. Determine the fossil fuel and/or electrical energy consumed during the entire 24-hour simulated-use test and designate the quantity as Q . Record the time during which water is not being withdrawn from the water heater during the entire 24-hour period as $\tau_{sby,2}$.

7.4.2.2 Completion of Test when Standby Period Occurs after All Draws.

In the event that the recovery period continues from the end of the last draw of the first draw cluster until the subsequent draw, or the time from the observed maximum mean tank temperature after cut-out to the start of the next draw following the first draw cluster is less than 6 hrs, the standby period will start after the last draw of the simulated-use test. If a recovery is occurring at or within five minutes of the end of the final draw, as identified in the applicable draw pattern table in Section 7.5 of this test procedure, then the standby period starts when a maximum average tank temperature is observed starting five minutes after the end of the recovery period that follows that draw. If a recovery does not occur at or within five minutes of the end of the final draw, as identified in the applicable draw pattern table in Section 7.5 of this appendix, then the standby period starts five minutes after the end of that draw. The standby period shall last eight hours, so testing will extend beyond the 24-hour duration of the simulated-use test.

Determine and record the total electrical energy and/or fossil fuel consumed from the beginning of the simulated-use test to the start of the 8-hour standby period, $Q_{su,0}$. In preparation for determining the energy consumed during standby, record the reading(s) given on the electrical energy (watt-hour) meter, the gas meter, and/or the scale used to determine oil consumption, as

appropriate. Record the mean tank temperature at the start of the standby period as $\bar{T}_{su,0}$. Record the mean tank temperature, the ambient temperature, and the electric and/or fuel instrument readings until the end of the 8 hour period. Record the mean tank temperature at the end of the 8 hour standby period as $\bar{T}_{su,f}$. If the water heater is undergoing recovery at the end of the standby period, record the mean tank temperature $\bar{T}_{su,f}$ at the minute prior to the start of the recovery, which will mark the end of the standby period. Determine the total electrical energy and/or fossil fuel energy consumption from the beginning of the test to the end of the standby period and record this value as $Q_{su,f}$. Record the time interval between the start of the standby period and the end of the standby period as $\tau_{stby,1}$. Record the time during which water is not being withdrawn from the water heater during the 24-hour period as $\tau_{stby,2}$.

Following the final draw of the prescribed draw pattern and subsequent recovery, allow the water heater to remain in the standby mode until exactly 24 hours have elapsed since the start of the simulated-use test (i.e., since $\tau = 0$). If no recovery has taken place between hour 23 and 24, record the reading given by the gas meter, oil meter, and/or the electrical energy meter, as appropriate, at hour 24. Determine the fossil fuel and/or electrical energy consumed during the entire 24-hour simulated-use test and designate the quantity as Q . Determine the mean tank temperature at hour 24, T_{24} .

If the water heater undergoes a recovery between elapsed times of 23 hrs and 24 hrs since the start of the test, record the total energy used, Q_{24*} , and the mean tank temperature \bar{T}_{24*} at 1 minute prior to the start of the recovery. Record the elapsed time in hours since the start of the test until 1 minute prior to the start of the recovery, t_{24*} . Determine the average ambient temperature, $\bar{T}_{amb,24*}$, during the period from the minute prior to the recovery until an elapsed time of 24 h.

7.4.3 Test Sequence for Water Heaters with Rated Storage Volume Less than 2 Gallons (7.6 Liters).

7.4.3.1 Test Preparation for Flow Activated Water Heaters

Establish normal operation with the outlet water temperature at the nominal outlet temperature, $T_{del,nom}$ as determined in Section 7.2.2.1 of this test procedure. Prior to commencement of the 24-hour simulated-use test, the unit shall remain in an idle state in which controls are active but no water is drawn through the unit for a period of one hour.

7.4.3.2 Test Preparation for Water Heaters that Are Not Flow-Activated

If the water heater is turned off, fill the water heater with supply water and maintain supply water pressure as described in Section 4.6. Turn on the water heater and associated heat pump unit, if present. If turned on in this fashion, the soak-in period described in Section 7.2.4 shall be implemented. If the water heater has undergone a first-hour rating test prior to conduct of the simulated-use test, allow the water heater to fully recover after completion of that test such that the main burner, heating elements, or heat pump compressor of the water heater are no longer raising the temperature of the stored water. In all cases, the water heater shall sit idle for 1 hour prior to the start of the 24-hour test; during which time no water is drawn from the unit and there is no energy input to the main heating elements, heat pump compressor, and/or burners. At the

end of this period, the 24-hour simulated-use test will begin.

7.4.3.3 Test Sequence of 24 Hour Simulated Use Test.

With no draw occurring, record the reading given by the gas meter and/or the electrical energy meter as appropriate. Begin the 24-hour simulated-use test by withdrawing the volume specified in the applicable draw pattern for the first draw at the flow rate specified. Record the time when this first draw is initiated and designate it as an elapsed time, τ , of 0. At the elapsed times specified for a particular draw pattern, initiate additional draws, removing the volume of hot water at the prescribed flow rate specified in the applicable draw pattern. The maximum allowable deviation from the specified volume of water removed for any single draw taken at a nominal flow rate less than or equal to 2.0 GPM (7.6 L/min) is ± 0.1 gallons (± 0.4 liters). The maximum allowable deviation from the specified volume of water removed for any single draw taken at a nominal flow rate greater than 2.0 GPM (7.6 L/min) is ± 0.25 gallons (± 0.9 liters). The quantity of water drawn during the final draw shall be increased or decreased as necessary such that the total volume of water withdrawn equals the prescribed daily amount for that draw pattern ± 1.0 gallon (± 3.8 liters). If this adjustment to the volume drawn in the last draw results in no draw taking place, the test is considered invalid.

Measurements of the inlet and outlet water temperatures shall be made 5 seconds after the draw is initiated and at every 3-second interval thereafter throughout the duration of the draw. Calculate the mean of the hot water outlet temperature, $\bar{T}_{del,i}$, and the cold water inlet temperature, $\bar{T}_{in,i}$, for each draw. Record the mass of the withdrawn water or the water meter reading, as appropriate, after each draw. At the end of the recovery period following the first draw, determine and record the fossil fuel and/or electrical energy consumed, Q_r . Following the final draw and subsequent recovery, allow the water heater to remain in the standby mode until exactly 24 hours have elapsed since the start of the test (*i.e.*, since $\tau = 0$). At 24 hours, record the reading given by the gas meter, oil meter, and/or the electrical energy meter, as appropriate. Determine the fossil fuel and/or electrical energy consumed during the entire 24-hour simulated-use test and designate the quantity as Q .

7.5 Draw Patterns. The draw patterns to be imposed during 24-hour simulated-use tests are to be specified by the entity requesting the test. Provided strictly for informative purposes, examples of these draw patterns are shown in Annex A – U.S. Values for Test Variables.) Subject each water heater under test to one of the draw patterns based on its first-hour rating or maximum GPM rating, as discussed in Section 7.4.1 of this test procedure. Each draw pattern specifies the elapsed time in hours and minutes during the 24-hour test when a draw is to commence, the total volume of water that is to be removed during each draw, and the flow rate at which each draw is to be taken.

8. CALCULATION OF RESULTS

8.1 First Hour Rating

The first-hour rating, FHR, shall be computed using,

$$FHR = \sum_{i=1}^n V_i$$

Where:

n = the number of draws that are completed as defined in Section 7.3.3.

V_i^* = the volume of water removed during the i th draw of the first-hour rating test, gal (L)
or, if the mass of water is being measured,

$$V_i = \frac{M_i}{\rho_i}$$

Where:

M_i^* = the mass of water removed during the i th draw of the first-hour rating test, lb (kg).

ρ_i = the water density corresponding to where the flow rate is measured during the i th draw, lb/gal (kg/L).

8.2 Maximum GPM (L/min) Rating:

Compute the maximum GPM (L/min) rating, F_{\max} , as:

$$F_{\max} = \frac{M_{10m}(\bar{T}_{\text{del}} - \bar{T}_{\text{in}})}{10(\rho)(T_{\text{del,nom}} - T_{\text{in,nom}})}$$

Where:

M_{10m} = the mass of water collected during the 10-minute test, lb (kg).

\bar{T}_{del} = the average outlet temperature, °F (°C).

\bar{T}_{in} = the average inlet temperature, °F (°C).

ρ = the water density corresponding to where the flow rate is measured, lb/gal (kg/L).

$\bar{T}_{\text{del,nom}}$ = the nominal outlet temperature, °F (°C).

$\bar{T}_{\text{in,nom}}$ = the nominal inlet temperature, °F (°C).

If a water meter is used, the maximum GPM (L/min) rating is computed as:

$$F_{\max} = \frac{V_{10m}(\bar{T}_{\text{del}} - \bar{T}_{\text{in}})}{10(T_{\text{del,nom}} - T_{\text{in,nom}})}$$

Where:

V_{10m} = the volume of water measured during the 10-minute test, gal (L).

\bar{T}_{del} = the average outlet temperature, °F (°C).

\bar{T}_{in} = the average inlet temperature, °F (°C).

$\bar{T}_{del,nom}$ = the nominal outlet temperature, °F (°C).

$\bar{T}_{in,nom}$ = the nominal inlet temperature, °F (°C).

8.3 Uniform Energy Factor: Water Heaters with a Rated Storage Volume Greater than or Equal to 2 gallons (7.6 L)

8.3.1 Storage Tank Capacity

The storage tank capacity, V_{st} , is computed as follows:

$$V_{st} = \frac{(W_f - W_t)}{\rho_{st}}$$

Where:

V_{st} = the storage capacity of the water heater, gal (L)

W_f = the weight of the storage tank when completely filled with water, lb (kg)

W_t = the (tare) weight of the storage tank when completely empty, lb (kg)

ρ_{st} = the density of water used to fill the tank measured at the temperature of the water, lb/gal (kg/L)

8.3.2 Recovery Efficiency. The recovery efficiency for gas, oil, and heat pump storage-type water heaters, η_r , is computed as:

$$\eta_r = \sum_{i=1}^{N_r} \frac{m_i * C_{pi} * (\bar{T}_{del,i} - \bar{T}_{in,i})}{Q_r} + \frac{V_{st} \rho_2 C_{p2} (\bar{T}_{max,1} - \bar{T}_0)}{Q_r}$$

Where:

m_i = total mass removed during the i th draw, lb (kg).

$$m_i = V_i \rho_i$$

N_r = number of draws that occurred during the first recovery period.

V_i = total volume removed during the i th draw, gal (L).

ρ_i = the water density corresponding to where the flow rate is measured during the i th draw, lb/gal (kg/L).

C_{pi} = specific heat of the i th draw, Btu/(lb•°F) (kJ/(kg•°C))

$\bar{T}_{del,i}$ = average water outlet temperature measured during the i th draw, °F (°C).

$\bar{T}_{in,i}$ = average water inlet temperature measured during the i th draw, °F (°C).

V_{st} = as defined in Section 8.3.1.

ρ_2 = density of stored hot water evaluated at $(\bar{T}_{max,1} + \bar{T}_o)/2$, lb/gal (kg/L).

C_{p2} = specific heat of stored hot water evaluated at $(\bar{T}_{max,1} + \bar{T}_o)/2$, Btu/(lb•°F) (kJ/(kg•°C)).

$\bar{T}_{max,1}$ = maximum mean tank temperature recorded after cut-out following the first recovery of the 24-hour simulated use test, °F (°C).

\bar{T}_o = maximum mean tank temperature recorded prior to the first draw of the 24-hour simulated-use test, °F (°C).

The first recovery period is from the cut-out prior to the first draw and ending at the following cut-out. If the first recovery period ends during a draw, then the first recovery period ends at the conclusion of that draw.

Q_r = the total energy used by the water heater during the first recovery period, including auxiliary energy such as pilot lights, pumps, fans, etc., Btu (kJ). (Electrical auxiliary energy shall be converted to thermal energy using the following conversion: 1 kWh = 3412 Btu).

The recovery efficiency for electric water heaters with immersed heating elements is assumed to be 98 percent.

8.3.3 Hourly Standby Losses. The energy consumed as part of the standby loss test of the 24-hour simulated-use test, Q_{stby} , is computed as:

$$Q_{stby} = Q_{su,f} - Q_{su,0}$$

Where:

$Q_{su,0}$ = cumulative energy consumption of the water heater from the start of the 24-hour simulated-use test to the time at which the maximum mean tank temperature is attained starting five minutes after the recovery following the end of the first draw cluster, Btu (kJ).

$Q_{su,f}$ = cumulative energy consumption of the water heater from the start of the 24-hour simulated-use test to the minute prior to the start of the draw following the end of the first draw cluster

or the minute prior to a recovery occurring at the start of the draw following the end of the first draw cluster, Btu (kJ).

The hourly standby energy losses are computed as:

$$Q_{hr} = \frac{Q_{stby} - \frac{V_{st}\rho C_p(\bar{T}_{su,f} - \bar{T}_{su,0})}{\eta_r}}{\tau_{stby,1}}$$

Where:

Q_{hr} = the hourly standby energy losses of the water heater, Btu/h (kJ/h).

V_{st} = as defined in Section 8.3.1.

ρ = density of stored hot water at $(\bar{T}_{u,f} + \bar{T}_{u,0})/2$, lb/gal (kg/L).

C_p = specific heat of the stored water at $(\bar{T}_{u,f} + \bar{T}_{su,0})/2$, Btu/(lb•F), (kJ/(kg•K))

$\bar{T}_{su,f}$ = the mean tank temperature observed at the minute prior to the start of the draw following the first draw cluster or the minute prior to a recovery occurring at the start of the draw following the end of the first draw cluster, °F (°C).

$\bar{T}_{su,0}$ = the maximum mean tank temperature observed starting five minutes after the first recovery following the final draw of the first draw cluster, °F (°C).

η_r = as defined in Section 8.3.2.

$\tau_{stby,1}$ = elapsed time between the time at which the maximum mean tank temperature is observed starting five minutes after recovery from the first draw cluster and the minute prior to the start of the first draw following the end of the first draw cluster of the 24-hour simulated-use test or the minute prior to a recovery occurring at the start of the draw following the end of the first draw cluster, h.

The standby heat loss coefficient for the tank is computed as:

$$UA = \frac{Q_{hr}}{\bar{T}_{t,stby,1} - \bar{T}_{a,stby,1}}$$

Where:

UA = standby heat loss coefficient of the storage tank, Btu/(h•°F), (kJ/(h•°C)).

$\bar{T}_{t,stby,1}$ = overall average storage tank temperature between the time when the maximum mean tank temperature is observed starting five minutes after cut-out following the first draw cluster

and the minute prior to commencement of the next draw following the first draw cluster of the 24-hour simulated-use test or the minute prior to a recovery occurring at the start of the draw following the end of the first draw cluster, °F (°C).

$\bar{T}_{a, \text{stby}, 1}$ = overall average ambient temperature between the time when the maximum mean tank temperature is observed starting five minutes after cut-out following the first draw cluster and the minute prior to commencement of the next draw following the first draw cluster of the 24-hour simulated-use test or the minute prior to a recovery occurring at the start of the draw following the end of the first draw cluster, °F (°C).

8.3.4 Daily Water Heating Energy Consumption. If no recovery occurred between hour 23 and hour 24 of the 24-hour simulated-use test, then Q , the total energy used by the water heater during the 24-hour simulated-use test is as measured in Section 7.4.

$Q = Q_f + Q_e$ = total energy used by the water heater during the 24-hour simulated-use test, including auxiliary energy such as pilot lights, pumps, fans, etc., Btu (kJ). (Electrical energy shall be converted to thermal energy using the following conversion: 1 kWh = 3412 Btu.)

Q_f = total fossil fuel energy used by the water heater during the 24-hour simulated-use test, Btu (kJ).

Q_e = total electrical energy used during the 24-hour simulated-use test, Btu (kJ).

If a recovery occurred between hour 23 and hour 24 of the 24-hour simulated-use test, compute the total energy used by the water heater during the 24-hour simulated-use test as:

$$Q = Q_{24*} + UA(\bar{T}_{24*} - \bar{T}_{amb,24*})(24 - t_{24*})$$

Where:

Q_{24*} = total energy used by the water heater from the start of the 24-hour simulated-use test until the minute prior to the recovery that occurs between hour 23 and 24, including auxiliary energy such as pilot lights, pumps, fans, etc., Btu (kJ) ((Electrical energy shall be converted to thermal energy using the following conversion: 1 kWh = 3412 Btu.)

\bar{T}_{24*} = mean tank temperature one minute prior to a recovery occurring between hours 23 and 24 of the simulated-use test, °F (°C).

$\bar{T}_{amb,24*}$ = mean ambient temperature from the minute prior to the recovery that occurs between hours 23 and 24 and an elapsed time of 24 h from the start of the test, °F (°C).

t_{24*} = elapsed time from start of test until minute prior to the start of the recovery that occurs between hours 23 and 24 of the simulated-use test, h.

The daily water heating energy consumption, Q_d , is computed as:

$$Q_d = Q - \frac{V_{st} \rho C_p (\bar{T}_{24} - \bar{T}_0)}{\eta_r}$$

Where:

V_{st} = as defined in Section 8.3.1.

ρ = density of the stored hot water, evaluated at $(\bar{T}_{24} + \bar{T}_0)/2$, lb/gal (kg/L)

C_p = specific heat of the stored water, evaluated at $(\bar{T}_{24} + \bar{T}_0)/2$, Btu/(lb•F), (kJ/(kg•K)).

\bar{T}_{24} = mean tank temperature at the end of the 24-hour simulated-use test if no recovery has occurred between hours 23 and 24 of the simulated-use test or $= \bar{T}_{24}^*$ if a recovery has occurred between hours 23 and 24 of the simulated-use test, °F (°C) .

\bar{T}_{24}^* = mean tank temperature one minute prior to a recovery occurring between hours 23 and 24 of the simulated-use test, °F (°C).

\bar{T}_0 = mean tank temperature at the beginning of the 24-hour simulated-use test, recorded one minute before the first draw is initiated, °F (°C).

η_r = as defined in Section 8.3.2.

8.3.5 Adjusted Daily Water Heating Energy Consumption. The adjusted daily water heating energy consumption, Q_{da} , takes into account that the ambient temperature may differ from the nominal value due to the allowable variation in surrounding ambient temperature. The adjusted daily water heating energy consumption is computed as:

$$Q_{da} = Q_d - (T_{a,nom} - \bar{T}_{a,stby,2}) UA \tau_{stby,2}$$

Where:

Q_{da} = the adjusted daily water heating energy consumption, Btu (kJ).

Q_d = as defined in Section 8.3.4.

$\bar{T}_{a,stby,2}$ = the average ambient temperature during the total standby portion, $\tau_{stby,2}$, of the 24-hour simulated-use test, °F (°C).

$\bar{T}_{a,nom}$ = the nominal ambient temperature, °F (°C).

UA = as defined in Section 8.3.3.

$\tau_{stby,2}$ = the number of hours during the 24-hour simulated-use test when water is not being withdrawn from the water heater.

A modification is also needed to take into account that the temperature difference between the

outlet water temperature and supply water temperature may not be equivalent to the nominal value. The following equations adjust the experimental data to a nominal temperature rise.

The energy used to heat water, Btu/day (kJ/day), may be computed as:

$$Q_{HW} = \sum_{i=1}^N \frac{M_i C_{pi} (\bar{T}_{del,i} - \bar{T}_{in,i})}{\eta_r}$$

Where:

N = total number of draws in the draw pattern.

M_i = the mass withdrawn for the *i*th draw (i = 1 to N), lb (kg)

C_{pi} = the specific heat of the water of the *i*th draw evaluated at $(\bar{T}_{del,i} + \bar{T}_{in,i})/2$, Btu/(lb•°F) (kJ/(kg•°C)).

$\bar{T}_{del,i}$ = the average water outlet temperature measured during the *i*th draw (i = 1 to N), °F (°C).

$\bar{T}_{in,i}$ = the average water inlet temperature measured during the *i*th draw (i = 1 to N), °F (°C).

η_r = as defined in Section 8.3.2.

The energy required to heat the same quantity of water over a nominal temperature rise, Btu/day (kJ/day), is:

$$Q_{HW,nom} = \sum_{i=1}^N \frac{M_i C_{pi} (T_{del,nom} - T_{in,nom})}{\eta_r}$$

The difference between these two values is:

$$Q_{HWD} = Q_{HW,nom} - Q_{HW}$$

This difference (Q_{HWD}) must be added to the adjusted daily water heating energy consumption value. Thus, the daily energy consumption value which takes into account that the ambient temperature and the temperature rise across the storage tank may not be at their nominal values is:

$$Q_{dm} = Q_{da} + Q_{HWD}$$

8.3.6 Uniform Energy Factor. The uniform energy factor, UEF, is computed as:

$$UEF = \sum_{i=1}^N \frac{M_i C_{pi} (T_{del,nom} - T_{in,nom})}{Q_{dm}}$$

Where:

N = total number of draws in the draw pattern

Q_{dm} = the modified daily water heating energy consumption as computed in accordance with Section 8.3.5, Btu (kJ)

M_i = the mass withdrawn for the i th draw ($i = 1$ to N), lb (kg)

$T_{del,nom}$ = the nominal outlet temperature, °F (°C)

$T_{in,nom}$ = the nominal inlet temperature, °F (°C)

C_{pi} = the specific heat of the water of the i th draw, evaluated at $(T_{del,nom} + T_{in,nom})/2$, Btu/(lb•°F) (kJ/(kg•°C)).

8.3.7 Annual Energy Consumption. The annual energy consumption for water heaters with rated storage volumes greater than or equal to 2 gallons (7.6 L) is computed as:

$$E_{annual} = 365 \times \frac{(V)(\rho)(C_P)(T_{del,nom} - T_{in,nom})}{UEF}$$

Where:

UEF = the uniform energy factor as computed in accordance with Section 8.3.6

365 = the number of days in a year

V = the volume of hot water drawn during the applicable draw pattern, gallons (L)

ρ = the density of water at $T_{del,nom}$, lb/gal (kg/L)

C_P = the specific heat of water at $(T_{del,nom} + T_{in,nom})/2$, Btu/(lb•°F) (kJ/(kg•°C))

8.3.8 Annual Electrical Energy Consumption. The annual electrical energy consumption in kilowatt-hours for water heaters with rated storage volumes greater than or equal to 2 gallons (7.6 L), $E_{annual,e}$, is computed as:

$$E_{annual,e} = E_{annual} * (Q_e/Q) / 3412$$

Where:

E_{annual} = the annual energy consumption as determined in accordance with Section 8.3.7, Btu (kJ)

Q_e = the daily electrical energy consumption as defined in Section 8.3.4, Btu (kJ).

Q = total energy used by the water heater during the 24-hour simulated-use test in accordance with

Section 8.3.4, Btu (kJ)

3412 = conversion factor from kWh to Btu

8.3.9 Annual Fossil Fuel Energy Consumption. The annual fossil fuel energy consumption for water heaters with rated storage volumes greater than or equal to 2 gallons (7.6 L), $E_{\text{annual,f}}$, is computed as:

$$E_{\text{annual,f}} = E_{\text{annual}} - (E_{\text{annual,e}} \times 3412)$$

Where:

E_{annual} = the annual energy consumption as determined in accordance with Section 8.3.7, Btu (kJ)

$E_{\text{annual,e}}$ = the annual electrical energy consumption as determined in accordance with Section 8.3.8, kWh

3412 = conversion factor from kWh to Btu

8.4 Water Heaters With Rated Storage Volume Less Than 2 Gallons.

8.4.1 Recovery Efficiency. The recovery efficiency, η_r , is computed as:

$$\eta_r = \frac{M_1 C_{p1} (\bar{T}_{\text{del},1} - \bar{T}_{\text{in},1})}{Q_r}$$

Where:

M_1 = total mass removed during the first draw of the 24-hour simulated-use test, lb (kg), or, if the volume of water is being measured,

$$M_1 = V_1 \cdot \rho$$

Where:

V_1 = total volume removed during the first draw of the 24-hour simulated-use test, gal (L).

ρ = the water density corresponding to where the flow rate is measured, lb/gal (kg/L).

C_{p1} = specific heat of the withdrawn water at $(\bar{T}_{\text{del},1} + \bar{T}_{\text{in},1})/2$, Btu/(lb•°F) (kJ/(kg•°C)).

$\bar{T}_{\text{in},1}$ = average water inlet temperature measured during the first draw of the 24-hour simulated-use test, °F (°C).

$\bar{T}_{\text{del},1}$ = average water outlet temperature measured during the first draw of the 24-hour simulated-use test, °F (°C).

Q_r = the total energy used by the water heater between cut-out prior to the first draw and cut-out following the first draw, including auxiliary energy such as pilot lights, pumps, fans, etc., Btu (kJ). (Electrical auxiliary energy shall be converted to thermal energy using the following conversion: 1 kWh = 3412 Btu.)

8.4.2 Daily Water Heating Energy Consumption. The daily water heating energy consumption, Q_d , is computed as:

$$Q_d = Q$$

Where:

$Q = Q_f + Q_e$ = the energy used by the water heater during the 24-hour simulated-use test.

Q_f = total fossil fuel energy used by the water heater during the 24-hour simulated-use test, Btu (kJ).

Q_e = total electrical energy used during the 24-hour simulated-use test, Btu (kJ).

A modification is needed to take into account that the temperature difference between the outlet water temperature and supply water temperature may not be equivalent to the nominal value.

The following equations adjust the experimental data to a nominal temperature rise.

The energy used to heat water may be computed as:

$$Q_{HW} = \sum_{i=1}^N \frac{M_i C_{pi} (\bar{T}_{del,i} - \bar{T}_{in,i})}{\eta_r}$$

Where:

N = total number of draws in the draw pattern

M_i = the mass withdrawn for the i th draw ($i = 1$ to N), lb (kg)

C_{pi} = the specific heat of the water of the i th draw evaluated at $(\bar{T}_{del,i} + \bar{T}_{in,i})/2$, Btu/(lb•°F) (kJ/(kg•°C)).

$\bar{T}_{del,i}$ = the average water outlet temperature measured during the i th draw ($i = 1$ to N), °F (°C).

$\bar{T}_{in,i}$ = the average water inlet temperature measured during the i th draw ($i = 1$ to N), °F (°C).

η_r = as defined in Section 8.4.1.

The energy required to heat the same quantity of water over a nominal temperature rise is:

$$Q_{HW,nom} = \sum_{i=1}^N \frac{M_i C_{pi} (T_{del,nom} - T_{in,nom})}{\eta_r}$$

Where:

N = total number of draws in the draw pattern

M_i = the mass withdrawn during the *i*th draw, lb (kg)

C_{pi} = the specific heat of water of the *i*th draw, Btu/(lb•°F) (kJ/(kg•°C))

T_{del,nom} = the nominal delivered water temperature, °F (°C)

T_{in,nom} = the nominal inlet water temperature, °F (°C)

η_r = as defined in Section 8.4.1.

The difference between these two values is:

$$Q_{HWD} = Q_{HW,nom} - Q_{HW}$$

This difference (Q_{HWD}) must be added to the daily water heating energy consumption value. Thus, the daily energy consumption value, which takes into account that the temperature rise across the water heater may not be at its nominal value is:

$$Q_{dm} = Q_d + Q_{HWD}$$

8.4.3 Uniform Energy Factor. The uniform energy factor, UEF, is computed as:

$$UEF = \frac{\sum_{i=1}^N M_i C_{pi} (T_{del,nom} - T_{in,nom})}{Q_{dm}}$$

Where:

N = total number of draws in the draw pattern

Q_{dm} = the modified daily water heating energy consumption as computed in accordance with Section 8.4.2, Btu (kJ)

M_i = the mass withdrawn for the *i*th draw (i = 1 to N), lb (kg)

C_{pi} = the specific heat of the water at the *i*th draw, evaluated at (T_{del,nom} + T_{in,nom})/2, Btu/(lb•°F) (kJ/(kg•°C)).

8.4.4 Annual Energy Consumption. The annual energy consumption for water heaters with rated

storage volumes less than 2 gallons (7.6 L), E_{annual} , is computed as:

$$E_{\text{annual}} = 365x \frac{(V)(\rho)(C_P)(T_{\text{del,nom}} - T_{\text{in,nom}})}{\text{UEF}}$$

Where:

UEF = the uniform energy factor as computed in accordance with Section 8.4.3

365 = the number of days in a year.

V = the volume of hot water drawn during the applicable draw pattern, gallons (L)

ρ = the density of water at $T_{\text{del,nom}}$, lb/gal (kg/L)

C_P = the specific heat of water at $(T_{\text{del,nom}} + T_{\text{in,nom}}) / 2$, Btu/(lb•°F) (kJ/(kg•°C))

8.4.5 Annual Electrical Energy Consumption. The annual electrical energy consumption in kilowatt–hours for water heaters with rated storage volumes less than 2 gallons (7.6 L), $E_{\text{annual,e}}$, is computed as:

$$E_{\text{annual,e}} = E_{\text{annual}} * (Q_e / Q) / 3412$$

Where:

Q_e = the daily electrical energy consumption as defined in Section 8.4.2, Btu (kJ)

E_{annual} = the annual energy consumption as determined in accordance with Section 8.4.4, Btu (kJ)

Q = total energy used by the water heater during the 24-hour simulated-use test in accordance with Section 8.4.2, Btu (kJ)

Q_{dm} = the modified daily water heating energy consumption as computed in accordance with Section 8.4.2, Btu (kJ)

3412 = conversion factor from Btu to kWh

8.4.6 Annual Fossil Fuel Energy Consumption. The annual fossil fuel energy consumption for water heaters with rated storage volumes less than 2 gallons (7.6 L), $E_{\text{annual,f}}$, is computed as:

$$E_{\text{annual,f}} = E_{\text{annual}} - (E_{\text{annual,e}} \times 3412)$$

Where:

$E_{\text{annual,e}}$ = the annual electrical energy consumption as defined in Section 8.4.5, kWh.

E_{annual} = the annual energy consumption as defined in Section 8.4.4, Btu (kJ)

3412 = conversion factor from kWh to Btu

9. REFERENCES

1. ASHRAE Standard 41.1-2013 *Standard Method for Temperature Measurements*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.
2. ASHRAE Standard 41.3-2014 *Standard Methods for Pressure Measurement*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.
3. ASHRAE Standard 41.6-2014 *Standards Methods for Humidity Measurement*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.
4. ASHRAE Standard 41.8-2016 *Standard Methods for Liquid Flow Rate Measurement*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.
5. ASHRAE Standard 41.11-2014 *Standard Methods for Power Measurement*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.
6. *2013 ASHRAE Handbook—Fundamentals*, Chapter 1. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.
7. *ANSI/ASTM D2156-09 (2009), Standard Test Method for Smoke Density in Flue Gases from Burning Distillate Fuels*. American Society for Testing and Materials, Philadelphia, PA.

(This annex is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

ANNEX A – U.S. VALUES FOR TEST VARIABLES

In the United States, federal statutes require that residential water heaters be tested and rated in accordance with the US Department of Energy 10 Code of Federal Regulations (CFR) Part 430, Subpart B, Appendix E “Uniform Test Method of Measuring the Energy Consumption of Water Heaters.”

This test procedure provides ratings that are comparable to those determined by this standard. Shown below are US Values for Test Variables prescribed in this standard.

US Values for Test Variables

$$T_{a,nom} = 67.5 \text{ }^{\circ}\text{F} (19.7 \text{ }^{\circ}\text{C})$$

$$RH_{a,nom} = 50\%$$

$$T_{del,nom} = 125 \text{ }^{\circ}\text{F} (51.7 \text{ }^{\circ}\text{C})$$

$$T_{in,nom} = 58 \text{ }^{\circ}\text{F} (14.4 \text{ }^{\circ}\text{C})$$

For water heaters that have been tested according to the first-hour rating procedure, one of four different patterns shall be applied based on the measured first-hour rating, as shown in Table 1 of this section. For water heaters that have been tested according to the maximum GPM rating procedure, one of four different patterns shall be applied based on the maximum GPM, as shown in Table 2 of this section.

Table 1. Draw Pattern to be Used Based on First-Hour Rating.

First-Hour Rating		Draw Pattern To Be Used in Simulated-Use Test
greater than or equal to: (gal [L])	Rating less than: (gal [L])	
0	18 gallons (68 L)	Very-Small-Usage (Table 3.1)
18 gallons (68 L)	51 gallons (193 L)	Low-Usage (Table 3.2)

51 gallons (193 L)	75 gallons (284 L)	Medium-Usage (Table 3.3)
75 gallons (284 L)	No upper limit	High-Usage (Table 3.4)

Table 2. Draw Pattern to be Used Based on Maximum GPM Rating.

Maximum GPM Rating		Draw Pattern To Be Used in Simulated-Use Test
greater than or equal to: (GPM [L/min])	less than: (GPM [L/min])	
0	1.7 (6.4)	Very-Small-Usage (Table 3.1)
1.7 (6.4)	2.8 (10.6)	Low-Usage (Table 3.2)
2.8 (10.6)	4.0 (15.0)	Medium-Usage (Table 3.3)
4.0 (15.0)	No upper limit	High-Usage (Table 3.4)

The draw patterns selected from Table 1 or Table 2 are provided in Tables 3.1 through 3.4.

Table 3.1 Very-Small-Usage Draw Pattern

Draw Number	Time During Test [hh:mm]	Volume (gal [L])	Flow Rate** (GPM [L/min])
1*	0:00	2.0 (7.6)	1.0 (3.8)
2*	1:00	1.0 (3.8)	1.0 (3.8)
3*	1:05	0.5 (1.9)	1.0 (3.8)
4*	1:10	0.5 (1.9)	1.0 (3.8)
5*	1:15	0.5 (1.9)	1.0 (3.8)
6	8:00	1.0 (3.8)	1.0 (3.8)
7	8:15	2.0 (7.6)	1.0 (3.8)
8	9:00	1.5 (5.7)	1.0 (3.8)
9	9:15	1.0 (3.8)	1.0 (3.8)
Total Volume Drawn Per Day: 10 gallons (38 L)			

* Denotes draws in first draw cluster.

** Should the water heater have a maximum GPM rating less than the specified flow rate, then all draws shall be implemented at a flow rate equal to the rated maximum GPM.

Table 3.2 Low-Usage Draw Pattern

Draw Number	Time During Test [hh:mm]	Volume (gal [L])	Flow Rate (GPM [L/min])
1*	0:00	15.0 (56.8)	1.7 (6.4)
2*	0:30	2.0 (7.6)	1.0 (3.8)
3*	1:00	1.0 (3.8)	1.0 (3.8)
4	10:30	6.0 (22.7)	1.7 (6.4)
5	11:30	4.0 (15.1)	1.7 (6.4)
6	12:00	1.0 (3.8)	1.0 (3.8)
7	12:45	1.0 (3.8)	1.0 (3.8)
8	12:50	1.0 (3.8)	1.0 (3.8)
9	16:15	2.0 (7.6)	1.0 (3.8)
10	16:45	2.0 (7.6)	1.7 (6.4)
11	17:00	3.0 (11.4)	1.7 (6.4)
Total Volume Drawn Per Day: 38 gallons (144 L)			

* Denotes draws in first draw cluster.

Table 3.3 Medium-Usage Draw Pattern

Draw Number	Time During Test [hh:mm]	Volume (gal [L])	Flow Rate (GPM [L/min])
1*	0:00	15.0 (56.8)	1.7 (6.4)
2*	0:30	2.0 (7.6)	1.0 (3.8)
3*	1:40	9.0 (34.1)	1.7 (6.4)
4	10:30	9.0 (34.1)	1.7 (6.4)
5	11:30	5.0 (18.9)	1.7 (6.4)
6	12:00	1.0 (3.8)	1.0 (3.8)

7	12:45	1.0 (3.8)	1.0 (3.8)
8	12:50	1.0 (3.8)	1.0 (3.8)
9	16:00	1.0 (3.8)	1.0 (3.8)
10	16:15	2.0 (7.6)	1.0 (3.8)
11	16:45	2.0 (7.6)	1.7 (6.4)
12	17:00	7.0 (26.5)	1.7 (6.4)
Total Volume Drawn Per Day: 55 gallons (208 L)			

* Denotes draws in first draw cluster.

Table 3.4 High-Usage Draw Pattern

Draw Number	Time During Test [hh:mm]	Volume (gal [L])	Flow Rate (GPM [L/min])
1*	0:00	27.0 (102)	3.0 (11.4)
2*	0:30	2.0 (7.6)	1.0 (3.8)
3*	0:40	1.0 (3.8)	1.0 (3.8)
4*	1:40	9.0 (34.1)	1.7 (6.4)
5	10:30	15.0 (56.8)	3.0 (11.4)
6	11:30	5.0 (18.9)	1.7 (6.4)
7	12:00	1.0 (3.8)	1.0 (3.8)
8	12:45	1.0 (3.8)	1.0 (3.8)
9	12:50	1.0 (3.8)	1.0 (3.8)
10	16:00	2.0 (7.6)	1.0 (3.8)
11	16:15	2.0 (7.6)	1.0 (3.8)
12	16:30	2.0 (7.6)	1.7 (6.4)
13	16:45	2.0 (7.6)	1.7 (6.4)
14	17:00	14.0 (53.0)	3.0 (11.4)
Total Volume Drawn Per Day: 84 gallons (318 L)			

* Denotes draws in first draw cluster.

References

1. Code of Federal Regulations (CFR), Title 10, Part 430, Subpart B Appendix E, "Uniform Test Method of Measuring the Energy Consumption of Water Heaters." U.S. Department of Energy.

(This annex is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

ANNEX B – GAS HEATING VALUE CORRECTION FACTOR

Correction applied to the heating value, H, for a fuel gas when it is metered at temperature and/or pressure conditions other than the standard conditions on which the value of H is based:

Dry gas utilizing dry test meter:

$$C_S = \frac{P_g (459.7 + T_s)}{P_s (459.7 + T_g)} \quad (\text{IP}) \quad (\text{B-1a})$$

$$C_S = \frac{P_g (273.15 + T_s)}{P_s (273.15 + T_g)} \quad (\text{SI}) \quad (\text{B-1b})$$

Saturated gas utilizing a wet test meter:

$$C_S = \frac{(P_g - P_{wv}) (459.7 + T_s)}{(P_s - P_{wvs}) (459.7 + T_g)} \quad (\text{IP}) \quad (\text{B-2a})$$

$$C_S = \frac{(P_g - P_{wv}) (273.15 + T_s)}{(P_s - P_{wvs}) (273.15 + T_g)} \quad (\text{SI}) \quad (\text{B-2b})$$

where:

P_g = absolute pressure of gas being metered (barometric pressure plus gas pressure, in. Hg (kPa).

P_s = standard absolute pressure, in. Hg (kPa).

T_g = temperature of gas in meter, °F (°C).

T_s = standard temperature, °F (°C).

P_{wv} = water-vapor pressure at T_g , in. Hg (kPa).

P_{wvs} = water-vapor pressure at T_s , in. Hg (kPa).

For water-vapor pressures, see the *2017 ASHRAE Handbook—Fundamentals*, Chapter 1, Table 3, Thermodynamic Properties of Water at Saturation.

If the value of H is based upon a dry condition and the gas is metered with a wet test meter, its value must also be reduced by a factor as calculated by Equation B-3:

$$C_f = \frac{(P_s - P_{wvs})}{P_s} \quad (\text{B-3})$$

Conversely, if the value of H is based upon a saturated condition and the gas is metered dry, its value must be increased by a factor as calculated by Equation B-4:

$$C_f = \frac{P_s}{(P_s - P_{wvs})}. \quad (\text{B-4})$$

IP EXAMPLE

If the standard conditions are 30.00 in. Hg and 60°F, the equations above simplify to the following:

$$C_s = \frac{17.323 P_g}{459.7 + T_g}$$

and

$$C_s = \frac{17.63 (P_g - P_{wv})}{459.7 + T_g},$$

$C_s = 0.9826$ and $C_f = 1.0177$, respectively.