Title 10 —Energy
Chapter II —Department of Energy
Subchapter D —Energy Conservation
Part 430 —Energy Conservation Program for Consumer Products
Subpart B —Test Procedures

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Source: 42 FR 27898, June 1, 1977, unless otherwise noted.

Appendix E to Subpart B of Part 430—Uniform Test Method for Measuring the Energy Consumption of Water Heaters

Link to an amendment published at 89 FR 37943, May 6, 2024.

Note: Prior to December 18, 2023, representations with respect to the energy use or efficiency of consumer water heaters covered by this test method, including compliance certifications, must be based on testing conducted in accordance with either this appendix as it now appears or appendix E as it appeared at 10 CFR part 430, subpart B revised as of January 1, 2021.
On and after December 18, 2023, representations with respect to energy use or efficiency of consumer water heaters covered by this test method, including compliance certifications, must be based on testing conducted in accordance with this appendix, except as outlined in the following paragraphs.

Prior to June 17, 2024, representations with respect to the energy use or efficiency of residential-duty commercial water heaters covered by this test method, including compliance certifications, must be based on testing conducted in accordance with either this appendix as it now appears or appendix E as it appeared at 10 CFR part 430, subpart B revised as of January 1, 2021.

On and after June 17, 2024, representations with respect to energy use or efficiency of residential-duty commercial water heaters covered by this test method, including compliance certifications, must be based on testing conducted in accordance with this appendix.

Water heaters subject to section 4.10 of this appendix may optionally apply the requirements in section 4.10 of this appendix prior to the compliance date of a final rule reviewing potential amended energy conservation standards for these products and equipment published after June 21, 2023. After the compliance date of such standards final rule, the requirements of section 4.10 are mandatory.

In addition, certain electric resistance storage water heaters may optionally apply the requirements in section 5.1.2 of this appendix in lieu of the requirements in section 5.1.1 of this appendix for additional voluntary representations only. Water heaters must certify according to the

requirements in section 5.1.1 until the publication of a final rule reviewing potential amended energy conservation standards and specifying the required use of section 5.1.2 for these products published after June 21, 2023.

0. Incorporation by Reference.

DOE incorporated by reference in § 430.3 the entire standard for: ASHRAE 41.1-2020; ASHRAE 41.6-2014; ASHRAE 118.2-2022; ASTM D2156-09 (R2018); and ASTM E97-1987. However, only enumerated provisions of ASHRAE 118.2-2022 are applicable to this appendix, as follows:

0.1 ASHRAE 118.2-2022

(a) Annex B—Gas Heating Value Correction Factor;

(b) [Reserved]

0.2 [Reserved]

1. Definitions.

1.1. ***Cut-in*** means 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.

1.2. ***Cut-out*** means 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.

1.3. ***Design Power Rating*** means the power rating or input rate that a water heater manufacturer assigns to a particular design of water heater and that is included on the nameplate of the water heater, expressed in kilowatts or Btu (kJ) per hour as appropriate. For modulating water heaters, the design power rating is the maximum power rating or input rate that is specified by the manufacturer on the nameplate of the water heater.

1.4. ***Draw Cluster*** means a collection of water draws initiated during the 24-hour simulated-use test during which no successive draws are separated by more than 2 hours.

1.5. ***First-Hour Rating*** means an estimate of the maximum volume of “hot” water that a non-flow activated water heater can supply within an hour that begins with the water heater fully heated (*i.e.,* with all thermostats satisfied).

1.6. ***Flow-Activated*** describes an operational scheme in which a water heater initiates and terminates heating based on sensing flow.

1.7. ***Heat Trap*** means 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.

1.8. ***Maximum GPM (L/min) Rating*** means the maximum gallons per minute (liters per minute) of hot water that can be supplied by a flow-activated water heater when tested in accordance with section 5.3.2 of this appendix.

1.9. ***Modulating Water Heater*** means a water heater that can automatically vary its power or input rate from the minimum to the maximum power or input rate specified on the nameplate of the water heater by the manufacturer.

1.10. ***Rated Storage Volume*** means the water storage capacity of a water heater, in gallons (liters), as certified by the manufacturer pursuant to 10 CFR part 429.

1.11. ***Recovery Efficiency*** means the ratio of energy delivered to the water to the energy content of the fuel consumed by the water heater.

1.12. ***Recovery Period*** means the time when the main burner of a water heater with a rated storage volume greater than or equal to 2 gallons is raising the temperature of the stored water.

1.13. ***Split-system heat pump water heater*** means a heat pump-type water heater in which at least the compressor, which may be installed outdoors, is separate from the storage tank.

1.14. ***Standby*** means the time, in hours, during which water is not being withdrawn from the water heater.

1.15. ***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

$E_{annual,e}$ —annual electrical energy consumption of a water heater

$E_{annual,f}$ —annual fossil-fuel energy consumption of a water heater

E_X —energy efficiency of a heat pump-type water heater when the 24-hour simulated use test is optionally conducted at any of the additional air temperature conditions as specified in section 2.8 of this appendix, where the subscript "X" corresponds to the dry-bulb temperature at which the test is conducted.

F_{hr} —first-hour rating of a non-flow activated water heater

F_{max} —maximum GPM (L/min) rating of a flow-activated water heater

i —a subscript to indicate the draw number during a test

k_V —storage tank volume scaling ratio for water heaters with a rated storage volume greater than or equal to 2 gallons

$M_{del,i}$ —mass of water removed during the *i*th draw of the 24-hour simulated-use test

$M_{in,i}$ —mass of water entering the water heater during the *i*th draw of the 24-hour simulated-use test

$M^*_{del,i}$ —for non-flow activated water heaters, mass of water removed during the *i*th draw during the first-hour rating test

$M^*_{in,i}$ —for non-flow activated water heaters, mass of water entering the water heater during the *i*th draw during the first-hour rating test

$M_{del,10m}$ —for flow-activated water heaters, mass of water removed continuously during the maximum GPM (L/min) rating test

$M_{in,10m}$ —for flow-activated water heaters, mass of water entering the water heater continuously during the maximum GPM (L/min) rating test

n —for non-flow activated water heaters, total number of draws during the first-hour rating test

N —total number of draws during the 24-hour simulated-use test

N_r —number of draws from the start of the 24-hour simulated-use test to the end to the first recovery period as described in section 5.4.2 of this appendix

Q —total fossil fuel and/or electric energy consumed during the entire 24-hour simulated-use test

Q_d —daily water heating energy consumption adjusted for net change in internal energy

Q_{da} —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 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 of a water heater with a rated storage volume greater than or equal to 2 gallons

Q_{HW} —daily energy consumption to heat water at the measured average temperature rise across the water heater

$Q_{HW,67\ °F}$ —daily energy consumption to heat quantity of water removed during test over a temperature rise of 67 °F (37.3 °C)

Q_{HWD} —adjustment to daily energy consumption, Q_{HW}, due to variation of the temperature rise across the water heater not equal to the nominal value of 67 °F (37.3 °C)

Q_r —energy consumption of water heater from the beginning of the test to the end of the first recovery period

Q_{stby} —total energy consumed during the standby time interval $\tau_{stby,1}$, as determined in section 5.4.2 of this appendix

$Q_{su,0}$ —cumulative energy consumption, including all fossil fuel and electrical energy use, of the water heater from the start of the 24-hour simulated-use test to the start of the standby period as determined in section 5.4.2 of this appendix

$Q_{su,f}$ —cumulative energy consumption, including all fossil fuel and electrical energy use, of the water heater from the start of the 24-hour simulated-use test to the end of the standby period as determined in section 5.4.2 of this appendix

$\overline{T}_0$—mean tank temperature at the beginning of the 24-hour simulated-use test as determined in section 5.4.2 of this appendix

$\overline{T}_{24}$—mean tank temperature at the end of the 24-hour simulated-use test as determined in section 5.4.2 of this appendix

$\overline{T}_{a,stby}$—average ambient air temperature during all standby periods of the 24-hour simulated-use test as determined in section 5.4.2 of this appendix

$\overline{T}_{a,stby,1}$—overall average ambient temperature between the start and end of the standby period as determined in section 5.4.2 of this appendix

$\overline{T}_{t,stby,1}$— overall average mean tank temperature between the start and end of the standby period as determined in section 5.4.2 of this appendix

$\overline{T}_{del}$—for flow-activated water heaters, average outlet water temperature during the maximum GPM (L/min) rating test

$\overline{T}_{del,i}$—average outlet water temperature during the *i*th draw of the 24-hour simulated-use test

$\overline{T}_{in}$—for flow-activated water heaters, average inlet water temperature during the maximum GPM (L/min) rating test

$\overline{T}_{st}$—for water heaters which cannot have internal tank temperature directly measured, estimated average internal storage tank temperature

T_p—for water heaters which cannot have internal tank temperature directly measured, average of the inlet and the outlet water temperatures at the end of the period defined by τ_p

$\overline{T}_{in,p}$—for water heaters which cannot have internal tank temperature directly measured, average of the inlet water temperatures

$\overline{T}_{out,p}$—for water heaters which cannot have internal tank temperature directly measured, average of the outlet water temperatures

$\overline{T}_{in,i}$—average inlet water temperature during the *i*th draw of the 24-hour simulated-use test

$\overline{T}_{max,1}$—maximum measured mean tank temperature after the first recovery period of the 24-hour simulated-use test as determined in section 5.4.2 of this appendix

$\overline{T}_{su,0}$—maximum measured mean tank temperature at the beginning of the standby period as determined in section 5.4.2 of this appendix

$\overline{T}_{su,f}$—measured mean tank temperature at the end of the standby period as determined in section 5.4.2 of this appendix

$\overline{T}^*_{del,i}$—for non-flow activated water heaters, average outlet water temperature during the *i*th draw (i = 1 to n) of the first-hour rating test

$\overline{T}^*_{max,i}$—for non-flow activated water heaters, maximum outlet water temperature observed during the *i*th draw (i = 1 to n) of the first-hour rating test

$\overline{T}^*_{min,i}$—for non-flow activated water heaters, minimum outlet water temperature to terminate the *i*th draw (i = 1 to n) of the first-hour rating test

UA—standby loss coefficient of a water heater with a rated storage volume greater than or equal to 2 gallons

UEF—uniform energy factor of a water heater

V—the volume of hot water drawn during the applicable draw pattern

$V_{del,i}$—volume of water removed during the *i*th draw (i = 1 to N) of the 24-hour simulated-use test

$V_{in,i}$—volume of water entering the water heater during the *i*th draw (i = 1 to N) of the 24-hour simulated-use test

$V^*_{del,i}$ —for non-flow activated water heaters, volume of water removed during the *i*th draw (i = 1 to n) of the first-hour rating test

$V^*_{in,i}$ —for non-flow activated water heaters, volume of water entering the water heater during the *i*th draw (i = 1 to n) of the first-hour rating test

$V_{del,10m}$ —for flow-activated water heaters, volume of water removed during the maximum GPM (L/min) rating test

$V_{in,10m}$ —for flow-activated water heaters, volume of water entering the water heater during the maximum GPM (L/min) rating test

V_{st} —measured storage volume of the storage tank for water heaters with a rated storage volume greater than or equal to 2 gallons

V_{eff} —effective storage volume

$v_{out,p}$ —for water heaters which cannot have internal tank temperature directly measured, average flow rate

W_f —weight of storage tank when completely filled with water for water heaters with a rated storage volume greater than or equal to 2 gallons

W_t —tare weight of storage tank when completely empty of water for water heaters with a rated storage volume greater than or equal to 2 gallons

η_r —recovery efficiency

ρ —density of water

τ_p —for water heaters which cannot have internal tank temperature directly measured, duration of the temperature measurement period, determined by the length of time taken for the outlet water temperature to be within 2 °F of the inlet water temperature for 15 consecutive seconds (including the 15-second stabilization period)

$\tau_{stby,1}$ —elapsed time between the start and end of the standby period as determined in section 5.4.2 of this appendix

$\tau_{stby,2}$ —overall time of standby periods when no water is withdrawn during the 24-hour simulated-use test as determined in section 5.4.2 of this appendix

1.16. ***Temperature Controller*** means a device that is available to the user to adjust the temperature of the water inside a water heater that stores heated water or the outlet water temperature.

1.17. ***Thermal break*** means a thermally non-conductive material that can withstand a pressure of 150 psi (1.034 MPa) at a temperature greater than the maximum temperature the water heater is designed to produce and is utilized to insulate a bypass loop, if one is used in the test set-up, from the inlet piping.

1.18. ***Uniform Energy Factor*** means the measure of water heater overall efficiency.

1.19. ***Water Heater Requiring a Storage Tank*** means a water heater without a storage tank specified or supplied by the manufacturer that cannot meet the requirements of sections 2 and 5 of this appendix without the use of a storage water heater or unfired hot water storage tank.

2. Test Conditions.

2.1 ***Installation Requirements.*** Tests shall be performed with the water heater and instrumentation installed in accordance with section 4 of this appendix.

2.2 ***Ambient Air Temperature and Relative Humidity.***

2.2.1 ***Non-Heat Pump Water Heaters.*** The ambient air temperature shall be maintained between 65.0 °F and 70.0 °F (18.3 °C and 21.1 °C) on a continuous basis.

2.2.2 ***Heat Pump Water Heaters.*** The dry-bulb temperature shall be maintained at an average of 67.5 °F ± 1 °F (19.7 °C ± 0.6 °C) after a cut-in and before the next cut-out, an average of 67.5 °F ± 2.5 °F (19.7 °C ± 1.4 °C) after a cut-out and before the next cut-in, and at 67.5 °F ± 5 °F (19.7 °C ± 2.8 °C) on a continuous basis throughout the test. The relative humidity shall be maintained within a range of 50% ± 5% throughout the test, and at an average of 50% ± 2% after a cut-in and before the next cut-out.

When testing a split-system heat pump water heater or heat pump water heater requiring a separate storage tank, the heat pump portion of the system shall be tested at the conditions within this section and the separate water heater or unfired hot water storage tank shall be tested at either the conditions within this section or the conditions specified in section 2.2.1 of this appendix.

2.3 ***Supply Water Temperature.*** The temperature of the water being supplied to the water heater shall be maintained at 58 °F ± 2 °F (14.4 °C ± 1.1 °C) throughout the test.

2.4 ***Outlet Water Temperature.*** The temperature controllers of a non-flow activated water heater shall be set so that water is delivered at a temperature of 125 °F ± 5 °F (51.7 °C ± 2.8 °C).

2.5 ***Set Point Temperature.*** The temperature controller of a flow-activated water heater shall be set to deliver water at a temperature of 125 °F ± 5 °F (51.7 °C ± 2.8 °C). If the flow-activated water heater is not capable of delivering water at a temperature of 125 °F ± 5 °F (51.7 °C ± 2.8 °C) when supplied with water at the supply water temperature specified in section 2.3 of this appendix, then the flow-activated water heater shall be set to deliver water at its maximum water temperature.

2.6 ***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.

2.7 ***Electrical and/or Fossil Fuel Supply.***

2.7.1 ***Electrical.*** Maintain the electrical supply voltage to within ±2% of the center of the voltage range specified on the nameplate of the water heater by the water heater and/or heat pump manufacturer, from 5 seconds after a cut-in to 5 seconds before next cut-out.

2.7.2 ***Natural Gas.*** Maintain the supply pressure in accordance with the supply pressure specified on the nameplate of the water heater by the manufacturer. 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 and the gas appliance pressure regulator can be adjusted, the regulator outlet pressure shall be within the greater of ±10% of the manufacturer's specified manifold pressure, found on the nameplate of the water heater, or ±0.2 inches water column (0.05 kPa). Maintain the gas supply pressure and manifold pressure only when operating at the design power rating. 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).

2.7.3 ***Propane Gas.*** Maintain the supply pressure in accordance with the supply pressure specified on the nameplate of the water heater by the manufacturer. 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 and the gas appliance pressure regulator can be adjusted, the regulator outlet pressure shall be within the greater of ±10% of the manufacturer's specified manifold pressure, found on the nameplate of the water heater, or ±0.2 inches water column (0.05 kPa). Maintain the gas supply pressure and manifold pressure only when operating at the design power rating. 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).

2.7.4 ***Fuel Oil Supply.*** Maintain an uninterrupted supply of fuel oil. The fuel pump pressure shall be within ±10% of the pump pressure specified on the nameplate of the water heater or the installation and operations (I&O) manual by the manufacturer. Use fuel oil having a heating value of approximately 138,700 Btu per gallon (38,660 kJ per liter).

2.8 ***Optional Test Conditions (Heat Pump-Type Water Heaters).*** The following test conditions may be used for optional representations of E_X for heat pump-type water heaters. When conducting a 24-hour simulated use test to determine E_X, the test conditions in section 2.1 and sections 2.4 through 2.7 apply. The ambient air temperature and humidity conditions in section 2.2 and the supply water temperature in section 2.3 are replaced with the air temperature, humidity, and supply water temperature conditions as shown in the following table. Testing may optionally be performed at any or all of the conditions in the table, and the sampling plan found at 10 CFR 429.17(a) may be applied for voluntary representations.

Heat pump type	Metric	Outdoor air conditions		Indoor air conditions		Supply water temperature (°F)
		Dry-bulb temperature (°F)	Relative humidity (%)	Dry-bulb temperature (°F)	Relative humidity (%)	
Split-System or Circulating	E_5	5.0	30	67.5	50	42.0
	E_{34}	34.0	72			47.0
	E_{95}	95.0	25			67.0
Integrated, Split-System, or Circulating	E_{50}	N/A	N/A	50.0	58	50.0
	E_{95}	N/A	N/A	95.0	40	67.0

3. Instrumentation.

3.1 ***Pressure Measurements.*** 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).

3.2 ***Temperature Measurement***

3.2.1 ***Measurement.*** Temperature measurements shall be made in accordance with the Standard Method for Temperature Measurement, ASHRAE 41.1-2020, including the conditions as specified in ASHRAE 41.6-2014 as referenced in ASHRAE 41.1-2020, and excluding the steady-state temperature criteria in section 5.5 of ASHRAE 41.1-2020.

3.2.2 ***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).

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

3.2.4 ***Temperature Difference.*** Temperature difference between the entering and leaving water may be measured with any of the following:

(a) A thermopile

(b) Calibrated resistance thermometers

(c) Precision thermometers

(d) Calibrated thermistors

(e) Calibrated thermocouples

(f) Quartz thermometers

3.2.5 ***Thermopile Construction.*** If a thermopile is used, it shall be made from calibrated thermocouple wire taken from a single spool. Extension wires to the recording device shall also be made from that same spool.

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

3.3 ***Liquid Flow Rate Measurement.*** The accuracy of the liquid flow rate measurement, using the calibration if furnished, shall be equal to or less than ±1% of the measured value in mass units per unit time.

3.4 ***Electrical Energy.*** The electrical energy used shall be measured with an instrument and associated readout device that is accurate within ±0.5% of the reading.

3.5 ***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 ±1% of the reading.

3.6 ***Mass Measurements.*** For mass measurements greater than or equal to 10 pounds (4.5 kg), a scale that is accurate within ±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).

3.7 ***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 ±1% of the reading. The heating values of natural gas and propane must be corrected from those measured to the standard temperature of 60.0 °F (15.6 °C) and standard pressure of 30 inches of mercury column (101.6 kPa) using the method described in Annex B of ASHRAE 118.2-2022.

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

3.9 ***Volume.*** Volume measurements shall be measured with an accuracy of ±2% of the total volume.

3.10 ***Relative Humidity.*** If a relative humidity (RH) transducer is used to measure the relative humidity of the surrounding air while testing heat pump water heaters, the relative humidity shall be measured with an accuracy of ±1.5% RH.

4. Installation.

4.1 ***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 2x4 inch (5 cm x 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. Water heaters designed to be installed into a kitchen countertop space 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 2x4 inch (5 cm x 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. With the exception of using the storage tank described in section 4.10 of this appendix, the same requirements shall apply for water heaters requiring a storage tank. 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.

4.2 ***Water Supply.*** Connect the water heater to a water supply capable of delivering water at conditions as specified in sections 2.3 and 2.6 of this appendix.

4.3 ***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 of section 7 of this appendix. Inlet and outlet piping connections for wall-mounted water heaters shall be consistent with Figure 3 of section 7 of this appendix. 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 of section 7 of this appendix. 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 of section 7 of this appendix, 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 of section 7 of this appendix must be achieved. All piping between the water heater and inlet and outlet 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. Unions may be used to facilitate installation and removal of the piping arrangements. 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.

At the discretion of the test laboratory, the mass or water delivered may be measured on either the inlet or outlet of the water heater.

For water heaters designed to be used with a mixing valve and that do not have a self-contained mixing valve, a mixing valve shall be installed according to the water heater and/or mixing valve manufacturer's installation instructions. If permitted by the water heater and mixing valve manufacturer's instructions, the mixing valve and cold water junction may be installed where the elbows are located in the outlet and inlet line, respectively. If there are no installation instructions for the mixing valve in the water heater or mixing valve manufacturer's instructions, then the mixing valve shall be installed on the outlet line and the cold water shall be supplied from the inlet line from a junction installed downstream from the location where the inlet water temperature is measured. The outlet water temperature, water flow rate, and/or mass measuring instrumentation, if installed on the outlet side of the water heater, shall be installed downstream from the mixing valve.

4.4 ***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 3 of this appendix.

4.5 ***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 should 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 in this section, install the maximum number of sensors that comply with the installation requirements. Install the temperature sensors through:

(a) The anodic device opening;

(b) The relief valve opening; or

(c) The hot water outlet.

If installed through the relief valve opening or the hot water outlet, 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 between 4 and 8 $h \cdot ft^{2} \cdot °F/Btu$ (0.7 and 1.4 $m^{2} \cdot °C/W$). If temperature measurement sensors cannot be installed within the water heater, follow the alternate procedures in section 5.4.2.2 of this appendix.

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

4.7 ***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 of section 7 of this appendix, as applicable.

4.8 ***Flow Control.*** Install a valve or valves to provide flow as specified in sections 5.3 and 5.4 of this appendix.

4.9 ***Flue Requirements.***

4.9.1 ***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 gas-fired water heaters with venting equipment specified by the manufacturer in the I&O manual using the minimum vertical and horizontal lengths of vent pipe recommended by the manufacturer.

4.9.2 ***Oil-Fired Water Heaters.*** Establish a draft at the flue collar at the value specified by the manufacturer in the I&O manual. 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 should be installed with venting equipment as specified by the manufacturer in the I&O manual, using the minimum vertical and horizontal lengths of vent pipe recommended by the manufacturer.

4.10 ***Storage Tank Requirement for Circulating Water Heaters.*** On or after the compliance date of a final rule reviewing potential amended energy conservation standards for these products published after June 21, 2023,when testing a gas-fired, oil-fired, or electric resistance circulating water heater (*i.e.,* any circulating water heater that does not use a heat pump), the tank to be used for testing shall be an unfired hot water storage tank having volume between 80 and 120 gallons (364-546 liters) determined using the method specified in section 5.2.1 that meets but does not exceed the minimum energy conservation standards required according to 10 CFR 431.110. When testing a heat pump circulating water heater, the tank to be used for testing shall be an electric storage water heater that has a measured volume of 40 gallons (±5 gallons), has a First-Hour Rating greater than or equal to 51 gallons and less than 75 gallons resulting in classification under the medium draw pattern, and has a rated UEF equal to the minimum UEF standard specified at § 430.32(d), rounded to the nearest 0.01. The operational mode of the heat pump circulating water heater and storage water heater paired system shall be set in accordance with section 5.1.1 of this appendix. If the

circulating water heater is supplied with a separate non-integrated circulating pump, install this pump as per the manufacturer's installation instructions and include its power consumption in energy use measurements.

4.11 ***External Communication.*** If the water heater can connect to an external network or controller, any external communication or connection shall be disabled for the duration of testing; however, the communication module shall remain in an "on" state.

5. Test Procedures.

5.1 ***Operational Mode Selection.*** For water heaters that allow for multiple user-selected operational modes, all procedures specified in this appendix shall be carried out with the water heater in the same operational mode (*i.e.,* only one mode).

5.1.1 ***Testing at Normal Setpoint.*** The operational mode shall be the default mode (or similarly named, suggested mode for normal operation) as defined by the manufacturer in the I&O manual 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 back-up 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 back-up heating element(s), the first-hour rating test and the 24-hour 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.

5.1.2 ***High Temperature Testing.*** This paragraph applies to electric storage water heaters that are capable of heating their stored water above the target delivery temperature without initiation from a utility or third-party demand-response program, except for those that meet the definition of "heat pump-type" water heater at 10 CFR 430.2.

For those equipped with factory-installed or built-in mixing valves, set the unit to maintain the highest mean tank temperature possible while delivering water at 125 °F ± 5 °F. For those not so equipped, install an ASSE 1017-certified mixing valve in accordance with the provisions in section 4.3 and adjust the valve to deliver water at 125 °F ± 5 °F when the water heater is operating at its highest storage tank temperature setpoint. Maintain this setting throughout the entirety of the test.

5.2 ***Water Heater Preparation.***

5.2.1 ***Determination of Storage Tank Volume.*** For water heaters with a rated storage volume greater than or equal to 2 gallons and for separate storage tanks used for testing circulating water heaters, determine the storage capacity, $V_{st,}$ of the water heater or separate storage tank under test, in gallons (liters), by subtracting the tare weight, W_t, (measured while the tank is empty) from the gross weight of the storage tank when completely filled with water at the supply water temperature specified in section 2.3 of this appendix, W_f, (with all air eliminated and line pressure applied as described in section 2.6 of this appendix) and dividing the resulting net weight by the density of water at the measured temperature.

5.2.2 ***Setting the Outlet Discharge Temperature.***

5.2.2.1 ***Flow-Activated Water Heaters, including certain instantaneous water heaters and certain storage-type water heaters.*** Initiate normal operation of the water heater at the design power rating. Monitor the discharge water temperature and set to the value specified in section 2.5 of this appendix in accordance with the manufacturer's I&O manual. If the water heater is not capable of providing this discharge 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 discharge water temperature. Once the proper temperature control setting is achieved, the setting must remain fixed for the duration of the maximum GPM test and the 24-hour simulated-use test.

5.2.2.2 ***All Other Water Heaters.***

5.2.2.2.1 ***Water Heaters with a Single Temperature Controller.***

5.2.2.2.1.1 ***Water Heaters with Rated Volumes Less than 20 Gallons.*** Starting with a tank at the supply water temperature as specified in section 2.3 of this appendix, 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 ± 0.25 gallons per minute (3.8 liters ± 0.95 liters per minute) for 2 minutes. Starting 15 seconds after commencement of the draw, record the outlet temperature at 15-second intervals until the end of the 2-minute period. Determine whether the maximum outlet temperature is within the range specified in section 2.4 of this appendix. If not, turn off the water heater, adjust the temperature controller, and then drain and refill the tank with supply water at the temperature specified in section 2.3 of this appendix. 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 within the range specified in section 2.4 of this appendix. Once the proper temperature control setting is achieved, the setting must remain fixed for the duration of the first-hour rating test and the 24-hour simulated-use test.

5.2.2.2.1.2 ***Water Heaters with Rated Volumes Greater than or Equal to 20 Gallons.*** Starting with a tank at the supply water temperature specified in section 2.3 of this appendix, 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 ± 0.25 gallons per minute (6.4 liters ± 0.95 liters per minute) for 5 minutes. Starting 15 seconds after commencement of the draw, record the outlet temperature at 15-second intervals until the end of the 5-minute period. Determine whether the maximum outlet temperature is within the range specified in section 2.4 of this appendix. If not, turn off the water heater, adjust the temperature controller, and then drain and refill the tank with supply water at the temperature specified in section 2.3 of this appendix. 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 within the range specified in section 2.4 of this appendix. Once the proper temperature control setting is achieved, the setting must remain fixed for the duration of the first-hour rating test and the 24-hour simulated-use test.

5.2.2.2.2 ***Water Heaters 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 5.3.3 of this appendix. The following criteria must be met to ensure that all temperature controllers are set to deliver water in the range specified in section 2.4 of this appendix:

(a) At least 50 percent of the water drawn during the first draw of the first-hour rating test procedure shall be delivered at a temperature within the range specified in section 2.4 of this appendix.

(b) No water is delivered above the range specified in section 2.4 of this appendix during first-hour rating test.

(c) The delivery 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 within the range specified in section 2.4 of this appendix.

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 at the temperature specified in section 2.3 of this appendix. Repeat the procedure described at the start of section 5.2.2.2.2 of this appendix 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 2 and 5.2.4 of this appendix in preparing the water heater were followed.

5.2.3 ***Power Input Determination.*** For all water heaters except electric types, initiate normal operation (as described in section 5.1 of this appendix) and determine the power input, P, to the main burners (including pilot light power, if any) after 15 minutes of operation. Adjust all burners to achieve an hourly Btu (kJ) rating that is within ±2% of the maximum input rate value specified by the manufacturer. For an oil-fired water heater, adjust the burner to give a CO_2 reading recommended by the manufacturer and an hourly Btu (kJ) rating that is within ±2% of the maximum input rate specified by the manufacturer. Smoke in the flue may not exceed No. 1 smoke as measured by the procedure in ASTM D2156 (R2018), including the conditions as specified in ASTM E97-1987 as referenced in ASTM D2156 (R2018). If the input rating is not within ±2%, first increase or decrease the fuel pressure within the tolerances specified in section 2.7.2, 2.7.3 or 2.7.4 (as applicable) of this appendix until it is ±2% of the maximum input rate value specified by the manufacturer. If, after adjusting the fuel pressure, the fuel input rate cannot be achieved within ±2 percent of the maximum input rate value specified by the manufacturer, for gas-fired models increase or decrease the gas supply pressure within the range specified by the manufacturer. Finally, if the measured fuel input rate is still not within ±2 percent of the maximum input rate value specified by the manufacturer, modify the gas inlet orifice, if so equipped, as necessary to achieve a fuel input rate that is within ±2 percent of the maximum input rate value specified by the manufacturer.

5.2.4 ***Soak-In Period for Water Heaters with Rated Storage Volumes Greater than or Equal to 2 Gallons.*** For water heaters with a rated storage volume greater than or equal to 2 gallons (7.6 liters), the water heater must sit filled with water, connected to a power source, and without any draws taking place for at least 12 hours after initially being energized so as to achieve the nominal temperature set-point within the tank and with the unit connected to a power source.

5.3 ***Delivery Capacity Tests.***

5.3.1 ***General.*** For flow-activated water heaters, conduct the maximum GPM test, as described in section 5.3.2, Maximum GPM Rating Test for Flow-Activated Water Heaters, of this appendix. For all other water heaters, conduct the first-hour rating test as described in section 5.3.3 of this appendix.

5.3.2 ***Maximum GPM Rating Test for Flow-Activated Water Heaters.*** Establish normal water heater operation at the design power rating with the discharge water temperature set in accordance with section 5.2.2.1 of this appendix.

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 mass of 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).

5.3.3 ***First-Hour Rating Test.***

5.3.3.1 ***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 water heaters with rated storage volumes below 20 gallons, remove water at a rate of 1.5 ± 0.25 gallon per minute (5.7 ± 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 mass or volume withdrawn during each draw.

5.3.3.2 ***Draw Initiation Criteria.*** Begin the first-hour rating test by starting a draw on the 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 within the range specified in section 2.4 of this appendix. If this criterion is not met, then the next draw should be initiated once the heat pump compressor cuts out.

5.3.3.3 ***Test Sequence.*** Establish normal water heater operation. If the water heater is not presently operating, initiate a draw. The draw may be terminated any time after cut-in occurs. After cut-out occurs (*i.e.,* all temperature controllers are satisfied), if the water heater can have its internal tank temperatures measured, record the internal storage tank temperature at each sensor described in section 4.5 of this appendix 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. If the water heater cannot have its internal tank temperatures measured, wait 5 minutes after 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 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 $T^*_{max,1}$. 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 supply water temperature test condition specified in section 2.3 of this appendix is met. Terminate the hot water draw when the outlet temperature decreases to $T^*_{max,1}$−15 °F ($T^*_{max,1}$−8.3 °C). (Note, if the outlet temperature does not decrease to $T^*_{max,1}$−15 °F ($T^*_{max,1}$−8.3 °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 $T^*_{max,1}$−15 °F ($T^*_{max,1}$−8.3 °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 $\overline{T}^*_{del,i}$ 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 5.3.3.2 of this appendix 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 $T^*_{max,i}$−15 °F ($T^*_{max,i}$−8.3 °C). Record this temperature as $T^*_{min,i}$. Calculate and record the average outlet temperature and the mass or volume removed during each draw ($\overline{T}^*_{del,i}$ 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 $T^*_{max,n}$−15 °F ($T^*_{max,n}$−8.3 °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 5.3.3.2 of this appendix 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 ($T^*_{min,n-1}$). 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 ($\overline{T}^*_{del,n}$ and M^*_n or V^*_n, respectively).

5.4 ***24-Hour Simulated-Use Test.***

5.4.1 ***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 5.3.3 of this appendix, or the maximum GPM rating obtained following the test prescribed in section 5.3.2 of this appendix, whichever is applicable. 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 I of this section. For water heater 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 II of this section.

Table I—Draw Pattern To Be Used Based on First-Hour Rating

First-hour rating greater than or equal to:	. . . and first-hour rating less than:	Draw pattern to be used in the 24-hour simulated-use test
0 gallons	18 gallons	Very-Small-Usage (Table III.1).
18 gallons	51 gallons	Low-Usage (Table III.2).
51 gallons	75 gallons	Medium-Usage (Table III.3).
75 gallons	No upper limit	High-Usage (Table III.4).

Table II—Draw Pattern To Be Used Based on Maximum GPM Rating

Maximum GPM rating greater than or equal to:	and maximum GPM rating less than:	Draw pattern to be used in the 24-hour simulated-use test
0 gallons/minute	1.7 gallons/minute	Very-Small-Usage (Table III.1).
1.7 gallons/minute	2.8 gallons/minute	Low-Usage (Table III.2).
2.8 gallons/minute	4 gallons/minute	Medium-Usage (Table III.3).
4 gallons/minute	No upper limit	High-Usage (Table III.4).

The draw patterns are provided in Tables III.1 through III.4 in section 5.5 of this appendix. Use the appropriate draw pattern when conducting the test sequence provided in section 5.4.2 of this appendix for water heaters with rated storage volumes greater than or equal to 2 gallons or section 5.4.3 of this appendix for water heaters with rated storage volumes less than 2 gallons.

5.4.2 ***Test Sequence for Water Heater With Rated Storage Volume Greater Than or Equal to 2 Gallons.***

If the water heater is turned off, fill the water heater with supply water at the temperature specified in section 2.3 of this appendix and maintain supply water pressure as described in section 2.6 of this appendix. 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 5.2.4 of this appendix shall be implemented. If the water heater has undergone a first-hour rating test prior to conduct of the 24-hour 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.

For water heaters that can have their internal storage tank temperature measured directly, perform testing in accordance with the instructions in section 5.4.2.1 of this appendix. For water heaters that cannot have their internal tank temperatures measured, perform testing in accordance with the instructions in section 5.4.2.2. of this appendix.

5.4.2.1 ***Water Heaters Which Can Have Internal Storage Tank Temperature Measured Directly.***

After the 1-hour period specified in section 5.4.2 of this appendix, the 24-hour simulated-use test will begin. One minute prior to the start of the 24-hour simulated-use test, record the mean tank temperature (T_0).

At the start of the 24-hour simulated-use test, record the electrical and/or fuel measurement readings, as appropriate. Begin the 24-hour simulated-use test by withdrawing the volume specified in the appropriate table in section 5.5 of this appendix (*i.e.,* Table III.1, Table III.2, Table III.3, or Table III.4, depending on the first-hour rating or maximum GPM rating) for the first draw at the flow rate specified in the applicable 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 in section 5.5 of this appendix for a particular draw pattern, initiate additional draws pursuant to the draw pattern, removing the volume of hot water at the prescribed flow rate specified by the table. The maximum allowable deviation from the specified volume of water removed for any single draw taken at a nominal flow rate of 1.0 GPM or 1.7 GPM 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 of 3.0 GPM 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 gallon (±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 in section 5.5 of this appendix, within a tolerance of ±0.25 gallons per minute (±0.9 liters per minute). Measurements of the inlet and outlet temperatures shall be made 15 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 discharge temperature and the cold water inlet temperature for each draw $T_{del,i}$ and $T_{in,i}$). Determine and record the net mass or volume removed (M_i or V_i), as appropriate, after each draw.

The first recovery period is the time from the start of the 24-hour simulated-use test and continues during the temperature rise of the stored water until the first cut-out; if the cut-out occurs during a subsequent draw, the first recovery period includes the time until the draw of water from the tank stops. If, after the first cut-out occurs but during a subsequent draw, a subsequent cut-in occurs prior to the draw completion, the first recovery period includes the time until the subsequent cut-out occurs, prior to another draw. The first recovery period may continue until a cut-out occurs when water is not being removed from the water heater or a cut-out occurs during a draw and the water heater does not cut-in prior to the end of the draw.

At the end of the first recovery period, record the maximum mean tank temperature observed after cut-out ($T_{max,1}$). At the end of the first recovery period, record the total energy consumed by the water heater from the beginning of the test (Q_r), including all fossil fuel and/or electrical energy use, from the main heat source and auxiliary equipment including, but not limited to, burner(s), resistive elements(s), compressor, fan, controls, pump, *etc.,* as applicable.

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 after the end of the final draw in the first draw cluster, as identified in the applicable draw pattern table in section 5.5 of this appendix, then the standby period starts when a maximum mean 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 after the end of the final draw in the first draw cluster, as identified in the applicable draw pattern table in section 5.5 of this appendix, then the standby period starts five minutes after the end of that draw. 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 ($Q_{su,0}$).

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. Record the mean tank temperature at the start of the standby period ($T_{su,0}$). At 1-minute intervals, record ambient temperature, the electric and/or fuel instrument readings, and the mean tank temperature until the next draw is initiated. The end of the standby period is when the final mean tank temperature is recorded, as described. Just prior to initiation of the next draw, record the mean tank temperature ($T_{su,f}$). If the water heater is undergoing recovery when the next draw is initiated, record the mean tank temperature ($T_{su,f}$) at the minute prior to the start of the recovery. Determine the total electrical energy and/or fossil fuel energy consumption from the beginning of the test to the end of the standby period ($Q_{su,f}$). Record the time interval between the start of the standby period and the end of the standby period ($\tau_{stby,1}$).

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 24-hour simulated-use test (*i.e.,* since $\tau = 0$). During the last hour of the 24-hour simulated-use test (*i.e.,* hour 23 of the 24-hour 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.

In the event that the recovery period continues from the end of the last draw of the first draw cluster until the subsequent draw, the standby period will start after the end of the first recovery period after the last draw of the 24-hour simulated-use test, when the temperature reaches the maximum mean tank temperature, though no sooner than five minutes after the end of this recovery period. The standby period shall last eight hours, so testing may extend beyond the 24-hour duration of the 24-hour simulated-use test. Determine and record the total electrical energy and/or fossil fuel consumed from the beginning of the 24-hour 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 ($T_{su,0}$). Record the mean tank temperature, the ambient temperature, and the electric and/or fuel instrument readings at 1-minute intervals until the end of the 8-hour period. Record the mean tank temperature at the end of the 8-hour standby period ($T_{su,f}$). If the water heater is undergoing recovery at the end of the standby period, record the mean tank temperature ($T_{su,f}$) 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 ($Q_{su,f}$). Record the time interval between the start of the standby period and the end of the standby period as $\tau_{stby,1}$. Record the average ambient temperature from the start of the standby period to the end of the standby period ($T_{a,stby,1}$). Record the average mean tank temperature from the start of the standby period to the end of the standby period ($T_{t,stby,1}$).

If the standby period occurred at the end of the first recovery period after the last draw of the 24-hour simulated-use test, allow the water heater to remain in the standby mode until exactly 24 hours have elapsed since the start of the 24-hour simulated-use test (*i.e.,* since $\tau = 0$) or the end of the standby period, whichever is longer. At 24 hours, record the mean tank temperature (T_{24}) and the reading given by the gas meter, oil meter, and/or the electrical energy meter as appropriate. If the water heater is undergoing a recovery at 24 hours, record the reading given by the gas meter, oil meter, and/or electrical energy meter, as appropriate, and the mean tank temperature (T_{24}) at the minute prior to the start of the recovery. Determine the fossil fuel and/or electrical energy consumed during the 24 hours 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 ($\tau_{stby,2}$). When the standby period occurs after the last draw of the 24-hour simulated-use test, the test may extend past hour 24. When this occurs, the measurements taken after hour 24 apply only to the calculations of the standby loss coefficient. All other measurements during the time between hour 23 and hour 24 remain the same.

5.4.2.2 ***Water Heaters Which Cannot Have Internal Storage Tank Temperature Measured Directly.***

After the water heater has undergone a 1-hour idle period (as described in section 5.4.2 of this appendix), deactivate the burner, compressor, or heating element(s).

Remove water from the storage tank by performing a continuous draw at the flow rate specified for the first draw of applicable draw pattern for the 24-hour simulated use test in section 5.5 of this appendix within a tolerance of ±0.25 gallons per minute (±0.9 liters per minute). While removing the hot water, measure the inlet and outlet temperature after initiating the draw at 3-second intervals. Remove water until the outlet water temperature is within ±2 °F (±1.1 °C) of the inlet water temperature for 15 consecutive seconds. Determine the mean tank temperature using section 6.3.77 of this appendix and assign this value of $\overline{T}_{st}$ for $\overline{T}_0$, $\overline{T}_{max,1}$, and $\overline{T}_{su,0}$.

After completing the draw, reactivate the burner, compressor, or heating elements(s) and allow the unit to fully recover such that the main burner, heating elements, or heat pump compressor is no longer raising the temperature of the stored water. Let the water heater sit idle again for 1 hour prior to beginning the 24-hour test, during which time no water shall be drawn from the unit, and there shall be no energy input to the main heating elements. After the 1-hour period, the 24-hour simulated-use test will begin.

At the start of the 24-hour simulated-use test, record the electrical and/or fuel measurement readings, as appropriate. Begin the 24-hour simulated-use test by withdrawing the volume specified in the appropriate table in section 5.5 of this appendix (*i.e.,* Table III.1, Table III.2, Table III.3, or Table III.4, depending on the first-hour rating or maximum GPM rating) for the first draw at the flow rate specified in the applicable 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 ambient temperature every minute throughout the 24-hour simulated-use test. At the elapsed times specified in the applicable draw pattern table in section 5.5 of this appendix for a particular draw pattern, initiate additional draws pursuant to the draw pattern, removing the volume of hot water at the prescribed flow rate specified by the table. The maximum allowable deviation from the specified volume of water removed for any single draw taken at a nominal flow rate of 1.0 GPM or 1.7 GPM 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 of 3.0 GPM 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 gallon (± 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 in section 5.5 of this appendix, within a tolerance of ±0.25 gallons per minute (±0.9 liters per minute). Measurements of the inlet and outlet temperatures shall be made 15 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 discharge temperature and the cold water inlet temperature for each draw $T_{del,i}$ and $T_{in,i}$). Determine and record the net mass or volume removed (M_i or V_i), as appropriate, after each draw.

The first recovery period is the time from the start of the 24-hour simulated-use test and continues until the first cut-out; if the cut-out occurs during a subsequent draw, the first recovery period includes the time until the draw of water from the tank stops. If, after the first cut-out occurs but during a subsequent draw, a subsequent cut-in occurs prior to the draw completion, the first recovery period includes the time until the subsequent cut-out occurs, prior to another draw. The first recovery period may continue until a cut-out occurs when water is not being removed from the water heater or a cut-out occurs during a draw and the water heater does not cut-in prior to the end of the draw.

At the end of the first recovery period, record the total energy consumed by the water heater from the beginning of the test (Q_r), including all fossil fuel and/or electrical energy use, from the main heat source and auxiliary equipment including, but not limited to, burner(s), resistive elements(s), compressor, fan, controls, pump, etc., as applicable.

The standby period begins at five minutes after the first time a recovery ends following last draw of the simulated-use test and shall continue for 8 hours. At the end of the 8-hour standby period, record the total amount of time elapsed since the start of the 24-hour simulated-use test (*i.e.,* since $\tau = 0$).

Determine and record the total electrical energy and/or fossil fuel consumed from the beginning of the 24-hour 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 ambient temperature and the electric and/or fuel instrument readings at 1-minute intervals until the end of the 8-hour period. At the 8-hour mark, deactivate the water heater before drawing water from the tank. Remove water from the storage tank by performing a continuous draw atthe flow rate specified for the first draw of applicable draw pattern for the 24-hour simulated use test in section 5.5 of this appendix within a tolerance of ±0.25 gallons per minute (±0.9 liters per minute). While removing the hot water, measure the inlet and outlet temperature after initiating the draw at 3-second intervals. Remove water until the outlet water temperature is within ±2 °F (±1.1 °C) of the inlet water temperature for 15 consecutive seconds. Determine the mean tank temperature using section 6.3.77 of this appendix and assign this value of $\overline{T}_{st}$ for $\overline{T}_{su,f}$ and $\overline{T}_{24}$.

Determine the total electrical energy and/or fossil fuel energy consumption from the beginning of the test to the end of the standby period ($Q_{su,f}$). Record the time interval between the start of the standby period and the end of the standby period as $\tau_{stby,1}$. Record the average ambient temperature from the start of the standby period to the end of the standby period ($T_{a,stby,1}$). The average mean tank temperature from the start of the standby period to the end of the standby period ($T_{t,stby,1}$) shall be the average of $T_{su,0}$ and $T_{su,f}$.

5.4.3 ***Test Sequence for Water Heaters With Rated Storage Volume Less Than 2 Gallons.***

Establish normal operation with the discharge water temperature at 125 °F ± 5 °F (51.7 °C ± 2.8 °C) and set the flow rate as determined in section 5.2 of this appendix. 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. 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 Tables III.1

through III.4 of section 5.5 of this appendix 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 in Tables III.1 through III.4 for a particular draw pattern, initiate additional draws, removing the volume of hot water at the prescribed flow rate specified in Tables III.1 through III.4. 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 1.7 GPM (6.4 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 of 3.0 GPM (11.4 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.

All draws during the 24-hour simulated-use test shall be made at the flow rates specified in the applicable draw pattern table in section 5.5 of this appendix within a tolerance of ±0.25 gallons per minute (±0.9 liters per minute) unless the unit being tested is flow-activated and has a rated Max GPM of less than 1 gallon per minute, in which case the tolerance shall be ±25% of the rated Max GPM. Measurements of the inlet and outlet water temperatures shall be made 15 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 discharge temperature and the cold-water inlet temperature 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 first 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.

5.5 ***Draw Patterns.***

The draw patterns to be imposed during 24-hour simulated-use tests are provided in Tables III.1 through III.4. Subject each water heater under test to one of these draw patterns based on its first-hour rating or maximum GPM rating, as discussed in section 5.4.1 of this appendix. 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 in gallons (liters) that is to be removed during each draw, and the flow rate at which each draw is to be taken, in gallons (liters) per minute.

Table III.1—Very-Small-Usage Draw Pattern

Draw No.	Time during test ** [hh:mm]	Volume [gallons (L)]	Flow rate *** [GPM (L/min)]
1 *	0:00	2.0 (7.6)	1 (3.8)
2 *	1:00	1.0 (3.8)	1 (3.8)
3 *	1:05	0.5 (1.9)	1 (3.8)
4 *	1:10	0.5 (1.9)	1 (3.8)
5 *	1:15	0.5 (1.9)	1 (3.8)
6	8:00	1.0 (3.8)	1 (3.8)

Draw No.	Time during test ** [hh:mm]	Volume [gallons (L)]	Flow rate *** [GPM (L/min)]
7	8:15	2.0 (7.6)	1 (3.8)
8	9:00	1.5 (5.7)	1 (3.8)
9	9:15	1.0 (3.8)	1 (3.8)
Total Volume Drawn Per Day: 10 gallons (38 L)			

* Denotes draws in first draw cluster.

** If a draw extends to the start of the subsequent draw, then the subsequent draw shall start when the required volume of the previous draw has been delivered.

*** Should the water heater have a maximum GPM rating less than 1 GPM (3.8 L/min), then all draws shall be implemented at a flow rate equal to the rated maximum GPM.

Table III.2—Low-Usage Draw Pattern

Draw No.	Time during test [hh:mm]	Volume [gallons (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 (3.8)
3 *	1:00	1.0 (3.8)	1 (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 (3.8)
7	12:45	1.0 (3.8)	1 (3.8)
8	12:50	1.0 (3.8)	1 (3.8)
9	16:15	2.0 (7.6)	1 (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 III.3—Medium-Usage Draw Pattern

Draw No.	Time during test [hh:mm]	Volume [gallons (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 (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)

Draw No.	Time during test [hh:mm]	Volume [gallons (L)]	Flow Rate [GPM (L/min)]
6	12:00	1.0 (3.8)	1 (3.8)
7	12:45	1.0 (3.8)	1 (3.8)
8	12:50	1.0 (3.8)	1 (3.8)
9	16:00	1.0 (3.8)	1 (3.8)
10	16:15	2.0 (7.6)	1 (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 III.4—High-Usage Draw Pattern

Draw No.	Time during test [hh:mm]	Volume [gallons (L)]	Flow rate [GPM (L/min)]
1 *	0:00	27.0 (102)	3 (11.4)
2 *	0:30	2.0 (7.6)	1 (3.8)
3 *	0:40	1.0 (3.8)	1 (3.8)
4 *	1:40	9.0 (34.1)	1.7 (6.4)
5	10:30	15.0 (56.8)	3 (11.4)
6	11:30	5.0 (18.9)	1.7 (6.4)
7	12:00	1.0 (3.8)	1 (3.8)
8	12:45	1.0 (3.8)	1 (3.8)
9	12:50	1.0 (3.8)	1 (3.8)
10	16:00	2.0 (7.6)	1 (3.8)
11	16:15	2.0 (7.6)	1 (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 (11.4)
Total Volume Drawn Per Day: 84 gallons (318 L)			

* Denotes draws in first draw cluster.

5.6 ***Optional Tests (Heat Pump-Type Water Heaters).*** Optional testing may be conducted on heat pump-type water heaters to determine E_X. If optional testing is performed, conduct the additional 24-hour simulated use test(s) at one or multiple of the test conditions specified in section 2.8 of this appendix. Prior to conducting a 24-hour simulated use test at an optional condition, confirm the air and water conditions specified in section 2.8 are met and re-set the outlet discharge temperature in accordance with section 5.2.2 of this appendix. Perform the optional 24-hour simulated use test(s) in accordance with section 5.4 of this appendix using the same draw pattern used for the determination of UEF.

6. Computations.

6.1 ***First-Hour Rating Computation.*** For the case in which the final draw is initiated at or prior to one hour from the start of the test, the first-hour rating, F_{hr}, shall be computed using,

$$F_{hr} = \sum_{i=1}^{n} V^*_{del,i}$$

Where:

n = the number of draws that are completed during the first-hour rating test.

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

$$V^*_{del,i} = \frac{M^*_{del,i}}{\rho_{del,i}}$$

Where:

$M^*_{del,i}$ = the mass of water removed during the *i*th draw of the first-hour rating test, lb (kg).

$\rho_{del,i}$ = the density of water removed, evaluated at the average outlet water temperature measured during the *i*th draw of the first-hour rating test, ($\overline{T}^*_{del,i}$), lb/gal (kg/L).

or, if the volume of the water entering the water heater is being measured,

$$V^*_{del,i} = V^*_{in,i} \frac{\rho_{in,i}}{\rho_{del,i}}$$

Where:

$V^*_{in,i}$ = the volume of water entering the water heater during the *i*th draw of the first-hour rating test, gal (L).

$\rho_{in,i}$ = the density of water entering the water heater, evaluated at the average inlet water temperature measured during the *i*th draw of the first-hour rating test, ($\overline{T}^*_{in,i}$), lb/gal (kg/L).

or, if the mass of water entering the water heater is being measured,

$$V^*_{del,i} = \frac{M^*_{in,i}}{\rho_{del,i}}$$

Where:

$M^*_{in,i}$ = the mass of water entering the water heater during the *i*th draw of the first-hour rating test, lb (kg).

For the case in which a draw is not in progress at one hour from the start of the test and a final draw is imposed at the elapsed time of one hour, the first-hour rating shall be calculated using,

$$F_{hr} = V^*_{del,n}\left(\frac{\bar{T}^*_{del,n} - \bar{T}^*_{min,n-1}}{\bar{T}^*_{del,n-1} - \bar{T}^*_{min,n-1}}\right) + \sum_{i=1}^{n-1} V^*_{del,i}$$

where n and $V^*_{del,i}$ are the same quantities as defined above, and

$V^*_{del,n}$ = the volume of water removed during the *n*th (final) draw of the first-hour rating test, gal (L).

$\bar{T}^*_{del,n-1}$ = the average water outlet temperature measured during the *(n−1)*th draw of the first-hour rating test, °F (°C).

$\bar{T}^*_{del,n}$ = the average water outlet temperature measured during the *n*th (final) draw of the first-hour rating test, °F (°C).

$T^*_{min,n-1}$ = the minimum water outlet temperature measured during the *(n−1)*th draw of the first-hour rating test, °F (°C).

6.2 ***Maximum GPM (L/min) Rating Computation.*** Compute the maximum GPM (L/min) rating, F_{max}, as:

$$F_{max} = \frac{V_{del,10m}(\bar{T}_{del} - \bar{T}_{in})}{10(125°F - 58°F)}$$

or,

$$F_{max} = \frac{V_{del,10m}(\bar{T}_{del} - \bar{T}_{in})}{10(51.7°C - 14.4°C)}$$

Where:

$V_{del,10m}$ = the volume of water removed during the maximum GPM (L/min) rating test, gal (L).

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

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

10 = the number of minutes in the maximum GPM (L/min) rating test, min.

or, if the mass of water removed is measured,

$$V_{del,10m} = \frac{M_{del,10m}}{\rho_{del}}$$

Where:

$M_{del,10m}$ = the mass of water removed during the maximum GPM (L/min) rating test, lb (kg).

ρ_{del} = the density of water removed, evaluated at the average delivery water temperature of the maximum GPM (L/min) rating test ($\overline{T}_{del}$), lb/gal (kg/L).

or, if the volume of water entering the water heater is measured,

$$V_{del,10m} = V_{in,10m} \frac{\rho_{in}}{\rho_{del}}$$

Where:

$V_{in,10m}$ = the volume of water entering the water heater during the maximum GPM (L/min) rating test, gal (L).

ρ_{in} = the density of water entering the water heater, evaluated at the average inlet water temperature of the maximum GPM (L/min) rating test ($\overline{T}_{del}$), lb/gal (kg/L).

or, if the mass of water entering the water heater is measured,

$$V_{del,10m} = \frac{M_{in,10m}}{\rho_{del}}$$

Where:

$M_{in,10m}$ = the mass of water entering the water heater during the maximum GPM (L/min) rating test, lb (kg).

6.3 ***Computations for Water Heaters with a Rated Storage Volume Greater Than or Equal to 2 Gallons and Circulating Water Heaters.***

6.3.1 ***Storage Tank Capacity.*** The storage tank capacity, V_{st}, is computed as follows:

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

Where:

V_{st} = the storage capacity of the water heater, or, for circulating water heaters, the storage capacity of the separate storage tank used in accordance with section 4.10, 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 = the density of water used to fill the tank measured at the temperature of the water, lb/gal (kg/L).

6.3.1.1 ***Effective Storage Volume.*** The effective storage tank capacity, V_{eff}, is computed as follows:

For water heaters requiring a separate storage tank, V_{eff} is the storage tank capacity of the separate storage tank as determined per section 6.3.1.

For all other water heaters:

$V_{eff} = k_V V_{st}$

Where:

V_{st} = as defined in section 6.3.1 and

k_V = a dimensionless volume scaling factor determined as follows:

If the first recovery period extends into the second draw of the 24-hour simulated use test, and

If $\overline{T}_0 > (\overline{T}_{del,1} + 5\ °F)$ and $\overline{T}_0 \geq 130\ °F$,

(if $\overline{T}_0 > (\overline{T}_{del,1} + 2.8\ °C)$ and $\overline{T}_0 \geq 54.4\ °C$),

$$k_V = \frac{\rho(\overline{T}_0) \times C_p(\overline{T}_0) \times (\overline{T}_0 - 67.5°F)}{\rho(125°F) \times C_p(125°F) \times (125°F - 67.5°F)}$$

$$(k_V = \frac{\rho(\overline{T}_0) \times C_p(\overline{T}_0) \times (\overline{T}_0 - 19.7°C)}{\rho(51.7°C) \times C_p(51.7°C) \times (51.7°C - 19.7°C)});$$

If the first recovery period does not extend into the second draw of the 24-hour simulated use test, and

If $\overline{T}_{max,1} > (\overline{T}_{del,2} + 5\ °F)$ and $\overline{T}_{max,1} \geq 130\ °F$,

(if $\overline{T}_{max,1} > (\overline{T}_{del,2} + 2.8\ °C)$ and $\overline{T}_{max,1} \geq 54.4\ °C$),

$$k_V = \frac{\rho(\overline{T}_{max,1}) \times C_p(\overline{T}_{max,1}) \times (\overline{T}_{max,1} - 67.5°F)}{\rho(125°F) \times C_p(125°F) \times (125°F - 67.5°F)}$$

$$(k_V = \frac{\rho(\overline{T}_{max,1}) \times C_p(\overline{T}_{max,1}) \times (\overline{T}_{max,1} - 19.7°C)}{\rho(51.7°C) \times C_p(51.7°C) \times (51.7°C - 19.7°C)});$$

Otherwise, $k_V = 1$.

Where:

$\overline{T}_0$= the mean tank temperature at the beginning of the 24-hour simulated-use test, °F(°C).

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

$\rho(\overline{T}_0)$ = the density of the stored hot water evaluated at the mean tank temperature at the beginning of the 24-hour simulated-use test ($\overline{T}_0$), lb/gal (kg/L).

$C_p(\overline{T}_0)$ = the specific heat of the stored hot water, evaluated at $\overline{T}_0$, Btu/(lb· °F) (kJ/(kg· °C)).

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

$\overline{T}_{del,2}$= the average outlet water temperature during the second draw of the 24-hour simulated-use test, °F(°C).

$\rho(\overline{T}_{max,1})$ = the density of the stored hot water evaluated at the maximum measured mean tank temperature after cut-out following the first draw of the 24-hour simulated-use test ($\overline{T}_{max,1}$), lb/gal (kg/L).

$C_p(\overline{T}_{max,1})$ = the specific heat of the stored hot water, evaluated at $\overline{T}_{max,1}$, Btu/(lb· °F) (kJ/(kg· °C)).

ρ(125 °F) = the density of the stored hot water at 125 °F, lb/gal (kg/L).

C_p(125 °F) = the specific heat of the stored hot water at 125 °F, Btu/(lb· °F) (kJ/(kg· °C)).

125 °F (51.7 °C) = the nominal maximum mean tank temperature for a storage tank that does not utilize a mixing valve to achieve a 125 °F delivery temperature.

67.5 °F (19.7 °C) = the nominal average ambient air temperature.

6.3.2 ***Mass of Water Removed.*** Determine the mass of water removed during each draw of the 24-hour simulated-use test ($M_{del,i}$) as:

If the mass of water removed is measured, use the measured value, or, if the volume of water removed is being measured,

$M_{del,i} = V_{del,i} * P_{del,i}$

Where:

$V_{del,i}$ = volume of water removed during the *i*th draw of the 24-hour simulated-use test, gal (L).

$\rho_{del,i}$ = density of the water removed, evaluated at the average outlet water temperature measured during the *i*th draw of the 24-hour simulated-use test, ($\overline{T}_{del,i}$), lb/gal (kg/L).

or, if the volume of water entering the water heater is measured,

$M_{del,i} = V_{in,i} * \rho_{in,i}$

Where:

$V_{in,i}$ = volume of water entering the water heater during draw *i*th draw of the 24-hour simulated-use test, gal (L).

$\rho_{in,i}$ = density of the water entering the water heater, evaluated at the average inlet water temperature measured during the *i*th draw of the 24-hour simulated-use test, ($\overline{T}_{in,i}$), lb/gal (kg/L).

or, if the mass of water entering the water heater is measured,

$M_{del,i} = M_{in,i}$

Where:

$M_{in,i}$ = mass of water entering the water heater during draw *i*th draw of the 24-hour simulated-use test, lb (kg).

6.3.3 ***Recovery Efficiency.*** The recovery efficiency for gas, oil, and heat pump water heaters with a rated storage volume greater than or equal to 2 gallons, η_r, is computed as:

$$\eta_r = \frac{V_{st}\,\rho_1\,C_{p1}\left(\overline{T}_{max,1} - \overline{T}_0\right)}{Q_r} + \sum_{i=1}^{N_r} \frac{M_{del,i}\,C_{pi}\left(\overline{T}_{del,i} - \overline{T}_{in,i}\right)}{Q_r}$$

Where:

V_{st} = as defined in section 6.3.1 of this appendix.

ρ_1 = density of stored hot water evaluated at ($\overline{T}_{max,1}$ + $\overline{T}_0$)/2, lb/gal (kg/L).

C_{p1} = specific heat of the stored hot water, evaluated at ($\overline{T}_{max,1}$ + $\overline{T}_0$)/2, Btu/(lb· °F) (kJ/(kg· °C).

$\overline{T}_{max,1}$ = maximum mean tank temperature recorded after the first recovery period as defined in section 5.4.2 of this appendix, °F (°C).

$\overline{T}_0$ = mean tank temperature recorded at the beginning of the 24-hour simulated-use test as determined in section 5.4.2 of this appendix, °F (°C).

Q_r = the total energy used by the water heater during the first recovery period as defined in section 5.4.2 of this appendix, 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).

N_r = number of draws from the start of the 24-hour simulated-use test to the end to the first recovery period as described in section 5.4.2.

$M_{del,i}$ = mass of water removed as calculated in section 6.3.2 of this appendix during the *i*th draw of the first recovery period as described in section 5.4.2, lb (kg).

C_{pi} = specific heat of the withdrawn water during the *i*th draw of the first recovery period as described in section 5.4.2, evaluated at $(\overline{T}_{del,i} + \overline{T}_{in,i})/2$, Btu/(lb· °F) (kJ/(kg· °C)).

$\overline{T}_{del,i}$ = average water outlet temperature measured during the *i*th draw of the first recovery period as described in section 5.4.2, °F (°C).

$\overline{T}_{in,i}$ = average water inlet temperature measured during the *i*th draw of the first recovery period as described in section 5.4.2, °F (°C).

The recovery efficiency for electric water heaters with immersed heating elements, not including heat pump water heaters with immersed heating elements, is assumed to be 98 percent.

6.3.4 ***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:

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

Where:

$Q_{su,0}$ = cumulative energy consumption, including all fossil fuel and electrical energy use, of the water heater from the start of the 24-hour simulated-use test to the start of the standby period as determined in section 5.4.2 of this appendix, Btu (kJ).

$Q_{su,f}$ = cumulative energy consumption, including all fossil fuel and electrical energy use, of the water heater from the start of the 24-hour simulated-use test to the end of the standby period as determined in section 5.4.2 of this appendix, Btu (kJ).

The hourly standby energy losses are computed as:

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

Where:

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

V_{st} = as defined in section 6.3.1 of this appendix.

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

C_p = specific heat of the stored water, evaluated at $(\overline{T}_{su,f} + \overline{T}_{su,0})/2$, Btu/(lb· °F), (kJ/(kg·K)).

$\overline{T}_{su,f}$ = the mean tank temperature measured at the end of the standby period as determined in section 5.4.2 of this appendix, °F (°C).

$\overline{T}_{su,0}$ = the maximum mean tank temperature measured at the beginning of the standby period as determined in section 5.4.2 of this appendix, °F (°C).

η_r = as defined in section 6.3.3 of this appendix.

$\tau_{stby,1}$ = elapsed time between the start and end of the standby period as determined in section 5.4.2 of this appendix, h.

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

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

Where:

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

$\overline{T}_{t,stby,1}$ = overall average mean tank temperature between the start and end of the standby period as determined in section 5.4.2 of this appendix, °F (°C).

$\overline{T}_{a,stby,1}$ = overall average ambient temperature between the start and end of the standby period as determined in section 5.4.2 of this appendix, °F (°C).

6.3.5 ***Daily Water Heating Energy Consumption.*** The total energy used by the water heater during the 24-hour simulated-use test (Q) is as measured in section 5.4.2 of this appendix, or,

$Q = Q_f + Q_e$ = 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).

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). (Electrical energy shall be converted to thermal energy using the following conversion: 1kWh = 3412 Btu.)

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

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

Where:

V_{st} = as defined in section 6.3.1 of this appendix.

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

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

$\overline{T}_{24}$ = mean tank temperature at the end of the 24-hour simulated-use test as determined in section 5.4.2 of this appendix, °F (°C).

$\overline{T}_{0}$ = mean tank temperature recorded at the beginning of the 24-hour simulated-use test as determined in section 5.4.2 of this appendix, °F (°C).

η_r = as defined in section 6.3.3 of this appendix.

6.3.6 ***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 of 67.5 °F (19.7 °C) due to the allowable variation in surrounding ambient temperature of 65 °F (18.3 °C) to 70 °C (21.1 °C). The adjusted daily water heating energy consumption is computed as:

$$Q_{da} = Q_d - (67.5\ °C - \overline{T}_{a,stby,2})\ UA\ \tau_{stby,2}$$

or,

$$Q_{da} = Q_d - (19.7\ °C - \overline{T}_{a,stby,2})\ UA\ \tau_{stby,2}$$

Where:

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

Q_d = as defined in section 6.3.4 of this appendix.

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

UA = as defined in section 6.3.4 of this appendix.

$\tau_{stby,2}$ = 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 of 67 °F (125 °F-58 °F) or 37.3 °C (51.7 °C-14.4 °C). The following equations adjust the experimental data to a nominal 67 °F (37.3 °C) temperature rise.

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

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

Where:

N = total number of draws in the 24-hour simulated-use test.

$M_{del,i}$ = the mass of water removed during the *i*th draw (i = 1 to N) as calculated in section 6.3.2 of this appendix, lb (kg).

C_{pi} = the specific heat of the water withdrawn during the *i*th draw of the 24-hour simulated-use test, evaluated at $(\overline{T}_{del,i} + \overline{T}_{in,i})/2$, Btu/(lb· °F) (kJ/(kg· °C)).

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

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

η_r = as defined in section 6.3.3 of this appendix.

The energy required to heat the same quantity of water over a 67 °F (37.3 °C) temperature rise, Btu/day (kJ/day), is:

$$Q_{HW,67°F} = \sum_{i=1}^{N} \frac{M_{del,i}\, C_{pi}(125°F - 58°F)}{\eta_r}$$

or,

$$Q_{HW,37.3°C} = \sum_{i=1}^{N} \frac{M_{del,i}\, C_{pi}(51.7°C - 14.4°C)}{\eta_r}$$

The difference between these two values is:

$Q_{HWD} = Q_{HW,67.\,°F} - Q_{HW}$

or,

$Q_{HWD} = Q_{HW,37.3\,°C} - Q_{HW}$

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 may not be 67.5 °F (19.7 °C) and that the temperature rise across the storage tank may not be 67 °F (37.3 °C) is:

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

6.3.7 ***Estimated Mean Tank Temperature for Water Heaters with Rated Storage Volumes Greater Than or Equal to 2 Gallons.*** If testing is conducted in accordance with section 5.4.2.2 of this appendix, calculate the mean tank temperature immediately prior to the internal tank temperature determination draw using the following equation:

$$\overline{T}_{st} = T_p - \frac{v_{out,p}}{V_{st}} \times \tau_p(\overline{T}_{in,p} - \overline{T}_{out,p})$$

Where:

$\overline{T}_{st}$ = the estimated average internal storage tank temperature, °F (°C).

T_p = the average of the inlet and the outlet water temperatures at the end of the period defined by τ_p, °F (°C).

$v_{out,p}$ = the average flow rate during the period, gal/min (L/min).

V_{st} = the rated storage volume of the water heater, gal (L).

τ_p = the number of minutes in the duration of the period, determined by the length of time taken for the outlet water temperature to be within 2 °F of the inlet water temperature for 15 consecutive seconds and including the 15-second stabilization period.

$\overline{T}_{in,p}$ = the average of the inlet water temperatures during the period, °F (°C).

$\overline{T}_{out,p}$ = the average of the outlet water temperatures during the period, °F (°C).

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

$$UEF = \sum_{i=1}^{N} \frac{M_{del,i}\, C_{pi}\, (125°F - 58°F)}{Q_{dm}}$$

or,

$$UEF = \sum_{i=1}^{N} \frac{M_{del,i}\, C_{pi}\, (51.7°C - 14.4°C)}{Q_{dm}}$$

Where:

N = total number of draws in the 24-hour simulated-use test.

Q_{dm} = the modified daily water heating energy consumption as computed in accordance with section 6.3.6 of this appendix, Btu (kJ).

$M_{del,i}$ = the mass of water removed during the *i*th draw (i = 1 to N) as calculated in section 6.3.2 of this appendix, lb (kg).

C_{pi} = the specific heat of the water withdrawn during the *i*th draw of the 24-hour simulated-use test, evaluated at (125 °F + 58 °F)/2 = 91.5 °F ((51.7 °C + 14.4 °C)/2 = 33 °C), Btu/(lb· °F) (kJ/(kg· °C)).

6.3.9 ***Annual Energy Consumption.*** The annual energy consumption for water heaters with rated storage volumes greater than or equal to 2 gallons is computed as:

$$E_{annual} = 365 * \frac{(V)(\rho)(C_p)(67)}{UEF}$$

Where:

UEF = the uniform energy factor as computed in accordance with section 6.3.88 of this appendix.

365 = the number of days in a year.

V = the volume of hot water drawn during the applicable draw pattern, gallons.

= 10 for the very-small-usage draw pattern.

= 38 for the low-usage draw pattern.

= 55 for the medium-usage draw pattern.

= 84 for high-usage draw pattern.

ρ = 8.24 lb/gallon, the density of water at 125 °F.

C_p = 1.00 Btu/(lb °F), the specific heat of water at 91.5 °F.

67 = the nominal temperature difference between inlet and outlet water

6.3.10 ***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, $E_{annual,e,}$ is computed as:

$$E_{annual,e} = \frac{E_{annual}}{3412} * \left(\frac{Q_e}{Q}\right)$$

Where:

E_{annual} = the annual energy consumption as determined in accordance with section 6.3.99 of this appendix, Btu (kJ).

Q_e = the daily electrical energy consumption as defined in section 6.3.5 of this appendix, Btu (kJ).

Q = total energy used by the water heater during the 24-hour simulated-use test in accordance with section 6.3.5 of this appendix, Btu (kJ).

3412 = conversion factor from Btu to kWh.

6.3.11 ***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, $E_{annual,f,}$ is computed as:

$E_{annual,f} = E_{annual} - (E_{annual,e} * 3412)$

Where:

E_{annual} = the annual energy consumption as determined in accordance with section 6.3.9 of this appendix, Btu (kJ).

$E_{annual,e}$ = the annual electrical energy consumption as determined in accordance with section 6.3.10 of this appendix, kWh.

3412 = conversion factor from kWh to Btu.

6.4 ***Computations for Water Heaters with a Rated Storage Volume Less Than 2 Gallons.***

6.4.1 ***Mass of Water Removed***

Calculate the mass of water removed using the calculations in section 6.3.2 of this appendix.

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

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

Where:

M_1 = mass of water removed during the first draw of the 24-hour simulated-use test, lb (kg).

C_{p1} = specific heat of the withdrawn water during the first draw of the 24-hour simulated-use test, evaluated at $(\overline{T}_{del,1} + \overline{T}_{in,1})/2$, Btu/(lb· °F) (kJ/(kg· °C)).

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

$\overline{T}_{in,1}$ = average water inlet 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 during the first recovery period as defined in section 5.4.3 of this appendix, 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.)

6.4.3 ***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). (Electrical auxiliary energy shall be converted to thermal energy using the following conversion: 1 kWh = 3412 Btu.)

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 of 67 °F (125 °F−58 °F) or 37.3 °C (51.7 °C−14.4 °C). The following equations adjust the experimental data to a nominal 67 °F (37.3 °C) temperature rise.

The energy used to heat water may be computed as:

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

Where:

N = total number of draws in the 24-hour simulated-use test.

$M_{del,i}$ = the mass of water removed during the *i*th draw (i = 1 to N) as calculated in section 6.4.1 of this appendix, lb (kg).

C_{pi} = the specific heat of the water withdrawn during the *i*th draw of the 24-hour simulated-use test, evaluated at $(\overline{T}_{del,i} + \overline{T}_{in,i})/2$, Btu/(lb· °F) (kJ/(kg· °C)).

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

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

η_r = as defined in section 6.4.2 of this appendix.

The energy required to heat the same quantity of water over a 67 °F (37.3 °C) temperature rise is:

$$Q_{HW,67°F} = \sum_{i=1}^{N} \frac{M_{del,i}\, C_{pi}(125°F - 58°F)}{\eta_r}$$

or,

$$Q_{HW,37.3°C} = \sum_{i=1}^{N} \frac{M_{del,i}\, C_{pi}(51.7°C - 14.4°C)}{\eta_r}$$

Where:

N = total number of draws in the 24-hour simulated-use test.

$M_{del,i}$ = the mass of water removed during the *i*th draw (i = 1 to N) as calculated in section 6.4.1 of this appendix, lb (kg).

C_{pi} = the specific heat of the water withdrawn during the *i*th draw of the 24-hour simulated-use test, evaluated at $(\overline{T}_{del,i} + \overline{T}_{in,i})/2$, Btu/(lb· °F) (kJ/(kg· °C)).

η_r = as defined in section 6.4.2 of this appendix.

The difference between these two values is:

$Q_{HWD} = Q_{HW,67\ °F} - Q_{HW}$

or,

$Q_{HWD} = Q_{HW,37.3\ °C} - Q_{HW}$

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 67 °F (37.3 °C), is:

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

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

$$UEF = \sum_{i=1}^{N} \frac{M_{del,i}\, C_{pi}\, (125°F - 58°F)}{Q_{dm}}$$

or,

$$UEF = \sum_{i=1}^{N} \frac{M_{del,i}\, C_{pi}\, (51.7°C - 14.4°C)}{Q_{dm}}$$

Where:

N = total number of draws in the 24-hour simulated-use test.

Q_{dm} = the modified daily water heating energy consumption as computed in accordance with section 6.4.3 of this appendix, Btu (kJ).

$M_{del,i}$ = the mass of water removed during the *i*th draw (i = 1 to N) as calculated in section 6.4.1 of this appendix, lb (kg).

C_{pi} = the specific heat of the water withdrawn during the *i*th draw of the 24-hour simulated-use test, evaluated at (125 °F + 58 °F)/2 = 91.5 °F ((51.7 °C + 14.4 °C)/2 = 33.1 °C), Btu/(lb· °F) (kJ/(kg· °C)).

6.4.5 ***Annual Energy Consumption.*** The annual energy consumption for water heaters with rated storage volumes less than 2 gallons, $E_{annual,}$ is computed as:

$$E_{annual} = 365 * \frac{(V)(\rho)(C_p)(67)}{UEF}$$

Where:

UEF = the uniform energy factor as computed in accordance with section 6.4.4 of this appendix.

365 = the number of days in a year.

V = the volume of hot water drawn during the applicable draw pattern, gallons.

= 10 for the very-small-usage draw pattern.

= 38 for the low-usage draw pattern.

= 55 for the medium-usage draw pattern.

= 84 for high-usage draw pattern.

ρ = 8.24 lb/gallon, the density of water at 125 °F.

C_p = 1.00 Btu/(lb °F), the specific heat of water at 91.5 °F.

67 = the nominal temperature difference between inlet and outlet water.

6.4.6 ***Annual Electrical Energy Consumption.*** The annual electrical energy consumption in kilowatt-hours for water heaters with rated storage volumes less than 2 gallons, $E_{annual,e,}$ is computed as:

$$E_{annual,e} = \frac{E_{annual}}{3412} * \left(\frac{Q_e}{Q}\right)$$

Where:

Q_e = the daily electrical energy consumption as defined in section 6.4.3 of this appendix, Btu (kJ).

E_{annual} = the annual energy consumption as determined in accordance with section 6.4.5 of this appendix, Btu (kJ).

Q = total energy used by the water heater during the 24-hour simulated-use test in accordance with section 6.4.3 of this appendix, Btu (kJ).

Q_{dm} = the modified daily water heating energy consumption as computed in accordance with section 6.4.3 of this appendix, Btu (kJ).

3412 = conversion factor from Btu to kWh.

6.4.7 ***Annual Fossil Fuel Energy Consumption.*** The annual fossil fuel energy consumption for water heaters with rated storage volumes less than 2 gallons, $E_{annual,f,}$ is computed as:

Where:

E_{annual} = the annual energy consumption as defined in section 6.4.5 of this appendix, Btu (kJ).

$E_{annual,e}$ = the annual electrical energy consumption as defined in section 6.4.6 of this appendix, kWh.

3412 = conversion factor from kWh to Btu.

6.5 ***Energy Efficiency at Optional Test Conditions.*** If testing is conducted at optional test conditions in accordance with section 5.6 of this appendix, calculate the energy efficiency at the test condition, $E_{X,}$ using the formulas in sections 6.3 or 6.4 of this appendix (as applicable), except substituting the applicable ambient temperature and supply water temperature used for testing (as specified in section 2.8 of this appendix) for the nominal ambient temperature and supply water temperature conditions used in the equations for determining UEF (*i.e.,* 67.5 °F and 58 °F).

7. Test Set-Up Diagrams

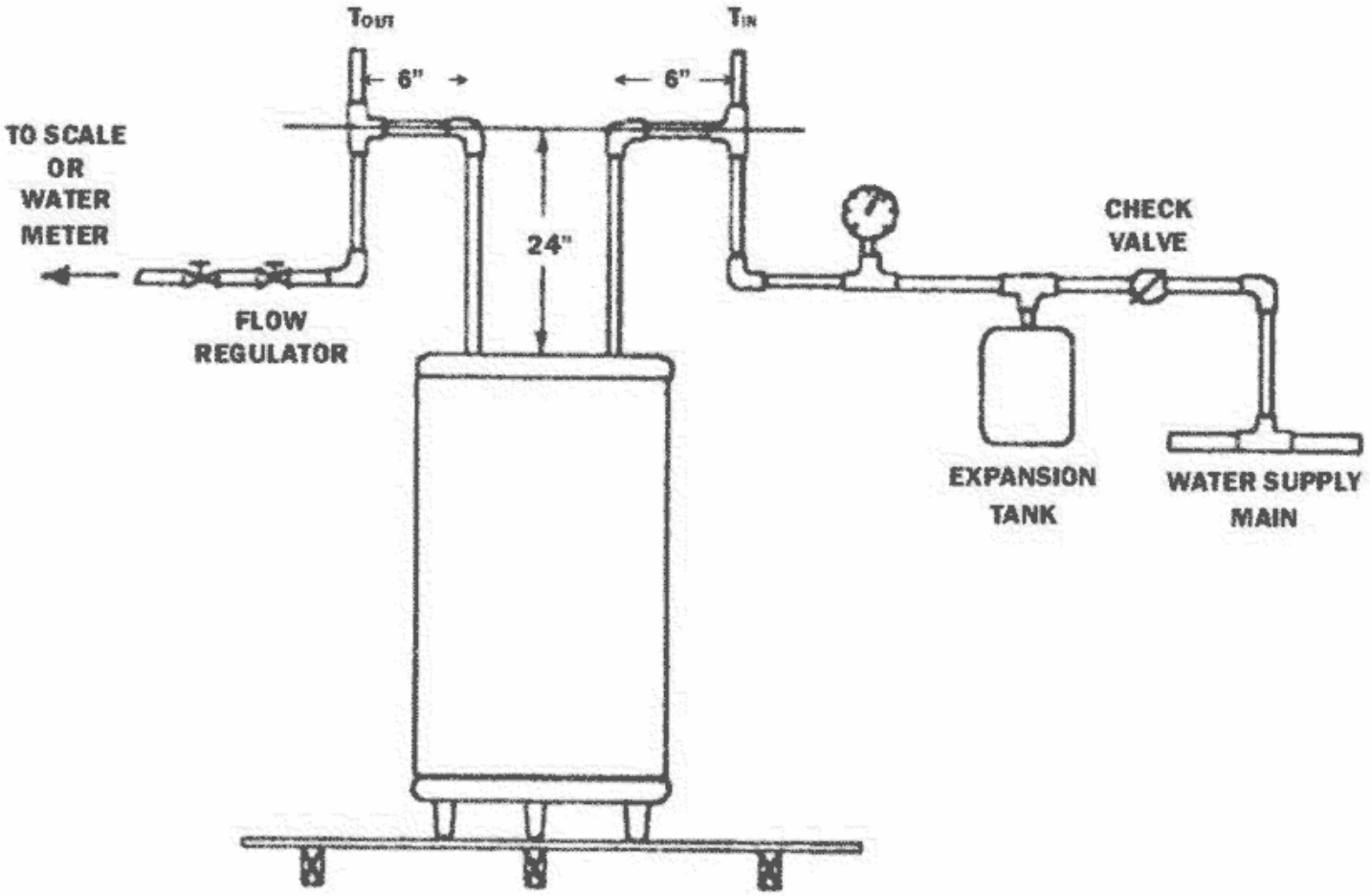


Figure 1.

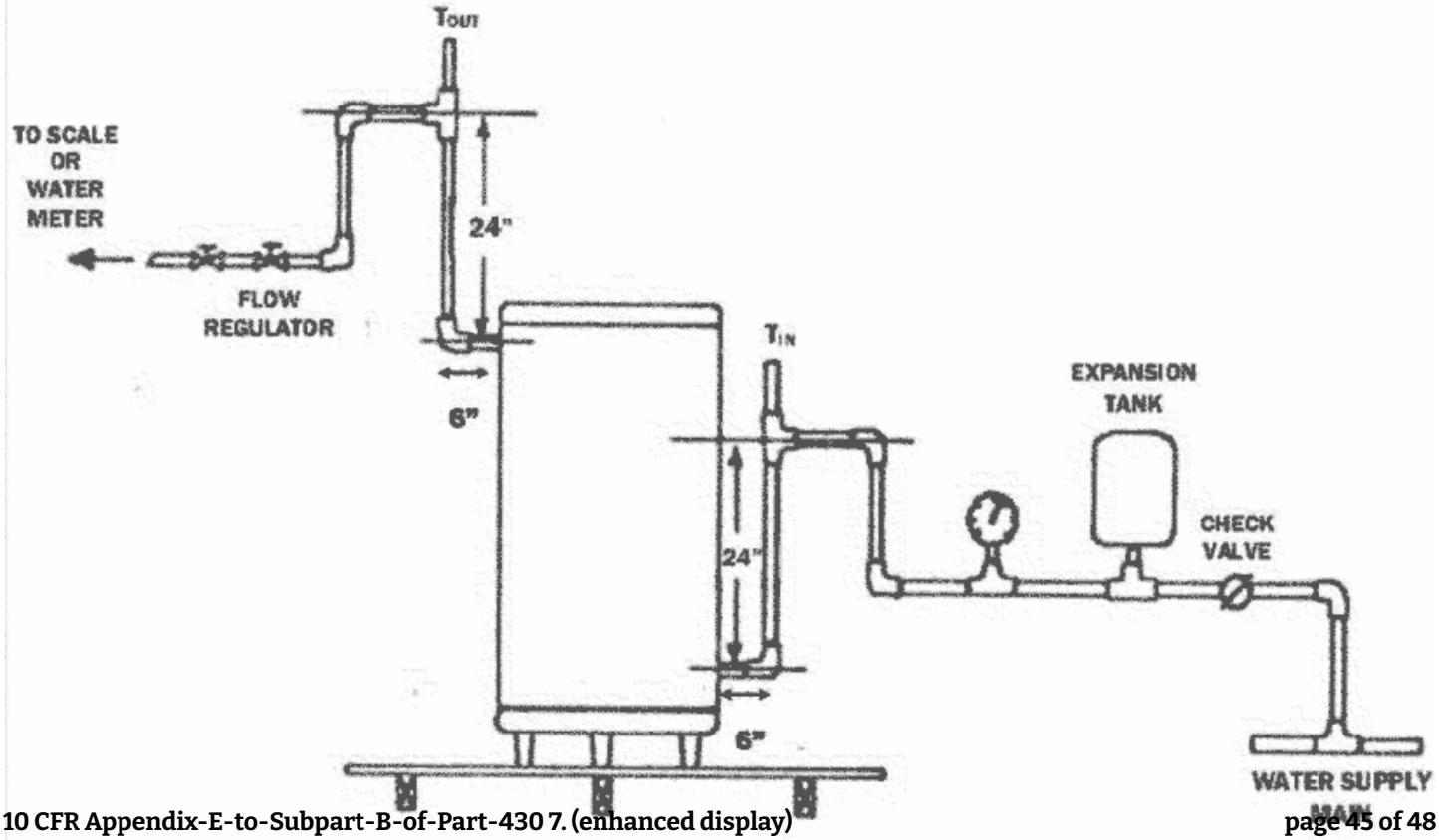


Figure 2.

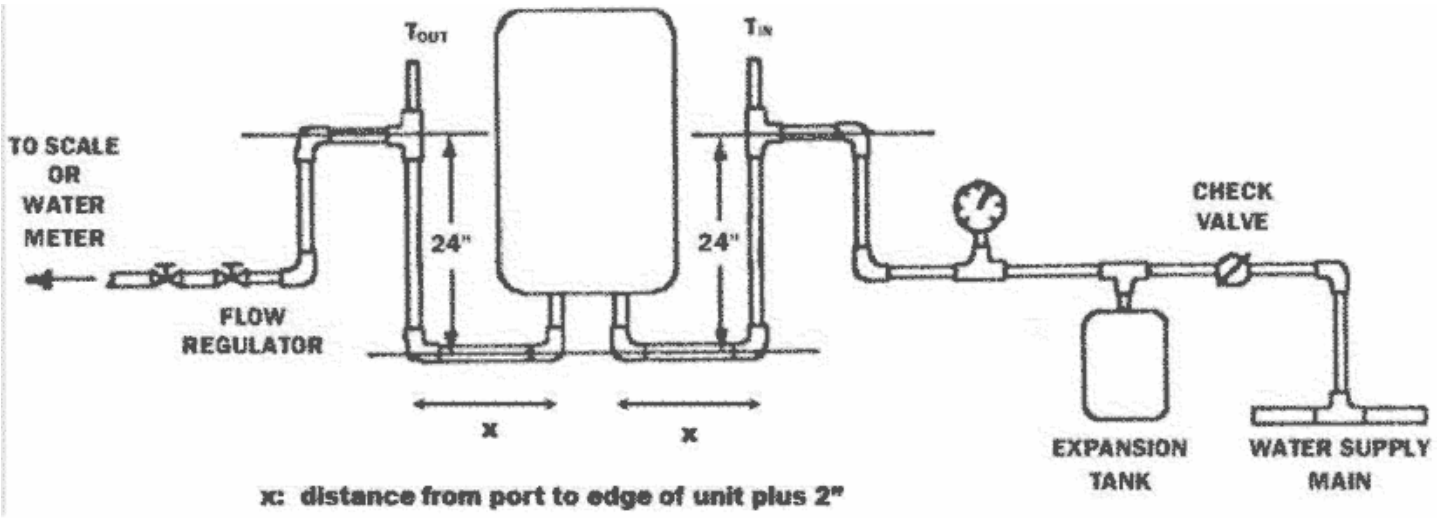


Figure 3.

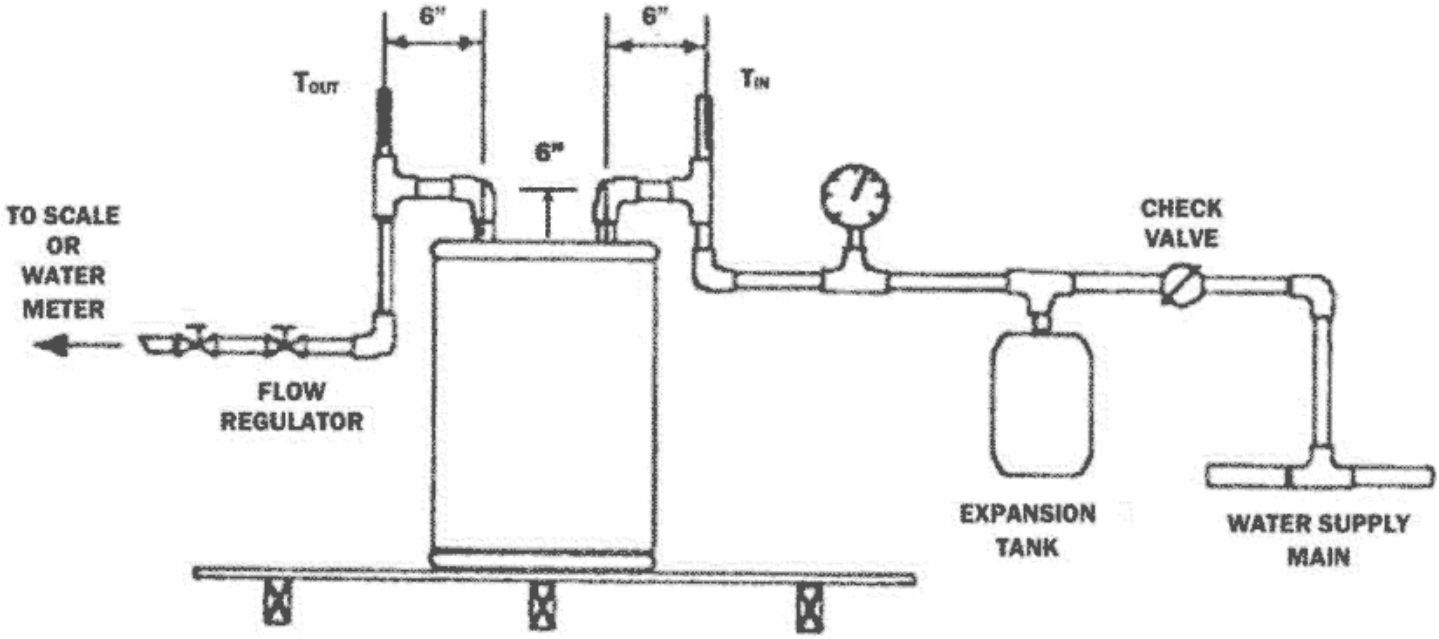
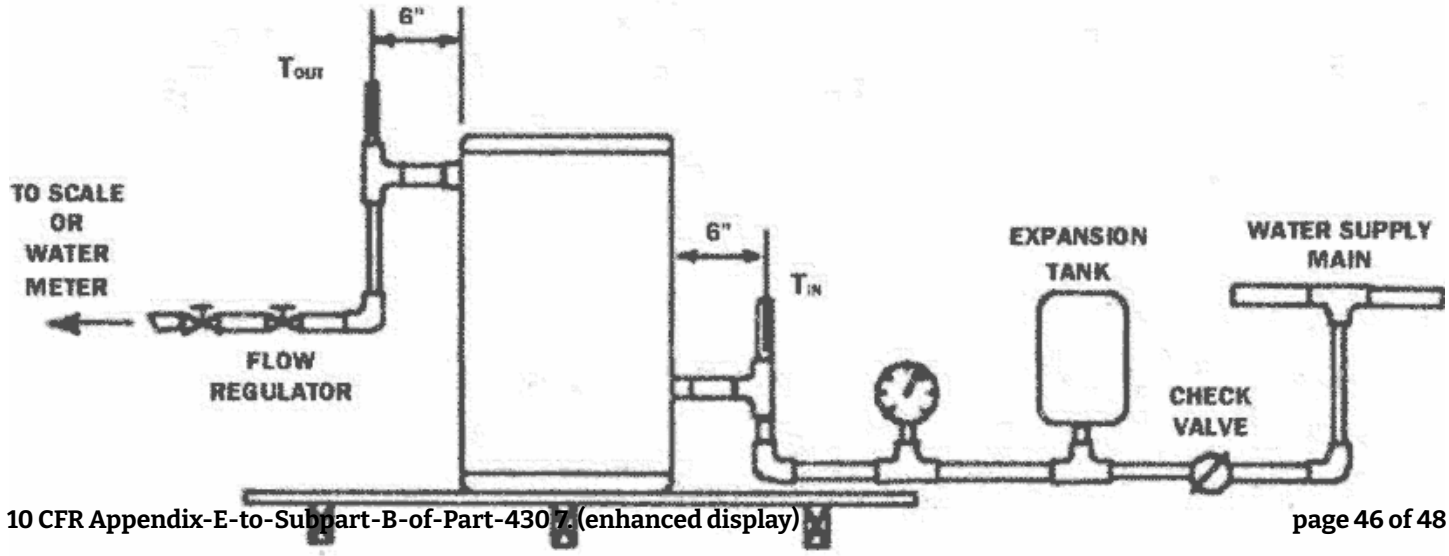


Figure 4.



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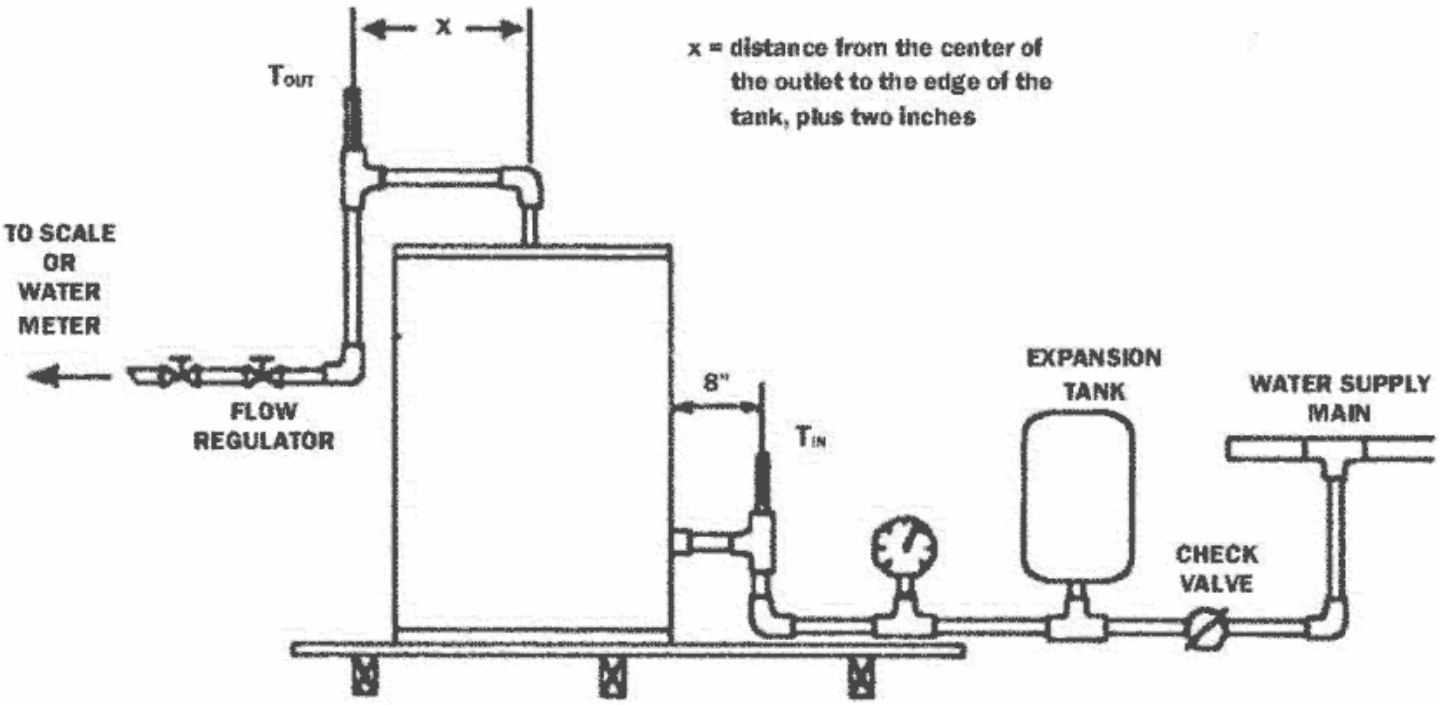

Figure 6.

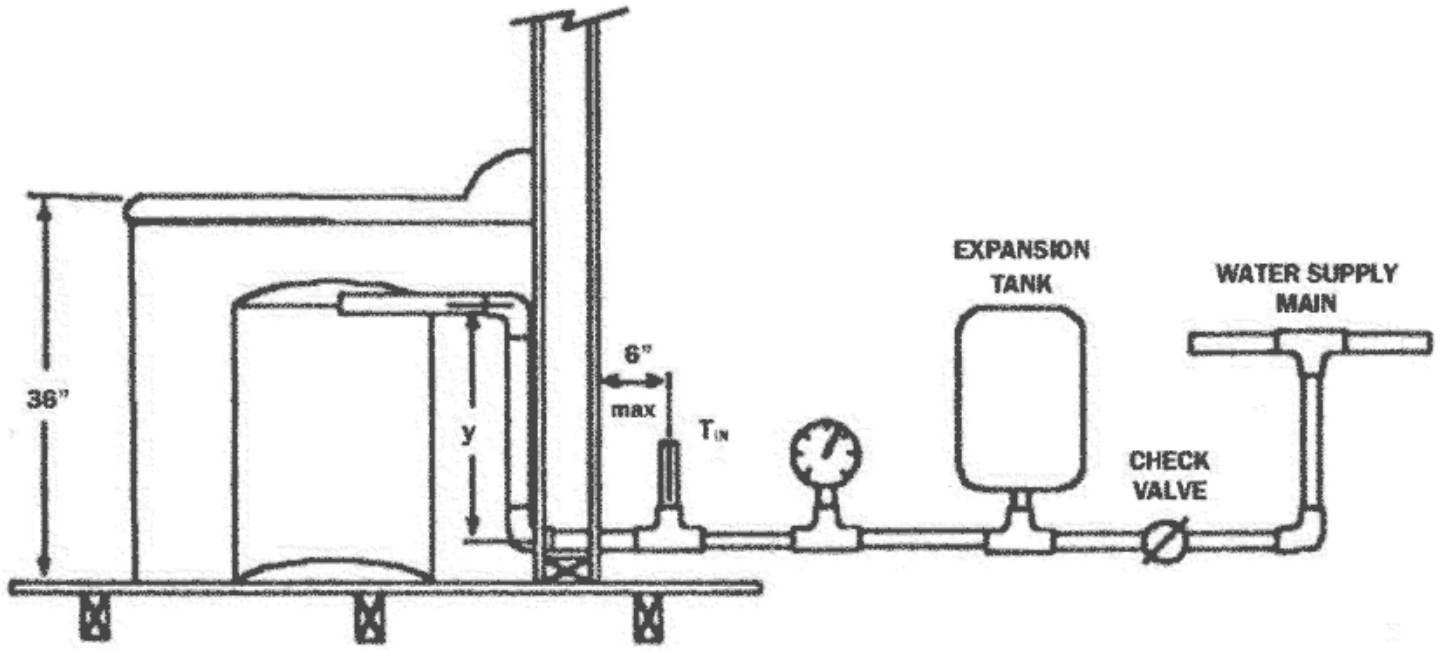

Figure 7a.

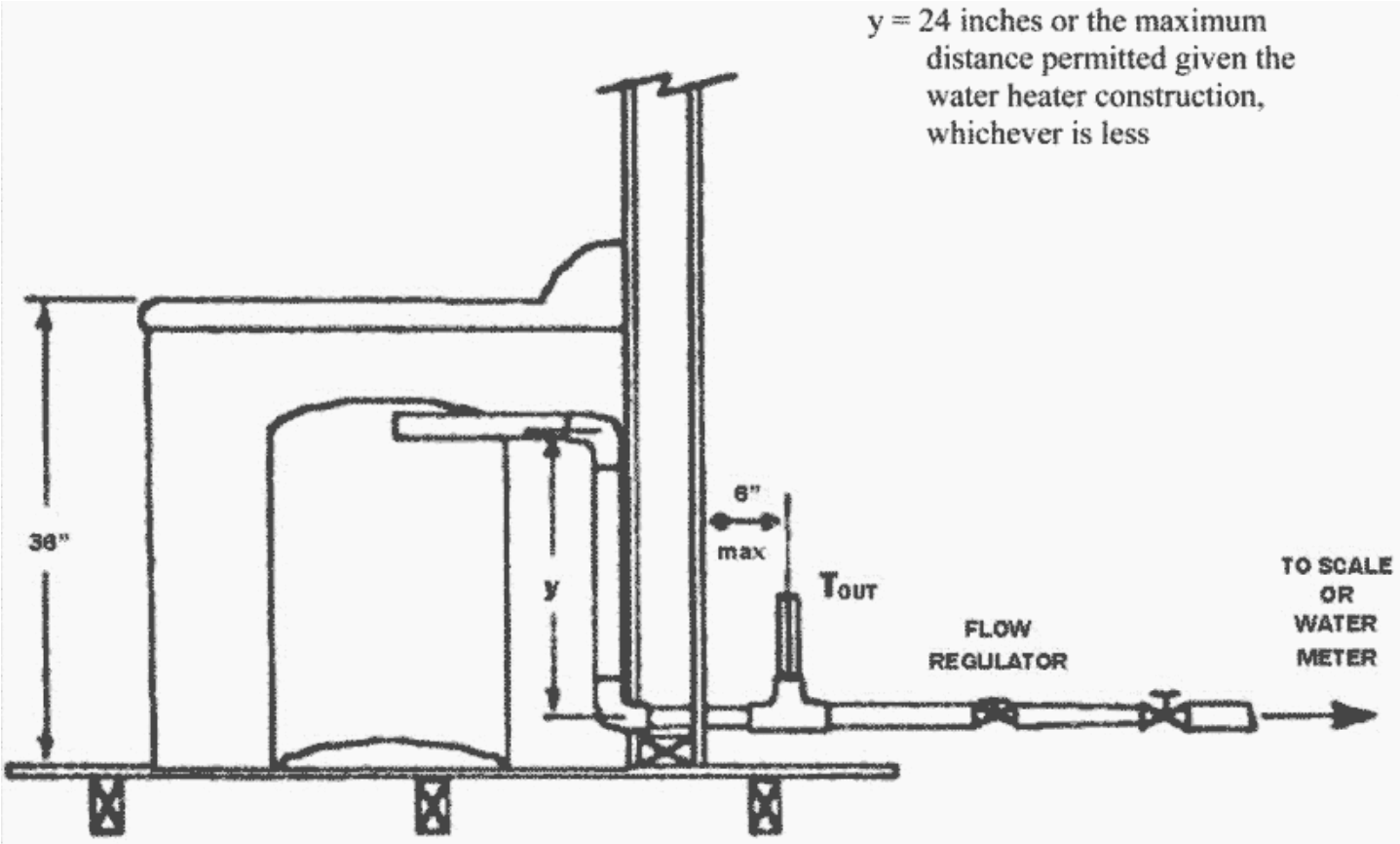

Figure 7b.

[88 FR 40473, June 21, 2023]