STANDARD

ANSI/ASHRAE Standard 118.1-2012
Supersedes ANSI/ASHRAE Standard 118.1-2008

Method of Testing for Rating Commercial Gas, Electric, and Oil Service Water-Heating Equipment

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NOTE

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FOREWORD

This test procedure is a revision of ASHRAE Standard 118.1–2008.

This standard was prepared under the auspices of ASHRAE. It may be used, in whole or in part by an association or government agency with due credit to ASHRAE. Adherence is strictly on a voluntary basis and merely in the interest of obtaining uniform standards throughout the industry.

The changes made to the 2008 revision are as follows:

- *References were updated.*
- *The definitions of "Type IV" and "Type V" equipment were revised.*
- *Test methods and performance calculations were revised for all heat-pump water heaters (including air source) to be steady state, consistent with Types I, II, and III water heaters.*
- *Appendix B4 was added to include heat transfer calculations for direct geoexchange and water-source heat-pump water heaters.*
- *Appendix B5 was added to establish test conditions for all heat-pump water heaters.*

1. PURPOSE

The purpose of this standard is to provide test procedures for rating directly heated commercial-service water-heating equipment.

2. SCOPE

2.1 This standard provides test procedures for determining the efficiency and hot-water delivery capability of the water-heating equipment to which it applies.

2.2 This standard applies to electric resistance, heat pump, gas-fired, and oil-fired water-heating equipment, including hot-water supply boilers, with input ratings less than 12,500,000 Btu/h (3660 kW) and greater than the following:

Electric resistance	12 kW
Heat pump	6 kW (20,500 Btu/h) (including all three-phase, regardless of input)
Gas-fired	75,000 Btu/h (22 kW) (see Section 2.3)
Oil-fired	105,000 Btu/h (31 kW)

2.3 This standard does not apply to gas-fired service water-heating equipment that

a. has a storage capacity of less than two gallons,
b. is designated to deliver water at a controlled temperature of less than 180°F (82°C), and
c. has an input rating less than 200,000 Btu/h (59 kW).

3. DEFINITIONS AND SYMBOLS

3.1 Definitions

boiler, hot-water supply: a boiler used to heat water for purposes other than space heating.

cutout: the time when a thermostat has acted to reduce the energy or fuel input to the heating elements or burners under its control to a minimum.

heating cycle: the period of operation including prepurge, primary heat-producing energy flow, and post-purge.

heat-pump water heater: a device (including all necessary ancillary equipment fans, blowers, pumps, storage tanks, piping, and controls) that uses a refrigeration cycle, such as vapor compression, to transfer heat from a low-temperature source to a higher-temperature sink for the purpose of heating potable water.

air-source heat-pump water heater (AS-HPWH): utilizes surrounding air as the heat source.

direct geoexchange heat-pump water heater (DG-HPWH): utilizes the earth as the heat source.

water-source heat-pump water heater (WS-HPWH): utilizes supplied liquid as the heat source.

input rating: the rating that appears on the water heater's rating plate, expressed in kilowatts (kW) or British thermal units per hour (Btu/h), as appropriate.

mean tank temperature: the mean of the water temperatures determined using the water-heating equipment tank thermocouple described in Section 7.3.1.

service water heating: heating water for purposes other than space heating.

3.2 Symbols

C_{fg} = volume conversion factor = 7.48055 gal/ft^3 (1000 L/m^3)

C_{ge} = conversion factor from kWh to Btu = 3412 Btu/kWh

COP_h = average coefficient of performance for heat-pump water heaters; dimensionless ratio of useful water-heating energy output to input energy

C_p = specific heat of water = 1.00 Btu/(lb·°F) (4184 J/kg·°C)

C_{pg} = nominal specific heat of water at 105°F (average of 140°F and 70°F), or the specific heat of water at the appropriate temperature = 8.25 Btu/gal·°F (1.15 kW/m^3·°C)

C_{ptw} = specific heat of test water solution (15% methanol by weight) at average test water solution temperature in Sections 9.1.1 and 9.1.2

C_s = correction factor applied to gas if it is not at standard temperature and pressure (see Appendix A)

C_{WJ} = conversion of electric power = 3,600,000 J/kWh

EB = energy balance; the heat pump water heater overall energy balance calculated in Section 9.1.3, Btu/h

Eg_{min} = equivalent gallons (litres) per hour, continuous

E_t = thermal efficiency as calculated in Section 10.2.1

E_{tp} = thermal efficiency during reduced input as calculated in Section 10.2.2

FR = flow rate; the water flow rate established at full input rating in Section 8.7, gal (L/min)

FR_a = average of flow rate for the duration of the thermal efficiency test in Section 9.1.1, gal (L/min)

FR_h = water flow rate during the heat-pump water heater water-heating-mode test, Types IV and V in Section 9.1, gal (L/min)

FR_{min} = water flow rate established at minimum input rating in Section 8.7.2, gal (L/min)

FR_p = tested flow rate at partial input; average of FR_{min} for the duration of the thermal efficiency test in Section 9.1.2, gal (L/min)

FR_{tw} = test water solution flow rate during the full capacity heating test for the DG-HPWH and WS-HPWH in Section 9.1.1, gal (L/min)

FR_{twp} = test water solution flow rate during the reduced-capacity heating test for the DG-HPWH and WS-HPWH in Section 9.1.2, gal (L/min)

H = actual higher heating value for the test gas, Btu/ft^3 (kJ/m^3)

H_o = actual higher heating value for the test fuel oil, Btu/lb (kJ/kg)

I = full input rating for water-heating equipment, Btu/h (kW) (tested input rating in kW for electric water-heating equipment)

PP_h = pump electric power coefficient in Section 7.6, W/gpm·psi [W/(L/s·kPa)]

P_{wd} = pressure differential between heat-pump water heater entering and leaving water flow in Section 7.6, psi (kPa)

Q_h = heat-pump water heater water-heating capacity; average of test results from the heat-pump water heater water-heating output test in Section 9.1, Btu/h (kW)

Q_{he} = heat-pump water heater power input from heat-pump water heater water-heating output test in Section 9.1, Btu/h (kW)

Q_n = quantity of energy calculated from standby energy consumption test in Section 10.4.1, Btu/h (kW)

Q_s = quantity of energy calculated from standby energy consumption test in Section 10.4.2, Btu (J)

Q_{se} = quantity of electrical energy consumed during the standby energy consumption test in Sections 9.2.1 and 9.2.3

Q_{sg} = quantity of gas energy consumed during the standby energy consumption test in Sections 9.2.1 and 9.2.3

Q_{so} = quantity of oil energy consumed during the standby energy consumption test in Sections 9.2.1 and 9.2.3

Q_{te} = quantity of electrical energy consumed during thermal efficiency test in Section 9.1.1

Q_{tep} = quantity of electrical energy consumed during reduced input thermal efficiency test in Section 9.1.2

Q_{tg} = quantity of gas energy consumed during thermal efficiency test in Section 9.1.1

Q_{tgp} = quantity of gas energy consumed during reduced input thermal efficiency test in Section 9.1.2

Q_{to} = quantity of oil energy consumed during thermal efficiency test in Section 9.1.1

Q_{top} = quantity of oil energy consumed during reduced input thermal efficiency test in Section 9.1.2

Q_{tw} = DG-HPWH or WS-HPWH evaporator energy input transferred by test water solution during heating capacity tests in Section 9.1.1, Btu/h (kW)

Q_{twp} = DG-HPWH or WS-HPWH evaporator energy input transferred by test water solution during heating capacity tests in Section 9.1.2, Btu/h (kW)

q_{lci} = heat-pump water-heater latent cooling capacity in heat-pump water-heater cooling capacity test in Section 9.3, Btu/h (kW)

q_{sci} = heat-pump water-heater sensible cooling capacity in heat-pump water-heater cooling capacity test in Section 9.3, Btu/h (kW)

q_{tci} = heat-pump water-heater total cooling capacity in heat-pump water-heater cooling capacity test in Section 9.3, Btu (kW) per hour

R = recovery rate, gal/h (L/h)

S = standby loss ratio as calculated in Section 10.4.1

S_{eh} = electrical energy consumed by the resistance heater only (the water heater bypassed or disconnected) during standby energy consumption test, kWh

T_{ah0} = initial air dry-bulb temperature of heat-pump water-heater test room during water-heating-mode test in Section 9.3, °F (°C)

T_{ahf} = final air dry-bulb temperature of heat-pump water-heater test room during water-heating-mode test in Section 9.3, °F (°C)

T_{ahs0} = initial air dry-bulb temperature of heat-pump water-heater test room during standby heat-loss test in Section 9.2, °F (°C)

T_{ahsf} = final air dry-bulb temperature of heat-pump water-heater test room during standby heat-loss test in Section 9.2, °F (°C)

T_{am} = ambient mean temperature during the standby energy consumption test in Section 9.2, °F (°C)

T_d = temperature difference = 65°F (36°C) (for 120°F – 55°F) or 10°F (5.6°C) (for 120°F – 110°F), per Table 2

T_D = temperature difference between nominal water supply temperature of 70°F (21°C) in Section 8.3

and nominal outlet water temperature of 140°F (60°C) as determined in Section 8.7.2, °F (°C)

T_{ih} = inlet water temperature to heat-pump water heater during water-heating-mode test in Section 9.4.1 and Appendix Tables B-1, B-2, and B-3, °F (°C)

$T_{th\text{-}j}$ = temperature for internal tank temperature sensors j = 1 to 6 during heat-pump water heater water-heating-mode test in Sections 9.1.1 and 9.1.2, °F (°C)

T_{mf} = maximum mean tank temperature at the end of the first cutout after the 24-hour test period in Sections 9.2.1 and 9.2.3, in °F (°C)

T_{mh} = mean heat-pump water-heater tank temperature during Type V heat-pump water-heater test in Sections 9.1.1 and 9.1.2, °F (°C)

T_{mh0} = mean heat-pump water-heater tank temperature at start of Type V heat-pump water-heater test in Sections 9.1.1 and 9.1.2, °F (°C)

T_{mhf} = mean heat-pump water-heater tank temperature at end of Type V heat-pump water-heater test in Sections 9.1.1 and 9.1.2, °F (°C)

T_{mhs0} = mean heat-pump water-heater tank temperature at start of Type V heat-pump water-heater standby heat-loss test in Section 9.2.3, °F (°C)

T_{mhs} = mean heat-pump water-heater tank temperature at one-hour intervals during Type V heat-pump water-heater standby heat-loss test in Section 9.2.3, °F (°C)

T_{mhsf} = mean heat-pump water-heater tank temperature at end of Type V heat-pump water-heater standby heat-loss test in Section 9.2.3, °F (°C)

T_{mi} = maximum mean tank temperature at the start of the standby energy consumption test in Sections 9.2.1 and 9.2.3, °F (°C)

T_{mm} = mean of mean tank temperatures during the standby energy consumption test in Section 9.2.1, °F (°C)

T_o = outlet water temperature readings during the thermal efficiency test in Section 9.1, °F (°C)

T_{oh} = outlet water temperature to heat-pump water heater during water-heating-mode test in Section 9.1, °F (°C)

T_{om} = outlet mean temperature during thermal efficiency test in Section 9.1, °F (°C)

T_r = controlled refrigerant vapor temperature into DG-HPWH during heating capacity tests in Sections 9.1.1 and 9.1.2, °F (°C)

T_s = supply water temperature readings during the thermal efficiency test in Section 9.1, °F (°C)

T_{sm} = mean of supply water temperatures during the thermal efficiency test in Section 9.1, °F (°C)

T_{two} = temperature of test water solution out of (1) water-to-refrigerant heat exchanger in DG-HPWH or (2) WS-HPWH during full-capacity heating test in Section 9.1.1, °F (°C)

T_{tws} = temperature of test water solution supply to (1) water-to-refrigerant heat exchanger in DG-HPWH or (2) WS-HPWH during full-capacity heating test in Section 9.1.1, °F (°C)

T_{twop} = temperature of test water solution out of (1) water-to-refrigerant heat exchanger in DG-HPWH or (2) WS-HPWH during reduced-capacity heating test in Section 9.1.2, °F (°C)

T_{twsp} = temperature of test water solution supply to (1) water-to-refrigerant heat exchanger in DG-HPWH or (2) WS-HPWH during reduced-capacity heating test in Section 9.1.2, °F (°C)

t_{0h} = starting time of heat-pump water heater water-heating-mode test in Section 9.1, hours

t_{0hs} = starting time of heat-pump water heater standby heat-loss test in Section 9.2.3, hours

t_{0s} = starting time of standby energy-consumption test in Section 9.2.1, hours

t_{0t} = starting time of thermal efficiency test in Section 9.1.1, hours

t_{0tp} = starting time of thermal efficiency test in Section 9.1.2, hours

t_{fh} = the end time of heat pump water heater water heating-mode test in Section 9.1, hours

t_{fhs} = end time of heat-pump water heater standby heat-loss test in Section 9.2.3, hours

t_{fs} = end time of standby energy consumption test in Section 9.2.1, in hours

t_{ft} = end time of thermal efficiency test in Section 9.1.1, in hours

t_{ftp} = final reduced input thermal efficiency; end time of thermal efficiency test in Section 9.1.2, hours

V = storage tank volume in gallons (litres) as determined in Section 8.5; includes plumbed heat-pump water heater

v = specific volume of water converted from *ASHRAE Handbook—Fundamentals*,[1] 0.016 ft^3/lb (0.001m^3/kg)

v_{tw} = specific volume of test water solution (15% methanol by weight) at average test water solution temperature; used in calculations in Sections 10.3.1 and 10.3.2, ft^3/lb (m^3/kg)

Vol_s = volume of gas metered in standby energy consumption test in Section 9.2, ft^3 (m^3)

Vol_t = volume of gas metered in thermal efficiency test in Section 9.1.1, ft^3 (m^3)

Vol_{tp} = volume of gas metered in reduced input thermal efficiency test in Section 9.1.2, ft^3 (m^3)

W_{fs} = weight of fuel oil used during the standby energy consumption test in Section 9.2, lbs (kgs)

W_{ft} = weight of fuel oil used during the thermal efficiency test in Section 9.1.1, lbs (kgs)

W_{ftp} = weight of fuel oil used during the reduced input thermal efficiency test in Section 9.1.2, lbs (kgs)

W_t = weight of water withdrawn during the thermal efficiency test in Section 9.1.1, lbs (kgs)

W_{tp} = weight of water withdrawn during the reduced input thermal efficiency test in Section 9.1.2, lbs (kgs)

Z_h = electrical energy used by heat-pump water heater in water-heating-mode test in Section 9.1, kWh

Z_{pc} = electrical energy used by heat-pump water-heater water pump, calculated in Section 7.6, kWh

Z_{pp} = electrical energy consumed during post-purge operation in Section 9.2.2, kWh

Z_{rh} = electrical energy consumed by resistance heater and water-heater combination during the standby energy-consumption test in Section 9.2.4, kWh

Z_s = electrical standby; electrical energy used, measured from initial to final meter reading in Section 9.2, kWh

Z_{sb} = electrical energy for one hour immediately following post-purge operation in Section 9.2.2, kWh

Z_t = electrical energy used at full input, measured from initial to final meter reading in Section 9.1.1, kWh

Z_{tp} = electrical energy used at reduced input, measured from initial to final meter reading in Section 9.1.2, kWh

Z_{uh} = electrical energy consumption attributed to the standby loss of the inactive water heater in Section 9.2.4, kWh

4. CLASSIFICATIONS BY MODE OF OPERATION

4.1 Type I. Unit equipped with a self-contained, temperature-activated primary operating control and not requiring circulation of water for heating.

4.2 Type II. Unit equipped with a self-contained, flow-activated primary operating control and requiring water flow for heating.

4.3 Type III. Unit equipped with a remote temperature-activated primary operating control and requiring circulation through the heater for heating.

4.4 Type IV. Heat-pump water heater that can be operated without connection to a storage tank.

4.5 Type V. Heat-pump water heater that includes an integral storage tank or requires connection to a storage tank for operation.

5. REQUIREMENTS

Water-heating equipment shall be tested to determine the efficiency and hot-water delivery capability using the test procedures and calculations in this standard. In addition, air source (AS-HPWH) and water source (WS-HPWH) heat pump water heaters shall be tested to determine cooling output for the purpose of calculating an energy balance.

6. INSTRUMENTS

6.1 General. Instruments are required for the following measurements with the degree of accuracy noted. Instruments shall be calibrated at least once per year, and a record shall be kept containing, at least, the date of calibration, the method of calibration, and the traceability to national standards. Instruments required for the conduct of this method of test must have the following accuracy, unless otherwise specified:

Instrument for Measuring	Accuracy
Heating value	±0.5% of measured value
Carbon dioxide	±0.1% by volume
Oxygen	±0.1% by volume
Smoke	1/2 Bacharach number
Gas/oil volume	±0.5% of measured value
Temperature (AS-HPWH)	±2°F (1°C)
Evaporator wet-bulb and dry-bulb temperature	±1.0°F (0.6°C)
Heat-pump inlet to outlet water temperature difference	±0.2°F (0.1°C)
Refrigerant temperature from water/refrigerant heat exchanger to DG-HPWH	±0.2°F (0.1°C)
Test water solution temperature to WS-HPWH	±0.2°F (0.1°C)
Inlet-to-outlet water temperature	±0.5°F (0.3°C)
Water flow	±1.0% of measured flow
Weight	±1.0% of tared measured weight
Gas pressure	±0.1 in. wc (20 Pa)
Atmospheric pressure	±0.01 in. Hg (30 Pa)
Oil pressure	±0.5 lb/in.^{2} (3 kPa)
Water pressure	±1.0 lb/in.^{2} (7 kPa)
Draft	±0.005 in. wc (1 Pa)
Relative humidity	±2.0% of measured value
Time	±0.5 s/h
Electrical measurements	±1.0% of measured value

6.2 Temperature. Temperature-measuring devices and any associated readout instrumentation shall be in accordance with ASHRAE Standard 41.1.[2] The time constant of the thermocouples used for measuring the inlet and outlet water temperatures shall be no greater than five seconds.

6.3 Draft. Minimum divisions on the draft gauge shall be 0.005 in. wc (1 Pa).

6.4 Higher Heating Value. The measurement of the higher heating value of natural gas, propane, or fuel oil shall be conducted on site.

Exception: Bottled gas and a single test batch of fuel oil can be third-party certified by an independent test laboratory documenting the traceability to national standards.

6.5 Water Flow. A flowmeter at the inlet or outlet may be used in lieu of a weight tank and scale for determining water flow rate and quantity. Conversion to mass flow, where required, shall be based upon the specific volume listed in the *ASHRAE Handbook—Fundamentals*,[1] for the temperature of the water metered.

6.6 Smoke. Smoke-measuring instruments shall comply with requirements for smoke meters as outlined in ANSI/ASTM D2156.[3]

7. APPARATUS

7.1 Test Platform. Free-standing equipment shall be placed on a plywood platform elevated about 4 in. (100 mm). If the water-heating equipment is not intended for installation on combustible flooring, suitable noncombustible material shall be placed between it and the platform. Equipment for which this is not practical may be placed on any suitable flooring. Water-heating equipment designed for wall mounting shall be mounted to a simulated wall. Placement in the test room shall be in an area protected from drafts.

7.2 Water Piping

7.2.1 All Water-Heating Equipment. Install a pressure gauge. An appropriately rated relief valve shall be installed in the location specified by the manufacturer. Any discharge piping shall be nonmetallic. Piping shall be installed as shown in Figures 1 through 8. Piping for units requiring a recirculation loop may be installed as shown in Figure 4.

7.2.2 Type I and Type V Equipment. Heat traps shall be formed with the piping by having it routed vertically downward a minimum of 1 ft (305 mm) from the inlet and outlet connection points. Lengths of piping from the connection points shall be as short as practical and consistent with the tank configuration. Unions may be used to facilitate installation and removal of piping. Any heat traps supplied by the manufacturer shall first be installed per their instructions. Provide a diaphragm-type expansion tank and check valve in the water supply line. Insulate all added pipe, valves, and fittings with thermal insulation having a minimum value of $R = 4\ h{\cdot}ft^{2}{\cdot}°F/Btu$ ($0.7\ m^{2}{\cdot}°C/W$).

7.3 Thermocouple Installation

7.3.1 In Tank. For Types I and V equipment, install six thermocouples inside the tank. Position each thermocouple along a vertical line that is centrally located or on the approximate center of a section of the tank away from any heat source or other irregularity. The level of each thermocouple measuring junction shall be the center of each of six horizontal sections of approximately equal volume. The thermocouple may be installed in the tank through the opening for the anode rod, the hot-water outlet, or the relief valve opening. An anodic protective device may be removed in order to install the thermocouple, and all testing may be carried out with the device removed. Remove only the minimum amount of thermal insulation necessary to gain access for removal of the anodic protective device. If there is no anodic protective device, or if it is mounted in a flue space or other inaccessible area, connect a tee to the relief valve opening. Use one opening for the thermocouple support and install a pressure-relief valve in the other. If it is not feasible to use the relief valve opening, use the hot-water outlet. Insulate all added pipe, valves, and fittings with thermal insulation having a minimum value of $R = 4\ h{\cdot}ft^{2}{\cdot}°F/Btu$ ($0.7\ m^{2}{\cdot}°C/W$).

7.3.2 In Piping for Type I, Type II, Type III, Type IV, and Type V Equipment. Install the thermocouple as illustrated in Figures 1 through 8, as appropriate. The sensing portion of the probe shall be located in the flow stream close to the pipe centerline. The junction of the thermocouple shall not extend more than 6 in. (150 mm) from the appropriate outlet of the tee.

7.3.3 Room Ambient. Install in the test room a thermocouple with the junction shielded against direct radiation and positioned at the vertical midpoint of the heater at a perpendicular distance of approximately 24 in. (610 mm) from the surface of the water-heating equipment jacket.

7.4 Vent Requirements

7.4.1 Natural Draft Gas-Fired. Galvanized steel vent connectors and elbows shall be used to form the following test vent configurations. If multiple draft hood outlet sizes are provided, the largest shall be used. If the appliance has no provision for vent connections, the unit is to be tested without a connected vent.

a. The following apply to an input rating of 400,000 Btu/h (120 kW) or less:
   - When the flue gases discharge horizontally, a 2 ft (610 mm) section of horizontal vent pipe, an elbow, and a vertical section of vent pipe shall be attached to the draft hood outlet, or in the absence of a draft hood, to the flue collar. The height of the vertical section shall be 5 ft (1500 mm), as measured from the highest point of the draft-hood relief opening(s) or from the flue collar.
   - When the flue gases discharge vertically, an elbow, a 2 ft (610 mm) section of horizontal vent pipe, a second elbow, and a vertical section of vent pipe shall be attached to the draft hood outlet, or in the absence of a draft hood, to the flue collar. The height of the vertical section shall be 5 ft (1500 mm), as measured from the highest point of the draft hood relief opening(s) or from the flue collar.

b. The following apply to input ratings over 400,000 Btu/h (120 kW):
   - When the flue gases discharge horizontally, an elbow and 5 ft (1500 mm) of vertical vent pipe shall be attached to the draft hood outlet, or in the absence of a draft hood, to the flue collar.
   - When the flue gases discharge vertically, 4 ft (1200 mm) of vertical vent pipe shall be attached to the outlet.

7.4.2 Oil-Fired. A vertical length of galvanized steel vent pipe shall be connected to the flue collar. It shall be of sufficient height to establish the minimum draft specified in the manufacturer's installation instructions. If the flue collar does not discharge vertically, a suitable elbow shall be installed first.

7.4.3 Special Vent. Equipment designed for use with a specific vent shall be installed with the vent materials supplied or specified by the manufacturer. Use the minimum vertical length specified by the manufacturer. If specified for horizontal venting only, use the minimum horizontal length specified.

7.5 Fuel or Energy Consumption Measurement. Install one or more instruments that measure, as appropriate, the

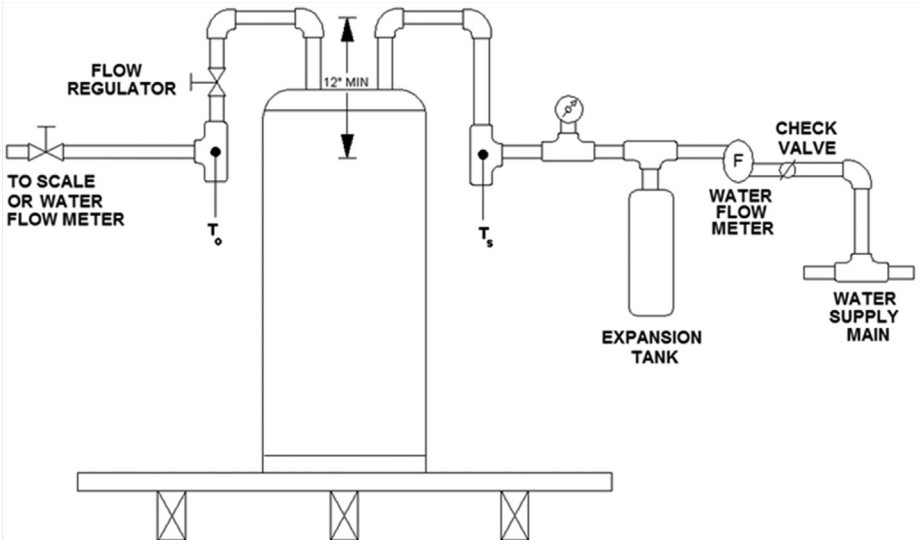

Figure 1 Vertical connections (top).

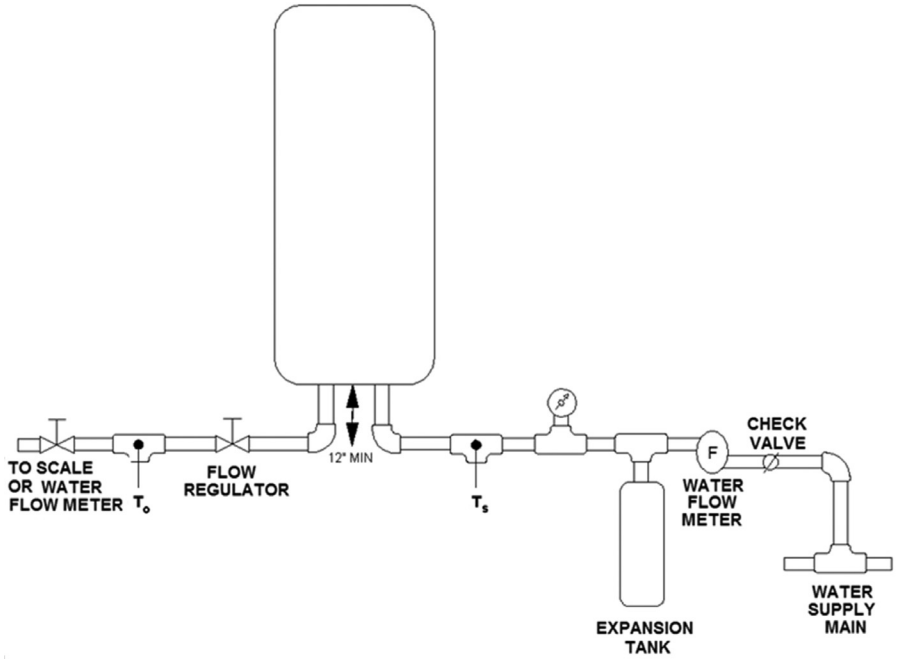

Figure 2 Vertical connections (bottom).

quantity and rate of electrical energy, appropriate gas supply, and fuel oil consumed by the water-heating equipment.

7.6 Heat-Pump Water-Heater Components. If the manufacturer neither submits nor specifies the water pump to be used for the laboratory testing, then components meeting the following criteria shall be used.

For heat-pump water heaters that require a circulating pump but for which none is provided, a water pump capable of meeting the manufacturer's water flow rate and pressure-drop specifications when installed as specified below shall be used.

If specifications are not provided in the manufacturer's installation instructions, the water pump shall be installed with no more than 3 ft (900 mm) of piping between the pump and the heat-pump water-heater water inlet. Locate the pump between the heat-pump water heater and the sensor used to measure the heat-pump inlet water temperature (see Figure 5).

When this water pump is used, pump electrical power input shall be determined using Equations 1 and 2:

$$Z_{pc} = \frac{\mathrm{FR}_h \times [(\mathrm{PP}_h \times P_{wd}) + 65]}{1000} \quad (1)$$

$$Z_{pc} = \frac{\mathrm{FR}_h \times [(\mathrm{PP}_h \times P_{wd}) + 17.2]}{1000} \quad (2)$$

where PP_h is a coefficient from Table 1.