ENERGY STAR® Program Requirements
Product Specification for Commercial Water Heaters

Final Draft Test Method for Central Heat Pump Water Heater Systems
December 2024

1 OVERVIEW

The following test method shall be used for qualifying the performance for central heat pump water heater ("central HPWH") systems. For the purpose of this proposed test method, the Environmental Protection Agency (EPA) is focusing on the performance of the heat-pump water heater(s), the storage tank(s) (electric or unfired), and the circulator pump(s), which altogether make up a central HPWH system. The system components as well as the number of each component in a system may vary between installations and can be sold individually or as a package.

This test method separately tests each component of the system to determine its efficiency. In a later version of this test procedure, the Department of Energy (DOE) and EPA may combine the metric of performance of each system component into an overall system performance metric to better account for the system effects and interactions between different components.

2 APPLICABILITY

This test method is applicable to central HPWH system components, including the heat pump unit, auxiliary water storage tanks (including unfired hot water storage tanks and commercial electric storage water heaters), and recirculating pumps. Specifically, this method is applicable to heat pump units that are supplied without a matching storage tank (Type IV equipment, as defined in section 4.4 of ANSI/ASHRAE 118.1-2022) and heat pump units that are supplied with a matching storage tank (Type V equipment, as defined in section 4.5 of ANSI/ASHRAE 118.1-2022) that is not integrated (*i.e.*, the matching storage tank is supplied as a separate assembly). This method is not applicable to gas-fuelled HPWHs.

3 DEFINITIONS

All terms used in this document are intended to be consistent with the definitions in 10 CFR 431. In case of any inconsistencies, definitions in the CFR are authoritative.

A) Air-source commercial heat-pump water heater: A commercial heat pump water heater that utilizes indoor or outdoor air as the heat source.

B) Active defrost: The removal of frost and ice on the evaporator coil by actively heating the evaporator coil. Running the evaporator fan without additional evaporator coil heat input is not active defrost.

C) Circulator Energy Rating: The weighted average electric input power to the driver or control of a circulator pump, over a specific load profile for each control type (expressed in HP).

D) Central Heat Pump Water Heater System: A water heating system that uses a commercial split-system heat pump water heater as the primary water heater (i.e., the water heater that the systems controls seek to maximize the use of). A central heat pump water heater system can include products that come pre-mounted on a skid or pallet with multiple components and may require infield plumbing between components.

E) Compressor cut-out temperature: The temperature below which a heat pump unit's compressor will no longer operate.

F) Compressor cut-in temperature: The temperature above which a heat pump unit's compressor will begin to function.

G) Commercial Electric Storage Water Heater: means a water heater that uses electricity to heat and store water within the appliance at a thermostatically-controlled temperature for delivery on demand with a rated input both greater than 12 kW and less than 4,000 Btu/h per gallon of stored water.

H) Commercial heat pump water heater: A water heater (including all necessary ancillary equipment such as fans, blowers, pumps, storage tanks, piping, and controls, as applicable) 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, and operates with a current rating greater than 24 amperes or a voltage greater than 250 volts. Such equipment includes, but is not limited to, air-source heat pump water heaters and water-source heat pump water heaters.

1) Split-system heat pump water heater: A commercial heat pump water heater in which the compressor is not contained within the same casing as the storage tank(s) and thus is not an integrated heat pump water heater.

2) Integrated heat pump water heater: A heat pump water heater that has a built-in storage tank contained within the same casing.

I) Heat Pump Water Heater Coefficient of Performance: The dimensionless ratio of the rate of useful heat transfer gained by the water (expressed in Btu/h), to the rate of electric power consumed during operation (expressed in Btu/h).

J) Commercial Heat Pump Water Heater Unit: The commercial heat pump water heater component of the central HPWH system (i.e. not including any auxiliary components such as tanks)

1) Type A heat pump unit: A commercial heat pump water heater unit that does not have active defrost or for which the specified compressor cut-in and cut-out temperatures are not both less than 40°F.

2) Type B heat pump unit: A commercial heat pump water heater unit that has active defrost and for which the specified compressor cut-in and cut-out temperatures are both less than 40°F but not both less than 17°F.

3) Type C heat pump unit: A commercial heat pump water heater unit that has active defrost and for which the specified compressor cut-in and cut-out temperatures are both less than 17°F but not both less than 5°F.

4) Type D heat pump unit: A commercial heat pump water heater unit that has active defrost and for which the specified compressor cut-in and cut-out temperatures are both less 5°F.

K) Indoor heat pump unit: A commercial heat pump water heater unit that is intended to only operate within typical indoor ambient air conditions (i.e. boiler room/machine room).

L) Outdoor heat pump unit: A commercial heat pump water heater unit that is intended to only operate within outdoor ambient air conditions.

M) Indoor/Outdoor heat pump unit: A commercial heat pump water heater unit that can be operated in both indoor and outdoor ambient air conditions.

N) Indoor $COP_{80.6}$: The coefficient of performance of an indoor commercial heat pump water heater unit as calculated in section 4.5.

O) Multi-pass HPWH: A HPWH that cannot meet the requirements of a Single Pass central HPWH.

P) Single-pass HPWH: A HPWH which has equipment that can modulate the flow rate through the heat pump to achieve the outlet water temperature at each of the specified inlet temperatures in section 4.2 (E) below.

Q) Standby Loss: The energy required to maintain the stored water temperature.

R) Thermal Efficiency: The ratio of the heat transferred to the water flowing through the electric storage water heater to the amount of energy consumed by the electric storage water heater.

S) Unfired hot water storage tank: a tank used to store water that is heated externally.

T) Water-source commercial heat pump water heater: A commercial heat pump water heater that utilizes water or a brine solution as the heat source. For the purposes of this test procedure, it refers to ground-source closed-loop commercial heat pump water heaters, ground water-source commercial heat pump water heaters, and indoor water-source commercial heat pump water heaters.

U) Ground-source closed-loop commercial heat pump water heater: A commercial heat pump water heater that utilizes a fluid circulated through a closed piping loop as a medium to transfer heat from the ground to the refrigerant in the evaporator. The piping loop may be buried inside the ground in horizontal trenches or vertical bores or submerged in a surface water body.

V) Ground water-source commercial heat pump water heater: A commercial heat pump water heater that utilizes ground water as the heat source.

1) Indoor water-source commercial heat pump water heater: A commercial heat pump water heater that utilizes indoor water as the heat source.

W) Water Heating Energy Efficiency Ratio (WHEER): The heating energy efficiency of a commercial heat pump water heater in British thermal units per watt-hour (Btu/Wh) using the national average temperature fractional bin hours, as calculated in section 4.4 of this test method. WHEER representations for heat pump units using single pass and multi-pass test conditions are labeled as $WHEER_{SP}$ and $WHEER_{MP}$ respectively.

1) $WHEER_{C}$: The heating energy efficiency of a commercial heat pump water heater in British thermal units per watt-hour (Btu/Wh) using the cold climate temperature fractional bin hours, as calculated in section 4.4 of this test method. $WHEER_{C}$ representations for heat pump units using single pass and multi-pass test conditions are labeled as $WHEER_{C,SP}$ and $WHEER_{C,MP}$ respectively.

A) Acronyms:

1) ANSI: American National Standards Institute
2) AS: Air-Source
3) AS-central HPWH: Air-Source Central Heat Pump Water Heater
4) ASHRAE: American Society of Heating Refrigerating and Air-Conditioning Engineers
5) BTU: British Thermal Unit
6) CER: Circulator Energy Rating
7) CFR: Code of Federal Register
8) Central HPWH: Central Heat Pump Water Heater
9) COP_{H}: Coefficient of Performance of the Central Heat Pump Water Heater as measured in section 4.1
10) DOE: United States Department of Energy
11) DR: Decay Rate
12) EPA: United States Environmental Protection Agency
13) E_{H}: heat-pump water heater power input from heat-pump water heater water-heating output test
14) F: Fahrenheit
15) FR: Flow Rate
16) GPM: Gallons Per Minute
17) hp: horsepower
18) in WC: Inches of water column
19) lb: Pound
20) kW: kilowatt
21) MP: Multi-Pass
22) OH: Operating Hours
23) psi: pound per square inch
24) Q_{H}: heat-pump water heater water-heating capacity; average of test results from the heat-pump water heater water-heating output test
25) SL: Standby Loss
26) SP: Single-Pass
27) T: Temperature
28) T_{L}: Lowest operating temperature equal to the average of the certified cut-out and cut-in temperatures
29) t: Time
30) V: Volume
31) W: Watt
32) WS-central HPWH: Water-Source Central Heat Pump Water Heater
33) WHEER: Water Heating Energy Efficiency Ratio

4 TEST METHODS

4.1 Supplemental Test Instructions

A) Manufacturers of units must submit the following information:

1) Where the heat pump unit is designed to be operated (Indoor, Outdoor, or Outdoor/Indoor Unit)
2) Heat pump unit type (A-D)
3) Compressor Cut-in and Cut-out temperatures
4) Defrost method and settings (if adjustable and multiple options exist in the installation instructions)

4.2 Heat Pump Unit Test Method

A) General.

Determine the average water-heating capacity, Q_h and the average rate of energy input, Q_{he},at each test condition for the heat pump unit in accordance with the procedures in the sections that follow. Once the water-heating capacity and range of energy input are determined at each test condition, the WHEER seasonal metric shall be calculated for outdoor air-source heat pump units. For indoor AS-HPWHs and other types of HPWHs a single COP shall be calculated. The following test procedure references certain sections of ANSI/ASHRAE 118.1-2022 for set-up, testing instructions, and data collection. Where the instructions contained in this section differ from ANSI/ASHRAE 118.1-2022, this document controls.

B) Definitions and Symbols.

The definitions and symbols used in this test procedure are as listed in section 3 of ANSI/ASHRAE 118.1-2022.

C) Instrumentation.

The instruments required for the test are as described in section 6 of ANSI/ASHRAE 118.1-2022 (except sections 6.3, 6.4, and 6.6).

D) Outdoor Air Source Cut-out and Cut-In Temperatures.

1) This section is only applicable for Type B-D outdoor air source heat pump units. For Type A heat pump units, the cut-out and cut-in temperatures shall be assumed to be 42°F.

2) If the UUT is not a Type A heat pump unit, follow these optional instructions to verify the cut-out and cut-in temperatures. If these tests are not conducted, T_L shall be equal to the average of the certified cut-out and cut-in temperatures. If these tests are conducted, T_L shall be equal to the average of the cut-out and cut-in temperatures determined by the test.

3) Capacity does not need to be measured. Measure a parameter that provides positive indication that the heat pump unit is operating (e.g., power). Also monitor the temperature of the air entering the unit using one or more air samplers or parallel thermocouple grid(s). Collect measurements at a rate of once every 15 seconds or faster. The temperature of air entering the unit shall be used for determining temperature in the subsequent sections. Set single-pass heat pump units to operate with the target outlet water temperature set to 140°F± 2°F and the inlet water temperature set to 70°F± 1°F. Set multi-pass heat pump units to operate with the target outlet water temperature set to 140°F± 2°F and the inlet water temperature set to 125°F± 1°F.

4) Determine the cut-out temperature, T_{off}, using the following steps. Reduce air temperature to 5°F warmer than the specified cut-out temperature for dry-bulb temperature. When the air temperature is above 17°F, maintain a relative humidity below 60%. Pause chamber temperature reduction for at least three minutes to allow conditions to stabilize. Then continue to reduce chamber temperature in steps or continuously at an average rate of not more than 1°F every 5 minutes. Compressor operation momentarily stopping for the purposes of a defrost cycle, not exceeding 30 seconds, is not considered a compressor cut-out. The test ends when one of the following conditions is met:

   a) Test Facility has not reached the certified cut-out temperature, but the compressor stops running. Record the average coil air inlet temperature when the compressor operation stopped as the tested cut-out temperature T_{off}. Proceed to the Cut-In test.

   b) Test Facility reaches the certified cut-out temperature and compressor stops running at that temperature. Set T_{off} equal to the certified cut-out temperature. Proceed to the Cut-In test.

   c) Test Facility reaches the certified cut-out temperature, but the compressor continues to run. Set T_{off} equal to the certified cut-out temperature.

   d) If the chamber temperature reaches the colder of -5°F or the lowest temperature for which performance is specified, but no lower than -22°F, and the compressor continues to run proceed to the Simulated Cut-out in section 4.2.D5).

5) Simulated Cut-out. For a unit where the compressor continues to run as described in section 4.2D4)d remove the water heating demand when the air temperature reaches the colder of - 5°F or the lowest temperature for which performance is specified, but no lower than -22°F. Remove the water heating demand by adjusting the controls to reduce the water temperature setpoint so that compressor cut-out occurs. Allow the unit to remain off for not less

than 30 seconds, then supply the heating demand by adjusting the controls back to the setpoint of 140°F± 2°F. Proceed to the cut-in temperature test.

6) Determine the cut-in temperature, T_{on}. Maintain the air temperature within 2°F of T_{off} for 5 minutes following compressor cut-out—then increase chamber temperature by no more than 1°F every 5 minutes. Continue temperature ramp until either the compressor operation restarts, or the specified cut-in temperature is reached, whichever occurs first. The cut-in temperature is determined as follows:

   a) If the compressor operation restarts before the specified cut-in temperature is reached, the test is complete. Set T_{on} equal to the specified cut-in temperature.

   b) If the compressor operation restarts within 2.5 minutes of the time that the specified cut-in temperature is reached, the test is complete. Set T_{on} equal to the specified cut-in temperature.

   c) If the compressor operation has not restarted more than 2.5 minutes after the certified cut-in temperature is reached, proceed as follows.

      i. Stabilize the air temperature for at least five minutes until it remains within 0.5ºF of the specified cut-in temperature. Wait a minimum of at least five minutes after stabilization of the air temperature.

      ii. Adjust the unit's leaving water temperature setting to at least 2°F lower than the tank temperature measured by the unit's control to stop the unit's heating demand. Wait 30 seconds, then increase the unit's leaving water temperature to 2°F higher than the tank temperature measured by the unit's control. Alternatively, use the tank temperature sensor if the unit's control lacks indication of the measured tank temperature.

      iii. If the compressor operation restarts and the compressor continues running for five minutes, set Ton equal to the specified cut-in temperature—at this point, the test is complete. If the compressor operation does not restart, continue to step iv

      iv. Increase the target air temperature 1ºF. Stabilize the air temperature for at least five minutes until it remains within 0.5ºF of this target. Wait a minimum of at least five minutes after stabilization of the air temperature.

      v. Adjust the unit's leaving water temperature to at least 2°F lower than the tank temperature measured by the unit's control to stop the unit's heating demand. Wait 30 seconds, then increase the unit's leaving water temperature to 2°F higher than the tank temperature measured by the unit's control.

      vi. If the compressor operation restarts and the compressor continues running for five minutes, set T_{on} equal to the current target outdoor temperature—at this point, the test is complete. Otherwise, go back to step iv and repeat until compressor operation restarts or until the current target outdoor temperature is 42ºF.

E) Test Set-Up, Apparatus, and Conditions

Set-up and install the heat pump unit as per the provisions described in ANSI/ASHRAE 118.1-2022 and in the subsections that follow for either "Type IV" or "Type V" equipment, as appropriate. If a Type V AS-central HPWH and matching storage tank are unable to meet the plumbing configuration shown in ANSI/ASHRAE 118.1-2022, test the AS-central HPWH as Type IV equipment.

1) Test set-up and installation instructions.

   a) For outdoor AS heat pump units follow the instructions in sections 7.1 and 7.7.1 of ANSI/ASHRAE 118.1-2022, for heat pump units that can be installed in either ducted or non-ducted configurations, test in either the ducted or non-ducted configuration. For indoor AS heat pump units test in the ducted configuration. When testing in the ducted configuration, follow the instructions in section 7.7.5 of ANSI/ASHRAE 118.1-2022 except for the test operating tolerance for external static pressure which shall be ±0.05 in WC and for the airflow (nozzle pressure drop) tolerance which shall be ±5%.

   b) For WS heat pump units, set up the unit for testing as per section 7.1 and section 7.7.3 of ANSI/ASHRAE 118.1-2022.

2) Use the water piping instructions described in section 7.2 of ANSI/ASHRAE 118.1-2022 and, if applicable, section 7.7.6 of ANSI/ASHRAE 118.1-2022.

3) Install the thermocouples, including the room thermocouples, as per the instructions in sections 7.3.1, 7.3.2, and 7.3.3 (as applicable) of ANSI/ASHRAE 118.1-2022. The outlet heat exchanger water temperature (T_{ohx}) does not need to be measured for heat pump units.

4) Install the temperature sensors at the locations specified in Figures 6-14 of ANSI/ASHRAE 118.1-2022, as applicable. Follow the instructions provided in section 7.7.7.1 of ANSI/ASHRAE 118.1-2022 to install the temperature and flow-sensing instruments.

5) For outdoor AS heat pump units, use the evaporator-side rating conditions in Table 4.1 through Table 4.4 corresponding to Type A-D of the heat pump unit. For heat pump units that choose to conduct the H_{35} defrost test, conduct the H_{35} test according to section 4.2G). If the H_{35} optional test is not conducted, the H_L test must be conducted, using the lowest specified compressor operating temperature as the test condition. Maintain the specified conditions throughout the test.

6) For indoor AS heat pump units and WS heat pump units, use the evaporator-side rating conditions in Table 4.5. Maintain the specified conditions throughout the test.

7) Follow the directions in section 7.7.4 of ANSI/ASHRAE 118.1-2022 for heat pump unit mounting and installation instructions, as applicable. Do not make any alterations to the equipment except as specified in this document for installation, testing, and the attachment of required test apparatus and instruments.

8) Use Table 1 of ANSI/ASHRAE 118.1-2022 for operating and condition tolerances of measured parameters.

9) If the heat pump unit is equipped with a thermostat that is used to control the throttling valve of the equipment, then use the provisions in section 7.7.7.2 of ANSI/ASHRAE 118.1-2022 to set up the thermostat.

10) Supplemental heat inputs such as electric resistance elements must be disabled when testing the heat pump.

11) Install instruments to measure the electricity supply to the equipment as specified in section 7.5 of ANSI/ASHRAE 118.1-2022.

12) Install the water pump as specified in section 7.6 of ANSI/ASHRAE 118.1-2022.

Table 4.1 Type A Outdoor AS Heat Pump Unit Evaporator Test Conditions

Test Number	Evaporator Entering Air Temperature °F (± 1°F)	
	Dry-bulb temperature	Wet-bulb temperature
H_{95} - required	95.0	75.0
H_{68} - required	68.0	57.0
H_{47} - required	47.0	43.0

Table 4.2 Type B Outdoor AS Heat Pump Unit Evaporator Test Conditions

Test Number	Evaporator Entering Air Temperature °F (± 1°F)	
	Dry-bulb temperature	Wet-bulb temperature
H_{95} - required	95.0	75.0
H_{68} - required	68.0	57.0
H_{47} - required	47.0	43.0
H_{35} - optional	35.0	33.0
H_L – optional[1]	See note 2	Max 60% RH

[1] Test is required if the H_{35} test is not performed
[2] Test at T_L as determined in section 4.2D)2)

Table 4.3 Type C Outdoor AS Heat Pump Unit Evaporator Test Conditions

Test Number	Evaporator Entering Air Temperature °F (± 1°F)	
	Dry-bulb temperature	Wet-bulb temperature
H_{95} - required	95.0	75.0
H_{68} - required	68.0	57.0
H_{47} - required	47.0	43.0

H_{35} - optional	35.0	33.0
H_{17} - required	17.0	15.0

Table 4.4 Type D Outdoor AS Heat Pump Unit Evaporator Test Conditions

Test Number	Evaporator Entering Air Temperature °F (± 1°F)	
	Dry-bulb temperature	Wet-bulb temperature
H_{95} - required	95.0	75.0
H_{68} - required	68.0	57.0
H_{47} - required	47.0	43.0
H_{35} - optional	35.0	33.0
H_{17} - required	17.0	15.0
H_5 - required	5.0	4.0

Table 4.5 Indoor AS Heat Pump Units and WS Heat Pump Units Evaporator Test Conditions

Heat Pump Unit Type	Test Condition
Indoor AS Heat Pump Unit ($H_{80.6}$)	Maintain the evaporator entering dry-bulb air temperature at 80.6°F ± 1°F and wet-bulb air temperature at 71.2°F ± 1°F.
Indoor WS Heat Pump Unit	Maintain the evaporator entering water temperature at 68.0°F ± 1°F.
Ground WS Heat Pump Unit	Maintain the evaporator entering water temperature at 50.0°F ± 1°F.
Ground-Source Closed-Loop Heat Pump Unit*	Maintain the evaporator entering water temperature at 32.0°F ± 1°F.

* For ground-source closed-loop heat pump units, the evaporator water must be mixed with 15-percent methanol by-weight to allow the solution to achieve the required rating conditions.

Note: The DOE and EPA received several comments that the previous draft's proposed evaporator entering air temperatures did not accurately represent the temperatures that central HWPHs would spend most of their time operating in. The DOE and EPA agreed with stakeholders and adjusted the evaporator entering air temperatures to be more evenly spaced out. Since the previous draft, the 80.6°F test point was removed and a 68.0°F test point was added for outdoor air-source heat pump units. The 50°F test condition remains, but was adjusted to 47°F to match test conditions from the space-heating industry and provide a lower test condition that all AS heat pump units would be able to conduct. The DOE and EPA continue to use the 17°F test condition as it is common in the space-heating industry and provides better information on outdoor central HPWHs performance at cold climate conditions.

The DOE and EPA are also requiring manufacturers to provide the outdoor AS heat pump unit Type, A-D, to streamline the testing process and help test labs apply the correct test conditions and formulas for calculating the WHEER metric. Type A-D do not represent different product classes, but will need to be used for determining which procedure should be used for the specific type of UUT.

The DOE and EPA also included a minimum temperature condition, H_L, which is required for Type B units that cannot conduct the 35°F defrost test. This test condition is intended to help interpolate between measured values for rather than relying on the calculated H_{35} defrost test. Units that are able to conduct the 17°F do not need to conduct the H_L test.

The DOE and EPA included a test condition and metric specifically for Central HPWHs that are only intended to operate indoors, Indoor AS-central HPWHs. This test point is conducted in the ducted configuration at 80.6°F and will result in a single Indoor COP at 80.6. This metric will more accurately represent the performance of a heat pump unit that is only intended to operate indoors compared to the WHEER metric which considers performance across a range of outdoor temperatures and temperature bins.

F) Test Procedure

Test all heat pump units as per the provisions described in ANSI/ASHRAE 118.1-2022 for either “Type IV” equipment as defined in section 4.4 of ANSI/ASHRAE 118.1-2022 or “Type V” equipment as defined in section 4.5 of ANSI/ASHRAE 118.1-2022, as appropriate. Tests for all heat pump units must follow the steps described below.

1) Supply the heat pump unit with electricity at the voltage specified by the manufacturer. Follow the provisions in section 8.2.1 of ANSI/ASHRAE 118.1-2022 to maintain the electricity supply at the required level. For models with multiple voltages specified by the manufacturer, use the minimum voltage specified by the manufacturer to conduct the test. Maintain the voltage as per the limits specified in section 8.2.1 of ANSI/ASHRAE 118.1-2022.

2) For Outdoor AS heat pump units, set the condenser entering water temperature and outlet water temperature for each test per the following provisions. For single-pass heat pump units test each of the evaporator test conditions from Table 4.1 through Table 4.4 (as applicable) with both the Single-Pass and Multi-Pass test conditions, if possible, in Table 4.6. For multi-pass heat pump units test each of the evaporator test conditions from Table 4.1 through Table 4.4(as applicable) with just the multi-pass test condition in Table 4.6.

3) For Indoor single-pass heat pump units test at the applicable dry-bulb and wet-bulb test conditions in Table 4.5 with both the single-pass and multi-pass test conditions, if possible, in Table 4.7. For indoor multi-pass heat pump units test at the applicable dry-bulb and wet-bulb test conditions in Table 4.5 with just the multi-pass test condition in Table 4.7.

4) For WS heat pump units, test at the applicable test conditions in Table 4.5 with both the single-pass and multi-pass test condition, if possible, in Table 4.8. For multi-pass heat pump units test at the applicable test condition in Table 4.5 with just the multi-pass entering water temperature and water temperature rise test condition in Table 4.8.

Use the applicable provisions in sections 8.7.2 of ANSI/ASHRAE 118.1-2022 with the conditions specified in Table 4.6, Table 4.7, and Table 4.8 (as applicable) of this document to adjust water flow rate and the mean condenser entering water temperature for each test. Equilibrium at a given target outlet water temperature is achieved when the target water temperature is maintained with no variation in excess of 2°F over a three-minute period.

Table 4.6 Condenser Entering Water Temperature and Outlet Water Temperature Conditions for Outdoor AS Heat Pump Units

Test Number	Mean Condenser Entering Water Temperature °F (± 1°F)		Mean Outlet Water Temperature (± 2°F)
	Single-Pass[1]	Multi-Pass	All Conditions
H_{95}	87	125	140
H_{68}	78	125	140
H_{47}	74	125	140
H_{35}	72	125	140
H_{17}	69	125	140
H_5 [2]	68	125	140

[1] If the tested unit is unable to achieve the required mean outlet water temperature condition at any test condition that the unit is required to test corresponding to heat pump unit type A-D, omit the single pass test.
[2] For the optional T_L test, use 68°F as the single-pass inlet water temperature condition.

Table 4.7 Condenser Entering Water Temperature and Outlet Water Temperature Conditions for Indoor AS Heat Pump Units

Test Number	Mean Condenser Entering Water Temperature °F (± 1°F)		Mean Outlet Water Temperature (± 2°F)
	Single-Pass*	Multi-Pass	All Conditions
$H_{80.6}$	82.3	125	140

*If the tested unit is unable to achieve the required mean outlet water temperature condition, omit the single pass test.

Note: The DOE and EPA received several comments that suggested adjusting the condenser entering water temperature to vary with the evaporator entering air temperature for single-pass tests. The DOE and EPA agreed that this would be more representative as groundwater temperatures correlate with air temperature. Therefore, the DOE and EPA adjusted the single-pass condenser entering water temperatures to vary between 68°F and 87°F depending on the test condition. These entering water test conditions were selected based on the assumption that, in a typical installation, the incoming mains water temperature will partially mix with hotter water in a tank or circulation loop. As a result, the entering water test conditions are warmer than mains entering water.

The DOE and EPA also included separate condenser entering water temperature conditions for indoor AS heat pump units and WS heat pump units as these only require one single-pass and one multi-pass test condition.

Table 4.8 Condenser Entering Water Temperature and Temperature Rise Conditions for WS Heat Pump Units

Single-Pass Test	Multi-Pass Test
Adjust the target mean outlet water temperature to 70°F ± 2°F above the mean condenser entering water temperature of 70°F ± 1°F. If the tested model is unable to achieve the required mean outlet water temperature condition, omit this test.	Adjust the target mean outlet water temperature to 15°F ± 2°F above the mean condenser entering water temperature of 125°F ± 1°F.

5) The flow rate, FR, is the flow rate of water through the heat pump unit expressed in gallons per minute obtained after following the steps in section 4.2F2) of this document. Use the evaporator side rating conditions specified in section 4.2E5) and section 4.2E6 (as applicable).The water-heating equipment shall be operated at this flow rate for 30 minutes. Record the initial electric meter reading ($Z_{i,H,y}$) and the test start time, $t_{i,H,y}$. Record the outlet water temperature ($T_{o,H,y}$), the supply water temperature ($T_{s,H,y}$), the water flow readings in gal/m ($FR_{H,y}$), and, if a pump is required to circulate water between the tank and heat pump unit, and is provided with the central HPWH, the electrical power input to the heat pump unit circulator pump, $Z_{p,H,y}$, at equal intervals no greater than one minute. At the end of the 30-minute period, record the final electric meter reading ($Z_{f,H,y}$) and the time, $t_{f,H,y}$. If the central HPWH requires a heat pump unit circulator pump but none is provided, record the pressure differential between the heat pump unit entering and leaving water flow, P_{wd}, at equal intervals no greater than one minute and use section 7.6 of ANSI/ASHRAE 118.1-2022 to calculate $Z_{p,H,y}$. The subscript H represents the condenser entering air/water test condition and the subscript *y* can be "SP" or "MP" to represent either the Single-Pass Test or the Multi-Pass Test from Table 4.6.

6) In addition to the above, record the following at equal intervals of one minute over the 30-minute test period for the heat-pump water heaters, as applicable:

a) AS Heat Pump Units: Heat-pump water-heater evaporator air dry-bulb, $T_{adb,H,y}$, and wet-bulb, $T_{awb,H,y}$, temperatures.

b) WS Heat Pump Units: Heat-pump water-heater evaporator test water supply temperature, $T_{tw,H,y}$; and test water flow rate, $FR_{tw,H,y}$ (gal/m).

Determine the following quantities:

i. P_{wd} = average of pressure differential between the central HPWH entering and leaving water flow over the 30-minute period (this value is used to calculate $E_{pc,k}$ in section 7.6 of ANSI/ASHRAE 118.1-2022), kPa.

ii. $Z_{H,y}$ is the electrical energy used by heat-pump water-heater in full-input water heating mode, measure from initial to final meter reading and is calculated as $Z_{f,H,y}$-$Z_{i,H,y}$, in kWh

iii. $Z_{p,H,y}$ is the average electrical power input to the heat-pump water-heater water pump water pump at full input as measured during the 30-minute test period, in kW, or as calculated according to section 7.6 of ANSI/ASHRAE 118.1-2022.

iv. Calculate the $Q_{H,y}$ and $E_{H,y}$ of the heat pump unit according to the procedure in this section. For all calculations, time differences must be expressed in minutes:

a. Use the data recorded in 4.2E)5) and 4.2E)6). Water heating capacity $Q_{H,y}$, in Btu/hr shall be calculated as follows. For each of the 31 readings made during the 30-minute test period, calculate $Q_{H,y,n}$ for reading n=0 to n=30 as:

$$Q_{H,y,n} = FR_{H,y,n} \times 60 \times (T_{o,H,y,n} - T_{s,H,y,n}) \times [C_p/(C_{fg} \times v)]$$

Where:

C_p = specific heat of water = 1.004 Btu/lb ·°F

C_{fg} = volume conversion factor = 7.48055 gal/ft^3

v = specific volume of water, temperature compensated, ft^3/lb

b. Determine $Q_{H,y}$ by calculating the average of these 31 values as follows:

$$Q_{H,y} = \sum_{n=0}^{30} \frac{Q_{H,y,n}}{31}$$

c. Calculate the average rate of energy input $E_{H,y}$, in Btu/hr during the test as follows

$$E_{H,y} = (C_{ge} \times Z_{p,H,y}) + \{(C_{ge} \times Z_{H,y})/(t_{f,H,y} - t_{i,H,y})\}$$

Where:

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

G) Defrost Test Procedure

1) Use these instructions to conduct the optional H_{35} tests specified above.

2) Operate the test room reconditioning apparatus and the heat pump for at least 30 minutes at the specified test conditions as a stabilization period.

3) Defrost termination occurs when the controls of the heat pump actuate the first change in converting from defrost operation to normal heating operation. Defrost initiation occurs when the controls of the heat pump first alter its normal heating operation in order to eliminate possible accumulations of frost on the outdoor coil.

4) Following the stabilization period, use the following criteria to determine when to begin the preliminary test period:

For heat pumps containing defrost controls which are likely to cause defrosts at intervals less than one hour, the preliminary test period starts at the termination of an automatic defrost cycle and ends at the termination of the next occurring automatic defrost cycle.

For heat pumps containing defrost controls which are likely to cause defrosts at intervals exceeding one hour, the preliminary test period must consist of a heating interval lasting at least one hour followed by a defrost cycle that is either manually or automatically initiated.

5) In all cases, the heat pump's own controls must govern when a defrost cycle terminates.

6) Begin the official test period immediately following the preliminary test period. The official test period ends at the termination of the next occurring automatic defrost cycle. If the heat pump has not undergone a defrost after 6 hours, immediately conclude the test and use the results from the full 6-hour period to calculate the average water heating capacity and average electrical power consumption.

7) To constitute a valid frost accumulation test, satisfy the test tolerances specified in Table 4.9 during both the preliminary and official test periods. As noted in Table 4.9, test operating tolerances are specified for two sub-intervals:

a) When heating, except for the first 10 minutes after the termination of a defrost cycle (sub-interval H) and
b) When defrosting, plus these same first 10 minutes after defrost termination (sub-interval D):

Evaluate compliance with Table 4.9 test condition tolerances and the majority of the test operating tolerances using the averages from measurements recorded only during sub-interval H. Continuously record the inlet and outlet water temperatures, and the dry bulb temperature and water vapor content of the air entering the outdoor coil. Sample the remaining parameters listed in Table 4.9 at equal intervals that span 5 minutes or less.

Table 4.9 Test Tolerances for Frost Accumulation Tests

Reading	Maximum Variation of Readings		Maximum Variation of Arithmetic Average
	Sub-interval H[1]	Sub-interval D[2]	Sub-interval H[1]
Inlet water temperature, °F	1.0	10.0	1.0
Outlet water temperature, °F	2.0	-	2.0
Entering air dry-bulb temperature, °F	3.0	10.0	0.5
Entering air wet-bulb temperature, °F	1.5		0.3
External resistance to airflow, inches of water	0.05		0.02
Electrical voltage, % of reading	2.0		1.5

[1] Applies when the heat pump is in the heating mode, except for the first 10 minutes after termination of a defrost cycle.
[2] Applies during a defrost cycle and during the first 10 minutes after the termination of a defrost cycle when the heat pump is operating in the heating mode.
[3] For heat pumps that turn off the indoor blower during the defrost cycle, the noted tolerance only applies during the 10-minute interval that follows defrost termination.

8) For the official test period, collect and use the following data to calculate average water heating capacity and electrical power. During heating and defrosting intervals when the controls of the heat pump have the water pump on, continuously record the inlet and outlet water temperatures and water flow rate. Determine the corresponding cumulative time (in hours) of water flow, $\Delta\tau_a$. Record the electrical energy consumed, expressed in watt-hours, from defrost termination to defrost termination, e(35), as well as the corresponding elapsed time in hours, $\Delta\tau_{FR}$.

4.3 WHEER Calculation

> **Note:** While WHEER is the applicable seasonal metric for all outdoor air-source CHPWHs, DOE and EPA envision that specific WHEER representations may be made based on the unit configuration (single-pass, multi-pass) and climate (national average, cold climate) to demonstrate the range of performance for a unit. A single unit may be able to make all of the following WHEER representations: $WHEER_{SP}$, $WHEER_{MP}$, $WHEER_{C,SP}$, $WHEER_{C,MP}$.
>
> Refer to section 4.2F) to see the applicable conditions for single-pass and multi-pass CHPWH units. To calculate national average or cold climate WHEER ratings, use the applicable fractional hours in Table 4.10.

Calculate WHEER and $WHEER_C$ where WHEER uses the national average climate fractional bin hours (n_j/N) and $WHEER_C$ uses the cold climate fractional bin hours (n_j/N) in Table 4.10 using Equation 4.3-1:

$$WHEER = \left(\frac{\sum_{j=1}^{30} n_j * BL(T_j)}{\sum_{j=1}^{30} e_h(T_j) + \sum_{j=1}^{30} RH(T_j)}\right) = \left(\frac{\sum_{j=1}^{30} \frac{n_j}{N} * BL(T_j)}{\sum_{j=1}^{30} \frac{e_h(T_j)}{N} + \sum_{j=1}^{30} \frac{RH(T_j)}{N}}\right)$$

Where:

$BL(T_j)$ = the value of the water heating demand evaluated at the outdoor bin temperature, Btu/hr, as calculated in Equation 4.3-2.

$\frac{e_h(T_j)}{N}$ = the ratio of the electrical energy consumed by the test unit when operating the heat pump during periods of the water heating season when the outdoor temperature fell within the range represented by the bin temperature T_j to the total number of hours in the heating season (N), W

$\frac{RH(T_j)}{N}$ = the ratio of the electrical energy used for resistive water heating during periods when the outdoor temperature fell within the range represented by the bin temperature, T_j, to the total number of hours in the water heating season (N), W. Resistive water heating is modeled as being used to meet that portion of the demand that the heat pump does not meet because of insufficient capacity or because the heat pump automatically turns off at the lowest outdoor temperatures.

$\frac{n_j}{N}$ = fractional bin hours for either the national average (WHEER) or cold climate ($WHEER_C$) water heating season; the ratio of the number of hours during the water heating season when the outdoor temperature fell within the range represented by bin temperature, T_j to the total number of hours in the water heating season, dimensionless, as defined in Table 4.10.

T_j = the representative outdoor bin temperature, °F, as found in Table 4.10.

j = the bin number, as found in Table 4.10.

Evaluate the demand, $\mathbf{BL(T_j)}$ using Equation 4.3-2:

$$BL(T_j) = \frac{Q_{H,47}}{SF}$$

Where:

Q_{H47} = the rated water heating capacity of the unit at 47°F, Btu/h.

SF = sizing factor, 1.1

T_j = the representative outdoor bin temperature, °F, for each bin, j, as defined in Table 4.10.

Table 4.10 Distribution of Fractional Hours Within Water Heating Season Temperature Bins

Bin number, j	Bin temperature range °F	Representative temperature for bin °F	National Average - Fraction of total temperature bin hours, n_j/N	Cold Climate – Fraction of total temperature bin hours, n_j/N	Default Defrost Degradation Coefficient, CD_{DF}
1	110 ≤ t <115	112.5	0.0002	0	1.00000
2	105≤ t <110	107.5	0.0010	0	1.00000
3	100≤ t <105	102.5	0.0027	0	1.00000
4	95≤ t <100	97.5	0.0071	0.0001	1.00000
5	90≤ t <95	92.5	0.0201	0.0014	1.00000
6	85≤ t <90	87.5	0.0454	0.0058	1.00000
7	80≤ t <85	82.5	0.0745	0.0193	1.00000
8	75≤ t <80	77.5	0.0961	0.0374	1.00000
9	70≤ t <75	72.5	0.1018	0.0607	1.00000
10	65≤ t <70	67.5	0.0963	0.0776	1.00000
11	60≤ t <65	62.5	0.0921	0.0828	1.00000
12	55≤ t <60	57.5	0.0855	0.0844	1.00000
13	50≤ t <55	52.5	0.0783	0.0792	1.00000
14	45≤ t <50	47.5	0.0691	0.0776	1.00000
15	40≤ t <45	42.5	0.0640	0.0838	1.00000
16	35≤ t <40	37.5	0.0553	0.0841	0.92500
17	30≤ t <35	32.5	0.0468	0.0842	0.86415
18	25≤ t <30	27.5	0.0273	0.0600	0.88634
19	20≤ t <25	22.5	0.0156	0.0473	0.90152
20	15≤ t <20	17.5	0.0091	0.0342	0.91106
21	10≤ t <15	12.5	0.0050	0.0259	0.91636
22	5≤ t <10	7.5	0.0032	0.0187	0.91880
23	0≤ t <5	2.5	0.0018	0.0131	0.91977
24	-5≤ t <0	-2.5	0.0010	0.0096	0.92065
25	-10≤ t <-5	-7.5	0.0002	0.0064	0.92282
26	-15≤ t <-10	-12.5	0.0001	0.0034	0.92769
27	-20≤ t <-15	-17.5	0	0.0017	0.93662
28	-25≤ t <-20	-22.5	0	0.0007	0.95101
29	-30≤ t <-25	-27.5	0	0.0002	0.97224

30	-35≤ t <-30	-32.5	0	0.0001	1.00000

Note: The national average and cold climate bin distribution comes from the AHRI standard 1600-202x draft Table M5 which included national and cold climate weighted average outdoor temperature bin hours. According to the AHRI 1600-202x draft “the number of hours in each outdoor temperature bin was determined by calculating the fraction of the total population attributed to each city, multiplying all bins for a given city by its corresponding fraction, then summing all the selected cities for the representative distribution.”

The default defrost degradation coefficient is based on the AHRI Standard 1340-2023 analysis on time and temperature controlled defrosts.

Evaluate $\frac{\mathbf{e_h(T_j)}}{\mathbf{N}}$ and $\frac{\mathbf{RH(T_j)}}{\mathbf{N}}$ using the following equations:

Equation 4.3-3:

$$\frac{e_h(T_j)}{N} = X(T_j) * \dot{E}_h(T_j) * \delta(T_j) * \frac{n_j}{N}$$

Equation 4.3-4:

$$\frac{RH(T_j)}{N} = \frac{BL(T_j) - [X(T_j) * \dot{Q}_h(T_j) * \delta(T_j)]}{3.413\frac{Btu/h}{W}} * \frac{n_j}{N}$$

Where:

$X(T_j) = \begin{cases} \frac{BL(T_j)}{\dot{Q}_h(T_j)} \\ or \\ 1 \end{cases}$, whichever is less; the heating mode load factor for temperature bin j, dimensionless.

$\dot{Q}_h(T_j)$ = the water heating capacity of the heat pump when operating at outdoor temperature T_j, Btu/h, as calculated in Equation 4.3-6, Equation 4.3-8, Equation 4.3-12, Equation 4.3-16 depending on which tests are conducted.

$\dot{E}_h(T_j)$ = the electrical power consumption of the heat pump when operating at outdoor temperature T_j, W, as calculated in Equation 4.3-7, Equation 4.3-14, Equation 4.3-10, Equation 4.3-18 depending on which tests are conducted.

$\boldsymbol{\delta(T_j)}$ = the heat pump low temperature cut-out factor, dimensionless, as calculated in Equation 4.3-5.

T_j = the representative outdoor bin temperature, °F, as found in Table 4.10.

j = the bin number, as found in Table 4.10.

Use Equation 4.3-2 determine $BL(T_j)$. Obtain fractional bin hours for the heating season, $\frac{n_j}{N}$, from Table 4.10.

Determine the low temperature cut-out factor, $\delta(T_j)$, using the equation below:

Equation 4.3-5:

$$\delta(T_j) = \begin{cases} 0, & if\ T_j \le T_{off} \\ \frac{1}{2}, & if\ T_{off} < T_j \le T_{on} \\ 1, & if\ T_j > T_{on} \end{cases}$$

Where:

T_{off} = the outdoor temperature when the compressor is automatically shut off, °F, as determined in section 4.2D). (If this temperature was not determined, T_{off} is equal to the lowest outdoor dry bulb temperature condition tested, or 47 °F for Type A heat pumps).

T_{on} = the outdoor temperature when the compressor is automatically turned back on, if applicable, following an automatic shut-off, °F, as determined in section 4.2D). (If this temperature was not determined, T_{on} is equal to the lowest outdoor dry bulb temperature condition tested, or 47°F for Type A heat pumps).

T_j = the representative outdoor bin temperature, °F, as found in Table 4.10.

j = the bin number, as found in Table 4.10.

WHEER Calculation by Heat Pump Type

A) Type A Heat Pumps

For Type A heat pumps, calculate $\dot{Q}_h(T_j)$ and $\dot{E}_h(T_j)$ as follows:

Equation 4.3-6:

$$\dot{Q}_h(T_j) = \begin{cases} \dot{Q}_{H95} + \dfrac{[\dot{Q}_{H95} - \dot{Q}_{H68}] * (T_j - 95)}{95 - 68}, & if\ T_j > 95°F \\ \dot{Q}_{H68} + \dfrac{[\dot{Q}_{H95} - \dot{Q}_{H68}] * (T_j - 68)}{95 - 68}, & if\ 68°F \le T_j \le 95°F \\ \dot{Q}_{H47} + \dfrac{[\dot{Q}_{H68} - \dot{Q}_{H47}] * (T_j - 47)}{68 - 47}, & if\ 42 \le T_j < 68°F \\ 0, & if\ T_j < 42°F \end{cases}$$

Where:

$\dot{Q}_h(T_j)$ = the water heating capacity of the heat pump when operating at outdoor temperature T_j, Btu/h

$\dot{Q}_{H95}$ = the water heating capacity of the heat pump as measured in the H_{95} Test, Btu/h

$\dot{Q}_{H68}$ = the water heating capacity of the heat pump as measured in the H_{68} Test, Btu/h

$\dot{Q}_{H47}$ = the water heating capacity of the heat pump as measured in the H_{47} Test, Btu/h

T_j = the representative outdoor bin temperature, °F, as found in Table 4.10.

j = the bin number, as found in Table 4.10.

Equation 4.3-7:

$$\dot{E}_h(T_j) = \begin{cases} \dot{E}_{H95} + \dfrac{[\dot{E}_{H95} - \dot{E}_{H68}] * (T_j - 95)}{95 - 68}, & if\ T_j > 95°F \\ \dot{E}_{H68} + \dfrac{[\dot{E}_{H95} - \dot{E}_{H68}] * (T_j - 68)}{95 - 68}, & if\ 68°F \le T_j \le 95°F \\ \dot{E}_{H47} + \dfrac{[\dot{E}_{H68} - \dot{E}_{H47}] * (T_j - 47)}{68 - 47}, & if\ 42 \le T_j < 68°F \\ 0, & if\ T_j < 42°F \end{cases}$$

Where:

$\dot{E}_h(T_j)$ = the electrical power consumption of the heat pump when operating at outdoor temperature T_j, Btu/h

$\dot{E}_{H95}$ = the electrical power consumption of the heat pump as measured in the H_{95} Test, Btu/h

$\dot{E}_{H68}$ = the electrical power consumption of the heat pump as measured in the H_{68} Test, Btu/h

$\dot{E}_{H47}$ = the electrical power consumption of the heat pump as measured in the H_{47} Test, Btu/h

T_j = the representative outdoor bin temperature, °F, as found in Table 4.10.

j = the bin number, as found in Table 4.10.

B) Type B Heat Pumps

For Type B heat pumps, calculate $\boldsymbol{\dot{Q}_h(T_j)}$ and $\boldsymbol{\dot{E}_h(T_j)}$ as follows:

Equation 4.3-8:

$$\dot{Q}_h(T_j) = \begin{cases} \dot{Q}_{H95} + \dfrac{[\dot{Q}_{H95} - \dot{Q}_{H68}] * (T_j - 95)}{95 - 68}, & if\ \ T_j > 95°F \\ \dot{Q}_{H68} + \dfrac{[\dot{Q}_{H95} - \dot{Q}_{H68}] * (T_j - 68)}{95 - 68}, & if\ 68°F \le T_j \le 95°F \\ \dot{Q}_{H47} + \dfrac{[\dot{Q}_{H68} - \dot{Q}_{H47}] * (T_j - 47)}{68 - 47}, & if\ 42 \le T_j < 68°F \\ \dot{Q}_{H35} + \dfrac{[\dot{Q}_{H47} - \dot{Q}_{H35}] * (T_j - T_L)}{47 - 35}, & if\ the\ 35\ test\ is\ conducted\ and\ T_{off} \le T_j < 42°F \\ \dot{CD}_{DF} * \left[\dot{Q}_{HL} + \dfrac{[\dot{Q}_{H47} - \dot{Q}_{HL}] * (T_j - T_L)}{47 - T_L}\right] & , if\ the\ 35\ test\ is\ not\ conducted\ and\ T_{off} \le T_j < 42°F \\ 0, & if\ T_j < T_{off} \end{cases}$$

Where:

$\dot{Q}_h(T_j)$ = the water heating capacity of the heat pump when operating at outdoor temperature T_j, Btu/h
$\dot{Q}_{H95}$ = the water heating capacity of the heat pump as measured in the H_{95} Test, Btu/h
$\dot{Q}_{H68}$ = the water heating capacity of the heat pump as measured in the H_{68} Test, Btu/h
$\dot{Q}_{H47}$ = the water heating capacity of the heat pump as measured in the H_{47} Test, Btu/h
$\dot{Q}_{H35}$= the water heating capacity of the heat pump when operating at 35°F, accounting for frost accumulation, as calculated in section 4.4, if the H_{35} test is conducted, Btu/h
$\dot{Q}_{HL}$ = the water heating capacity of the heat pump as measured in the H_L Test, Btu/h
T_j = the representative outdoor bin temperature, °F, as found in Table 4.10.
T_L = the average of the cut-out and cut-in temperatures, as determined in 4.2D)2)
j = the bin number, as found in Table 4.10 .
T_{off}= the cut-out temperature.
$\dot{CD}_{DF}$ = the default defrost degradation coefficient, as determined in table 4.

Equation 4.3-9:

$$\dot{E}_h(T_j) = \begin{cases} \dot{E}_{H95} + \dfrac{[\dot{E}_{H95} - \dot{E}_{H68}] * (T_j - 95)}{95 - 68}, & if\ \ T_j > 95°F \\ \dot{E}_{H68} + \dfrac{[\dot{E}_{H95} - \dot{E}_{H68}] * (T_j - 68)}{95 - 68}, & if\ 68°F \le T_j \le 95°F \\ \dot{E}_{H47} + \dfrac{[\dot{E}_{H68} - \dot{E}_{H47}] * (T_j - 47)}{68 - 47}, & if\ 42 \le T_j < 68°F \\ \dot{E}_{H35} + \dfrac{[\dot{E}_{H47} - \dot{E}_{H35}] * (T_j - T_L)}{47 - 35}, & if\ the\ 35\ test\ is\ conducted\ and\ T_{Off} \le T_j < 42°F \\ \dot{E}_{HL} + \dfrac{[\dot{E}_{H47} - \dot{E}_{HL}] * (T_j - T_L)}{47 - 35}, & if\ the\ 35\ test\ is\ not\ conducted\ and\ T_{Off} \le T_j < 42°F \\ 0, & if\ T_j < T_{Off} \end{cases}$$

Where:

$\dot{E}_h(T_j)$ = the electrical power consumption of the heat pump when operating at outdoor temperature T_j, Btu/h
$\dot{E}_{H95}$ = the electrical power consumption of the heat pump as measured in the H_{95} Test, Btu/h
$\dot{E}_{H68}$ = the electrical power consumption of the heat pump as measured in the H_{68} Test, Btu/h
$\dot{E}_{H47}$ = the electrical power consumption of the heat pump as measured in the H_{47} Test, Btu/h
$\dot{E}_{H35}$= the electrical power consumption of the heat pump when operating at 35°F, accounting for frost accumulation, as calculated in section 4.4, if the H_{35} test is conducted, or in Equation 4.3-11, below, if the H_{35} test is not conducted, Btu/h
$\dot{E}_{HL}$ = the electrical power consumption of the heat pump as measured in the H_L Test, Btu/h

T_j = the representative outdoor bin temperature, °F, as found in Table 4.10.
T_L = the average of the cut-out and cut-in temperatures, as determined in 4.2D)2)
j = the bin number, as found in Table 4.10.
T_{Off} = The cut-out temperature

C) Type C Heat Pumps

For Type C heat pumps, calculate $\dot{\boldsymbol{Q}}_{\boldsymbol{h}}(\boldsymbol{T_j})$ and $\dot{\boldsymbol{E}}_{\boldsymbol{h}}(\boldsymbol{T_j})$ as follows:

Equation 4.3-10:

$$\dot{Q}_h(T_j) = \begin{cases} \dot{Q}_{H95} + \dfrac{[\dot{Q}_{H95} - \dot{Q}_{H68}] * (T_j - 95)}{95 - 68}, & if\ T_j > 95°F \\ \dot{Q}_{H68} + \dfrac{[\dot{Q}_{H95} - \dot{Q}_{H68}] * (T_j - 68)}{95 - 68}, & if\ 68°F \le T_j \le 95°F \\ \dot{Q}_{H47} + \dfrac{[\dot{Q}_{H68} - \dot{Q}_{H47}] * (T_j - 47)}{68 - 47}, & if\ 42 \le T_j < 68°F \\ \dot{Q}_{H35} + \dfrac{[\dot{Q}_{H47} - \dot{Q}_{H35}] * (T_j - 35)}{47 - 35}, & if\ the\ 35\ test\ is\ conducted\ and\ 17 \le T_j < 42°F \\ \dot{CD}_{DF} * \left[\dot{Q}_{H17} + \dfrac{[\dot{Q}_{H47} - \dot{Q}_{17}] * (T_j - 17)}{47 - 17}\right] & , if\ the\ 35\ test\ is\ not\ conducted\ and\ T_{off} \le T_j < 42°F \\ \dot{Q}_{H17} + \dfrac{[\dot{Q}_{H47} - \dot{Q}_{H17}] * (T_j - 17)}{47 - 17}, & if\ the\ 35\ test\ is\ conducted\ and\ T_j < 2°F \\ 0, & if\ T_j < T_{off} \end{cases}$$

Where:

$\dot{Q}_h(T_j)$ = the water heating capacity of the heat pump when operating at outdoor temperature T_j, Btu/h
$\dot{Q}_{H95}$ = the water heating capacity of the heat pump as measured in the H_{95} Test, Btu/h
$\dot{Q}_{H68}$ = the water heating capacity of the heat pump as measured in the H_{68} Test, Btu/h
$\dot{Q}_{H47}$ = the water heating capacity of the heat pump as measured in the H_{47} Test, Btu/h
$\dot{Q}_{H35}$ = the water heating capacity of the heat pump when operating at 35°F, accounting for frost accumulation, as calculated in section 4.4, if the H_{35} test is conducted, Btu/h
$\dot{Q}_{H17}$ = the water heating capacity of the heat pump as measured in the H_{17} Test, Btu/h
T_j = the representative outdoor bin temperature, °F, as found in Table 4.10.
j = the bin number, as found in Table 4.10.
T_{off} = the cut-out temperature.
$\dot{CD}_{DF}$ = the default defrost degradation coefficient, as determined in table 4.

Equation 4.3-11:

$$\dot{E}_h(T_j) = \begin{cases} \dot{E}_{H95} + \dfrac{[\dot{E}_{H95} - \dot{E}_{H68}] * (T_j - 95)}{95 - 68}, & if\ T_j > 95°F \\ \dot{E}_{H68} + \dfrac{[\dot{E}_{H95} - \dot{E}_{H68}] * (T_j - 68)}{95 - 68}, & if\ 68°F \le T_j \le 95°F \\ \dot{E}_{H47} + \dfrac{[\dot{E}_{H68} - \dot{E}_{H47}] * (T_j - 47)}{68 - 47}, & if\ 42 \le T_j < 68°F \\ \dot{E}_{H35} + \dfrac{[\dot{E}_{H47} - \dot{E}_{H35}] * (T_j - 35)}{47 - 35}, & if\ the\ 35\ test\ is\ conducted\ and\ 17 \le T_j < 42°F \\ \dot{E}_{H17} + \dfrac{[\dot{E}_{H47} - \dot{E}_{H17}] * (T_j - 17)}{47 - 17}, & if\ the\ 35\ test\ is\ not\ conducted\ and\ T_{Off} \le T_j < 42°F \\ 0, & if\ T_j < T_{Off} \end{cases}$$

Where:

$\dot{E}_h(T_j)$ = the electrical power consumption of the heat pump when operating at outdoor temperature T_j, Btu/h
$\dot{E}_{H95}$ = the electrical power consumption of the heat pump as measured in the H_{95} Test, Btu/h
$\dot{E}_{H68}$ = the electrical power consumption of the heat pump as measured in the H_{68} Test, Btu/h
$\dot{E}_{H47}$ = the electrical power consumption of the heat pump as measured in the H_{47} Test, Btu/h
$\dot{E}_{H35}$= the electrical power consumption of the heat pump when operating at 35°F, Btu/h
$\dot{E}_{H17}$ = the electrical power consumption of the heat pump as measured in the H_{17} Test, Btu/h
T_j = the representative outdoor bin temperature, °F, as found in Table 4.10.
j = the bin number, as found in Table 4.10.

D) Type D Heat Pumps

For Type D Heat Pumps, calculate $\boldsymbol{\dot{Q}_h(T_j)}$ and $\boldsymbol{\dot{E}_h(T_j)}$ as follows:

Equation 4.3-12:

$$\dot{Q}_h(T_j) = \begin{cases} \dot{Q}_{H95} + \dfrac{[\dot{Q}_{H95} - \dot{Q}_{H68}] * (T_j - 95)}{95 - 68}, & if\ T_j > 95°F \\ \dot{Q}_{H68} + \dfrac{[\dot{Q}_{H95} - \dot{Q}_{H68}] * (T_j - 68)}{95 - 68}, & if\ 68°F \le T_j \le 95°F \\ \dot{Q}_{H47} + \dfrac{[\dot{Q}_{H68} - \dot{Q}_{H47}] * (T_j - 47)}{68 - 47}, & if\ 42 \le T_j < 68°F \\ \dot{Q}_{H35} + \dfrac{[\dot{Q}_{H47} - \dot{Q}_{H35}] * (T_j - 35)}{47 - 35}, & if\ the\ 35\ test\ is\ conducted\ and\ 17 \le T_j < 42°F \\ \dot{CD}_{DF} * \left[\dot{Q}_{H17} + \dfrac{[\dot{Q}_{H47} - \dot{Q}_{17}] * (T_j - 17)}{47 - 17}\right] & ,if\ the\ 35\ test\ is\ not\ conducted\ and\ 17 \le T_j < 42°F \\ \dot{Q}_{H5} + \dfrac{[\dot{Q}_{H17} - \dot{Q}_{H5}] * (T_j - 5)}{17 - 5}, & if\ the\ 35\ test\ is\ conducted\ and\ T_{off} \le T_j < 17°F \\ \dot{CD}_{DF} * \left[\dot{Q}_{H5} + \dfrac{[\dot{Q}_{H17} - \dot{Q}_{H5}] * (T_j - 5)}{17 - 5}\right], & if\ the\ 35\ test\ is\ not\ conducted\ and\ T_{off} \le T_j < 17°F \\ 0, & if\ T_j < T_{off} \end{cases}$$

Where:

$\dot{Q}_h(T_j)$ = the water heating capacity of the heat pump when operating at outdoor temperature T_j, Btu/h
$\dot{Q}_{H95}$ = the water heating capacity of the heat pump as measured in the H_{95} Test, Btu/h
$\dot{Q}_{H68}$ = the water heating capacity of the heat pump as measured in the H_{68} Test, Btu/h
$\dot{Q}_{H47}$ = the water heating capacity of the heat pump as measured in the H_{47} Test, Btu/h
$\dot{Q}_{H35}$= the water heating capacity of the heat pump when operating at 35°F, accounting for frost accumulation, as calculated in section 4.4, if the H_{35} test is conducted, Btu/h
$\dot{Q}_{H17}$ = the water heating capacity of the heat pump as measured in the H_{17} Test, Btu/h
$\dot{Q}_{H5}$ = the water heating capacity of the heat pump as measured in the H_5 Test, Btu/h
T_j = the representative outdoor bin temperature, °F, as found in Table 4.10.
j = the bin number, as found in Table 4.10.
T_{off} = the cut-out temperature.
$\dot{CD}_{DF}$ = the default defrost degradation coefficient, as determined in table 4.

Equation 4.3-13:

$$\dot{E}_h(T_j) = \begin{cases} \dot{E}_{H95} + \frac{[\dot{E}_{H95} - \dot{E}_{H68}] * (T_j - 95)}{95 - 68}, \quad if\ T_j > 95°\text{F} \\ \dot{E}_{H68} + \frac{[\dot{E}_{H95} - \dot{E}_{H68}] * (T_j - 68)}{95 - 68}, if\ 68°\text{F} \le T_j \le 95°\text{F} \\ \dot{E}_{H47} + \frac{[\dot{E}_{H68} - \dot{E}_{H47}] * (T_j - 47)}{68 - 47}, if\ 42 \le T_j < 68°\text{F} \\ \dot{E}_{H35} + \frac{[\dot{E}_{H47} - \dot{E}_{H35}] * (T_j - 35)}{47 - 35}, if\ the\ 35\ test\ is\ conducted\ and\ 17 \le T_j < 42°\text{F} \\ \dot{E}_{H17} + \frac{[\dot{E}_{H47} - \dot{E}_{H17}] * (T_j - 17)}{47 - 17}, if\ the\ 35\ test\ is\ not\ conducted\ and\ 17 \le T_j < 42°\text{F} \\ \dot{E}_{H5} + \frac{[\dot{E}_{H17} - \dot{E}_{H5}] * (T_j - 5)}{17 - 5}, if\ T_{Off} \le T_j < 17°\text{F} \\ 0, \quad if\ T_j < T_{Off} \end{cases}$$

Where:

$\dot{E}_h(T_j)$ = the electrical power consumption of the heat pump when operating at outdoor temperature T_j, Btu/h
$\dot{E}_{H95}$ = the electrical power consumption of the heat pump as measured in the H_{95} Test, Btu/h
$\dot{E}_{H68}$ = the electrical power consumption of the heat pump as measured in the H_{68} Test, Btu/h
$\dot{E}_{H47}$ = the electrical power consumption of the heat pump as measured in the H_{47} Test, Btu/h
$\dot{E}_{H35}$= the electrical power consumption of the heat pump when operating at 35°F, accounting for frost accumulation, as calculated in section 4.4, if the H_{35} test is conducted, Btu/h
$\dot{E}_{H17}$ = the electrical power consumption of the heat pump as measured in the H_{17} Test, Btu/h
$\dot{E}_{H5}$ = the electrical power consumption of the heat pump as measured in the H_5 Test, Btu/h
T_j = the representative outdoor bin temperature, °F, as found in Table 4.10.
j = the bin number, as found in Table 4.10.
T_{Off}= The cut-out temperature

4.4 Defrost Performance Calculations

A) If the H_{35} test is conducted, calculate the heating capacity at 35°F in the equations above using Equation 4.4-1:

Equation 4.4-1:

$$\dot{Q}_{35} = \frac{60 * FR_{35} * C_p * \Gamma}{\Delta\tau_{FR}(C_{fg} * v)}$$

Where:

$\dot{Q}_{35}$ = the heating capacity of a unit when defrosting at 35°F
FR_{35}= the average water flow readings in rate measured during sub-interval H, gpm
C_p = specific heat of water = 1.004 Btu/lb ·°F
C_{fg} = volume conversion factor = 7.48055 gal/ft^3
v = specific volume of water, temperature compensated, ft^3/lb
$\Delta\tau_{FR}$ = τ2 − τ1, the elapsed time from defrost termination to defrost termination, hr.
Γ = the result of Equation 4.4-2

Equation 4.4-2:

$$\Gamma = \int_{\tau 1}^{\tau_2} [T_{a2}(\tau) - T_{a1}(\tau)] d\tau$$

Where:

$T_{a1}(\tau)$ = entering water temperature at elapsed time τ, °F; only recorded when water flow occurs; assigned the value of zero during periods (if any) where the circulator pump cycles off.
$T_{a2}(\tau)$ = leaving water temperature at elapsed time τ, °F; only recorded when water flow occurs; assigned the value of zero during periods (if any) where the circulator pump cycles off.
τ_1 = the elapsed time when the defrost termination occurs that begins the official test period, hr.
τ_2 = the elapsed time when the next automatically occurring defrost termination occurs, thus ending the official test period, hr.

B) Calculate the energy use at 35°F in the equations above using Equation 4.4-3:

Equation 4.4-3:

$$\dot{E}_{35} = \frac{e(35)}{\Delta\tau_{FR}}$$

Where:

$\dot{E}_{35}$= the average electrical power of a unit when defrosting at 35°F
$e(35)$ = the electrical energy consumed from defrost termination to defrost termination, watt-hours.
$\Delta\tau FR = \tau 2 - \tau 1$, the elapsed time from defrost termination to defrost termination, hr.

4.5 Other Reported values

A) Heating Capacity

The heating capacity of the UUT shall be reported as the measured capacity in the H_{47} test.

B) COP for Indoor AS-CHPWHs and Other CHPWHs

1) Calculate and report the single-pass and/or multi-pass COP at 80.6°F, Indoor $COP_{80.6}$, for indoor air-source heat pump units, as follows:

$$COP_{80.6,y} = \frac{\dot{Q}_{H80.6,y}}{\dot{E}_{H80.6,y}}$$

2) Calculate and report the single-pass and/or multi-pass COP at the applicable test condition for WS heat pump units as follows:

$$COP = \frac{Q_{H,y}}{E_{H,y}}$$

4.7) Test Method for the Measurement of Storage Tank Standby Losses

In a central heat pump water heating system, the heat pump may be connected to an unfired tank or an external electric storage water heater. The standby losses of these tanks shall be measured according to the applicable test procedure in this section. Unfired storage tanks shall be tested according to the instructions in section 4.7A and electric storage water heaters shall be tested according to the instructions in section 4.7B

A) Unfired Storage Tanks

1) General

Determine standby loss in accordance with the following sections. Certain sections reference sections of GAMA Testing Standard IWH-TS-1 (March 2003 Edition). Where the instructions contained in the sections below conflict with instructions in GAMA IWH-TS-1, the instructions contained herein control.

2) Test Set up

Set up the tank for testing in accordance with sections 4, 5 (except for section 5.5), 6.0, and 6.1 of GAMA IWH-TS-1.

a) Piping Insulation

Insulate all water piping external to the water heater jacket including heat traps and piping that are installed by the manufacturer or shipped with the unit, for at least 4 ft of piping length from the connection at the appliance with material having an R-value not less than 8°F·ft^2·h/Btu. Ensure that the insulation does not contact any appliance surface except at the location where the pipe connections penetrate the appliance jacket.

3) Test Conditions

a) Water Supply.

The pressure of the water supply must be maintained between 40 psi and the maximum pressure specified by the manufacturer of the unit being tested. The accuracy of the pressure-measuring devices must be ± 1.0 pounds per square inch (psi).

b) Ambient Room Temperature.

During the soak-in period and standby loss test, maintain the ambient room temperature at 75°F ± 10°F at all times. Measure the ambient room temperature at one minute intervals during these periods. Measure the average ambient room temperature separately for the soak-in period and standby loss test. During the soak-in period and standby loss test, the measured room temperature must not vary more than ±5.0°F at any reading from the average ambient room temperature.

c) Maximum Air Draft.

During the soak-in period and standby loss test, the storage tank must be located in an area protected from drafts of more than 50 ft/min from room ventilation registers, windows, or other external sources of air movement. Prior to beginning the soak-in period and standby loss test, measure the air draft within three feet of the jacket of the water heater to ensure this condition is met. Ensure that no other changes that would increase the air draft are made to the test set up or conditions during conduct of the test.

d) Data Collection.

Follow the data recording intervals specified in the following sections.

i. Soak-In period

Measure the air draft, in ft/min, before beginning the soak-in period. Measure the ambient room temperature, in °F, every minute during the soak-in period.

ii. Standby Loss Test

Follow the data recording intervals specified in Table 4.11 of this section.

Table 4.11 Data to be Recorded Before and During the Standby Loss Test

Item recorded	Before test	Every minute[1]
Air draft, ft/min	X	
Time, minutes/seconds		X
Mean tank temperature[2], °F		X
Ambient room temperature, °F		X

[1] These measurements are to be recorded at the start and end of the test, as well as at intervals of one minute during the test.
[2] Mean tank temperature is the mean of the thermocouple readings within the tank.

4) Determination of Storage Volume

Determine the storage volume by subtracting the tare weight—measured while the system is dry and empty—from the weight of the system when filled with water and dividing the resulting net weight of water by the density of water at the measured water temperature.

5) Soak-In Period

Prior to conducting a standby loss test, a soak-in period must occur, in which the tank must sit without any draws taking place for at least 12 hours. Begin the soak-in period after filling the tank with water such that the initial mean tank temperature of 145°F ± 5°F is achieved.

6) Standby Loss Test

a) After conducting the soak-in period but prior to the start of the standby loss test, fill the storage tank with water that is heated sufficiently to achieve a mean tank temperature of at least 145°F.

b) When the mean tank temperature falls to 142°F, start recording mean tank temperature and ambient room temperature at regular minute intervals as the tank temperature decays.

c) When the mean tank temperature falls below 138°F, stop the test and record the final mean tank temperature reading.

d) Calculate the standby loss in Btu per hour as follows:

Select the data points starting when the mean tank temperature first falls to 142°F and ending when the mean tank temperature first falls below 138°F. Calculate the uncorrected decay rate, DR_u in °F/h, by a least squares method as given by:

$$DR_u = \frac{n\sum x_i T_i - (\sum x_i)(\sum T_i)}{n\sum(x_i^2) - (\sum x_i)^2}$$

Where:

n = the number of data points collected;

x_i = Elapsed time of each data point from the start of the decay period when the tank first achieves a mean temperature of 142°F (hours);

T_i = Mean tank temperature in °F measured at each one minute interval during the decay period between the time when the mean tank temperature first falls to 142°F and when the mean tank temperature drops below 138°F.

Calculate the mean tank water temperature decay rate ("DR"), in °F/h, as follows:

$$DR = DR_u \times \frac{140°\text{F} - 75°\text{F}}{140°\text{F} - T_a}$$

Where T_a is the average ambient room temperature during the test, °F.

The standby loss, SL, in Btu per hour, for unfired hot water storage tanks is determined as:

$$SL_U = DR \times V \times \rho \times C_p$$

Where:

DR = the decay rate, °F/h

V = tank volume expressed in gallons, measured in accordance with section 4.7.A.4 of this appendix

ρ = 8.205 pounds per gallon, density of water at 140°F

C_p = 0.999 Btu per pound-mass· °F, specific heat of water at 140°F

B) Electric Storage Water Heaters

1) General

Use appendix B to subpart G of 10 CFR 431 (“appendix B”) to set-up, test, and collect data to determine the standby loss expressed as a percentage per hour (%/h) of the heat content of the stored water above room temperature. Convert the standby loss in %/h to Btu/h using the equation below.

2) Standby Loss Calculation

Calculate the Standby loss (SL_E), in Btu/h, using the following equation:

$$SL_E = S\ x\ 8.25\ x\ V_a\ x\ 70$$

Where:

S = standby loss as determined by section 5.7 of appendix B, %/h
8.25 = nominal specific heat of water, Btu/gal°F
V_a = Volume of water contained in the water heater in gallons measured in accordance with section 4 of appendix B.
70 = representative temperature differential between stored water and the ambient temperature, °F

4.8) Test Method for the Measurement of Energy Consumption of Circulator Pumps

To measure the energy consumption of any additional circulator pumps in the central HPWH system other than the heat pump unit circulator pump, use sections 0-5 of appendix D to subpart Y of 10 CFR 431 to set-up, test, and collect data to determine the circulator energy rating (CER), in hp, determined in accordance with Table 1 of appendix D.

5 REFERENCES

A) 10 CFR Part 431, Subpart G, Appendix E. Uniform Test Method for the Measurement of Energy Efficiency of Commercial Heat Pump Water Heaters (as of November 6, 2017).

B) “Uniform Test Method for the Measurement of Energy Efficiency of Unfired Hot Water Storage Tanks (as proposed in the May 2016 NOPR for Commercial Water Heating Equipment Test Procedure)” 81 FR 28587, 28654-28655. Energy Conservation Program for Certain Commercial and Industrial Equipment: Test Procedure for Commercial Water Heating Equipment; Notice of Proposed Rulemaking. May 9, 2016.

C) 10 CFR Part 431. Subpart G, Appendix B. Uniform Test Method for the Measurement of Standby Loss of Electric Storage Water Heaters and Storage-Type Instantaneous Water Heaters.

D) 10 CFR Part 431, Subpart Y, Appendix D. Uniform Test Method for the Measurement of Energy Consumption of Circulator Pumps (as of March 20, 2023).

E) ANSI/AHRI Standard 1300-2013, (“ANSI/AHRI 1300-2013”), Performance Rating for Commercial Heat Pump Water Heaters, approved by ANSI on October 1, 2013

F) ANSI/ASHRAE Standard 37-2009, (“ANSI/ASHRAE 37-2009”), Methods of Testing for Rating Electrically Driven Unitary Air-Conditioning and Heat Pump Equipment, approved by ANSI on June 25, 2009

G) ANSI/ASHRAE Standard 118.1-2022, “Method of Testing for Rating Commercial Gas, Electric, and Oil Service Water Heating Equipment,” approved by ASHRAE and ANSI on August 31, 2022

H) AHRI Standard 1340-2023, Performance Rating of Commercial and Industrial Unitary Air-conditioning and Heat Pump Equipment