ENERGY STAR® Program Requirements Product Specification for Connected Residential Water Heaters

Test Method to Validate Demand Response
Final Draft
February 2021

1 OVERVIEW

The following test method shall be used for determining product compliance with requirements for Demand Response (DR) functionality in the ENERGY STAR Program Requirements Product Specification for Residential Water Heaters Eligibility Criteria Version 4.0 (ENERGY STAR Specification).

Note: In the Version 4.0 of the ENERGY STAR Specification, EPA has updated the connected product criteria in section 4 to explicitly state that the consumer override be limited to 72 hours without additional user input, that a CWHP capable of storing and operating with a time of use schedule may continue to operate on that schedule during a loss of connectivity event, and add demand response message mapping for the operational states presented in section 4.D.d. This test method refers to the sections as they are presented within the Final Draft of version 4.0 of the ENERGY STAR Specification.

2 APPLICABILITY

This test method is applicable to Residential Water Heaters designed to meet the eligibility criteria in the ENERGY STAR Specification, including the optional Connected Product Criteria found in section 4.

3 DEFINITIONS

Unless otherwise specified, all terms used in this document are consistent with the definitions in both the ENERGY STAR Specification and in the U.S. Department of Energy (DOE) Test Procedure in Title 10 of the Code of Federal Regulations (CFR) Part 430, Appendix E to Subpart B, as of January 1, 2020 (DOE Test Procedure).

A) Acceptable Response: The appropriate signal response from the connected water heater product (CWHP) after an operational state query is sent by the utility equivalent communication device (UECD).
B) Appliance Communication Module: A built-in or external device that enables bi-directional communication between the CWHP and the UECD. The CWHP and appliance communication module (ACM) are included in the CWHP test boundary as specified in Figure 1 of the ENERGY STAR Specification.
C) Load Shift Draw Pattern: The first draw cluster of the Rated Draw Pattern (i.e., draws 1 through 5 for the very-small-usage draw pattern, draws 1 through 3 for the low-usage draw pattern, draws 1 through 3 for the medium-usage draw pattern, and draws 1 through 4 for the high-usage draw pattern).
D) Normal Mode of Operation: The operational state in which the device would be operating independent of the information exchanged through the open communication link, as set by the consumer.
E) Operation State Query: Request from the UECD for the operation state of the CWHP.

F) Rated Draw Pattern: Draw pattern in which the CWHP was certified (i.e., either very-small-usage, low-usage, medium-usage, or high-usage).
G) Rated Recovery Efficiency: Recovery efficiency in which the CWHP was certified.
H) User Interface: A means for a user to control the operation of the water heater, which may be a remote and/or local user interface, such as a web-based portal, a mobile device application, or an interface directly on the CWHP.
I) Utility Equivalent Communication Device: Self-contained or Personal Computer (PC)-based device or devices capable of communicating with the CWHP and simulating signals sent from a utility. The utility equivalent communication device or devices will be controlled by the technician during the conduct of this test method, allowing the technician to execute and deliver the DR requests and queries and receive necessary feedback from the CWHP.
J) Acronyms:
    1) ACM: Appliance Communication Module
    2) API: Application Programming Interface
    3) CWHP: Connected Water Heating Product
    4) DR: Demand Response
    5) GPM: Gallons Per Minute
    6) ICD: Interface Control Document
    7) UECD: Utility Equivalent Communication Device

4 TEST SETUP

Unless otherwise specified, all test conditions, instrumentation, and installation requirements shall be identical to sections 2, 3, and 4 of the DOE Test Procedure.

The instrumentation which measures water volume, mass, and/or flow rate may be installed on either the inlet or outlet side of the water heater.

The data acquisition system shall be able to measure and record the internal tank temperature at a rate of 1 measurement every 5 seconds.

For solar water heaters that use grid energy as a backup heat source, all solar energy connections should be disabled. The solar water heater shall then be tested according to its backup heat source (e.g., if backup heating is provided by electric elements then the solar water heater shall be tested as an electric resistance water heater and if backup heating is provided by a gas burner then the solar water heater shall be tested as a gas-fired water heater).

4.1 Connected Water Heater Product (CWHP) System Setup

The ACM and UECD shall be set up in accordance with manufacturer instructions in the open standard protocol, ICD, and/or API. The communication devices must be set up as follows:

A) Establish the connection between the ACM and the UECD via wired or wireless connection depending on the ACM's capability. If both a wired and wireless connection are available, connection between the ACM and UECD shall be through the wireless connection.
B) Ensure that the ACM is connected properly and can both receive and send data to the UECD, in accordance with manufacturer instructions.

For CWHP designed to be used with a mixing valve (e.g., the CWHP raises the temperature of water in the tank above the temperature of the water after all thermostats are satisfied at the user setpoint under normal operation, as specified in section 5.2.2 of the DOE Test Procedure, and that do not have a self-contained mixing valve), a mixing valve shall be installed according to the water heater and mixing valve manufacturer's instructions and to Figure 1 or Figure 2. If permitted by the water heater and mixing valve manufacturer's instructions, the mixing valve and junction which supplies the cold water to the mixing valve may be installed where the elbows are located in the outlet and inlet water lines, respectively.. If there are no installation instructions for the mixing valve in the water heater or mixing valve manufacturer's instructions, then the mixing valve shall be installed on the outlet water line, as shown in Figure 1 or Figure 2, and the cold water shall be supplied from the inlet water line where a junction is installed between the water heater and the location where the inlet water temperature is measured. The outlet temperature, liquid flow rate, and/or mass measuring instrumentation, if installed on the outlet side of the CWHP, shall be installed after the mixing valve.

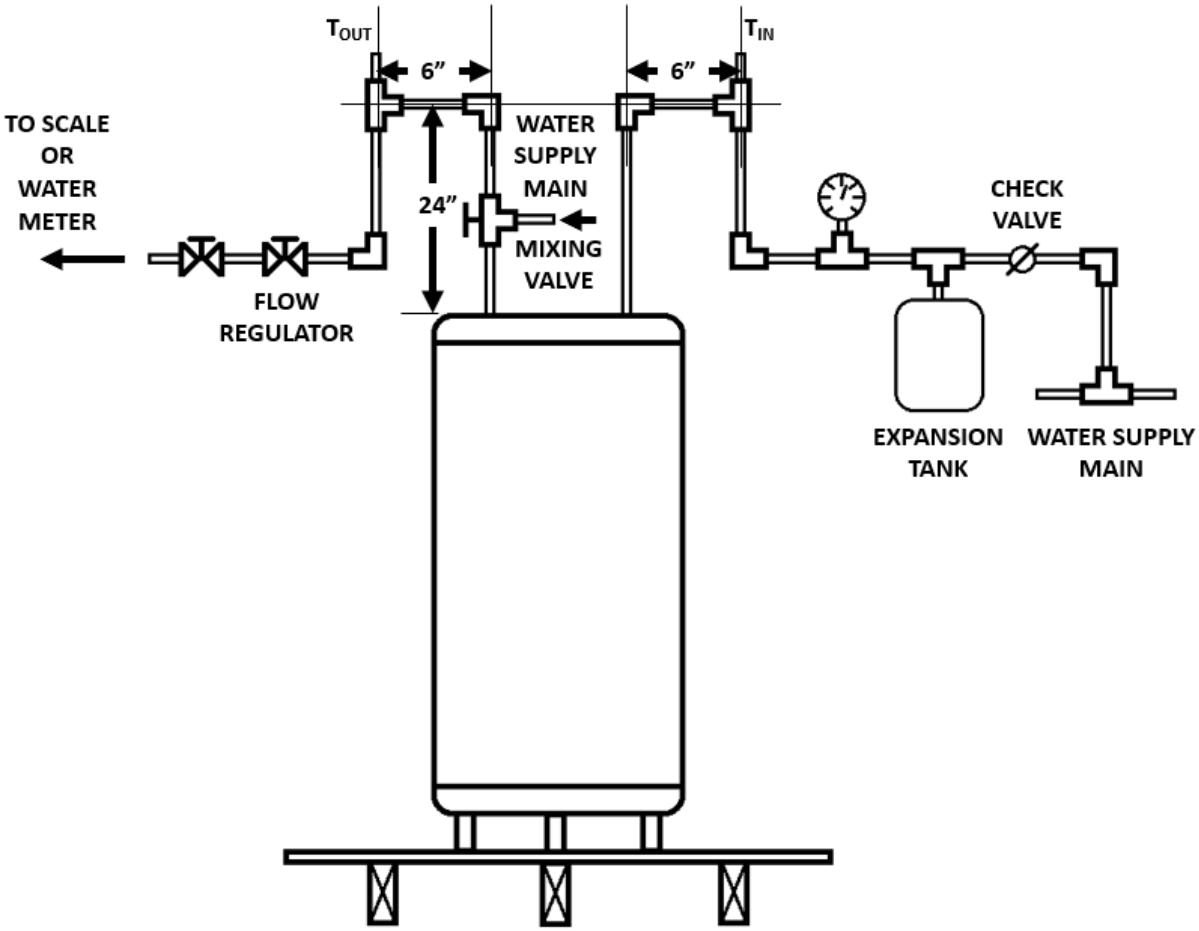

Figure 1: Mixing Valve location on a CWHP with top inlet and outlet connections

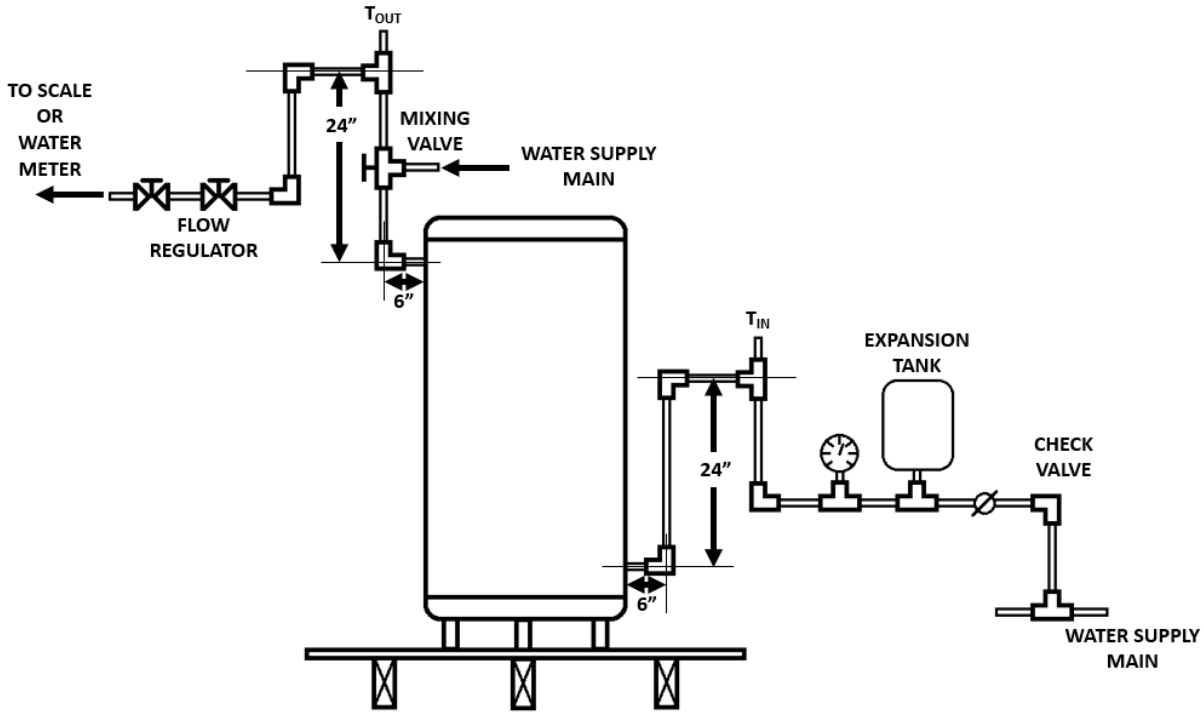

Figure 2: Mixing Valve location on a CWHP with side inlet and outlet connections

5 WATER HEATER PREPARATION

This section does not need to be performed to complete the CWHP Initialization (section 6.1), User Interface (section 6.2), Consumer Override (section 6.3), and Loss of Connectivity (section 6.4) tests.

Prior to the Load Shift (section 6.5.1) and Emergency Curtailment and Grid Emergency (section 6.5.2) tests, perform the procedures found in section 5.1 and 5.2 of the DOE Test Procedure. These include the operational mode selection, determination of storage tank volume, V_{st}, setting the outlet discharge temperature, power input determination, and a soak-in period.

When setting the outlet discharge temperature, first use the settings as shipped from the manufacturer. If the requirements in section 5.2.2 of the DOE Test Procedure are not met, then adjust the temperature controller and repeat the procedures for setting the outlet discharge temperature.

If the DOE Test Procedure was performed prior to this test method and electricity and/or fossil fuel supply have not been removed from the CWHP, then the soak-in period from section 5.2.4 of the DOE Test Procedure does not need to be conducted.

6 DEMAND RESPONSE TESTS

In sections 6.3 through 6.5 test instructions are provided in table form where each row is a distinct step. DR requests are sent with a start time and duration. Start times can be either "Immediately" (i.e., as soon as the request is received by the CWHP) or at a certain time after the request is received by the CWHP. Durations are stated as either "Maximum" or some other duration (e.g., 4 hours). For all tests except the Loss of Connectivity test in section 6.4,

a "Maximum" duration in the context of this test method means first, that the DR request does not end, and second, if the CWHP is incapable of receiving a DR request that does not end, then the DR request will last at least 4 hours.

Note: A commenter recommended that event durations should be specified as this is how the requests will typically be sent in the field. The commenter further stated that the 4-hour duration used in the Load Shift test described in section 6.5.1 is an appropriate duration. EPA and DOE have adjusted the General Curtailment duration in the Load Shift test to 4 hours and if not possible to send a duration without an end time. All other durations were left the same as a "Maximum" duration will ensure that the desired tank conditions have enough time occur, in particular the Load Up request is left at "Maximum" to ensure that the CWHP is fully heated when the General Curtailment period begins.

6.1 CWHP Initialization

Verify that the CWHP communicates using an open standard as defined in section 4.D.a of the ENERGY STAR Specification.

6.2 User Interface

Verify that the manufacturer literature supplied with the CWHP and/or ACM includes instructions for the user to override DR requests.

6.3 Consumer Override

The test steps described in Table 1 shall be performed for the General Curtailment request to verify the consumer override requirement of section 4.D.b of the ENERGY STAR Specification.

All communications between the UECD and CWHP must be logged. If any logged communications do not match the acceptable responses, then the CWHP fails.

Table 1: Consumer Override Verification Test Steps

Step	UECD	CWHP
1	Send a Return to Normal Operation request.	
2	Send an Operational State query.	Acceptable responses include: "Idle Normal" or "Running Normal"
3	Send a General Curtailment request. Start Time = Immediately Duration = Maximum	The CWHP must acknowledge the request.
4	Send an Operational State query.	Acceptable responses include: "Running Curtailed Grid" or "Idle Grid"

Step	UECD	CWHP
5	Initiate consumer override either through the local or remote user interface.	
6	Send an Operational State query.	Acceptable responses include: “Idle Opted Out” or “Running Opted Out”
7	Send a General Curtailment request. Start Time = Immediately Duration = Maximum	CWHP must acknowledge the request.
8	Send an Operational State query.	Acceptable responses include: “Idle Opted Out” or “Running Opted Out”
9	End consumer override either through the local or remote user interface.	
10	Send a General Curtailment request. Start Time = Shortest possible duration allowing for time to complete Step 11 Duration = Maximum	CWHP must acknowledge the request.
11	Initiate consumer override either through the local or remote user interface.	
12		Wait for Start Time from Step 10.
13	Send an Operational State query.	Acceptable responses include: “Idle Opted Out” or “Running Opted Out”
14	End consumer override either through the local or remote user interface.	
15	Send an Operational State query.	Acceptable responses include: “Idle Normal” or “Running Normal”

Note: A commenter suggested testing that the Consumer Override expires after a set time period. The Final Draft of version 4.0 of the ENERGY STAR Specification requires a maximum override time of 72 hours, without a requirement that it can be adjusted to be shorter (though manufacturers may provide this at their discretion). Given this, EPA and DOE have determined that testing the expiration of the override, which would take 72 hours, will unduly increase the test time and burden.

6.4 Loss of Connectivity

The test steps described in Table 2 shall be performed to verify the loss of connectivity requirement of section 4.D.c of the ENERGY STAR Specification.

If unable to automatically verify operational state when connectivity is removed, manually verify operational state on the local user interface.

All communications between the UECD and CWHP must be logged. If any logged communications do not match the acceptable responses, then the CWHP fails.

Determine the time at which the CWHP should know that it is experiencing a loss of connectivity by multiplying the number of polling intervals from section 4.D.c of the ENERGY STAR Specification by the polling interval, which is dependent on the CWHP, this time is used in steps 5 and 13 of Table 2.

Table 2: Loss of Connectivity Verification Test Steps

Step	UECD	CWHP
1	Send a Return to Normal Operation request.	
2	Send an Operational State query.	Acceptable responses include: “Idle Normal” or “Running Normal”
3	For CWHP’s capable of receiving DR requests without a set duration or end time, send a General Curtailment request. Otherwise, skip to step 11. Start Time = Immediately Duration = Maximum	CWHP must acknowledge the request.
4	Send an Operational State query.	Acceptable responses include: “Running Curtailed Grid” or “Idle Grid”
5		Remove connectivity and wait for the criteria described in section 4.D.c of the ENERGY STAR Specification to occur.
6		Wait for the time specified in section 4.D.c.ii of the ENERGY STAR Specification.
7		Re-establish connectivity and allow unit to perform any connection operations.
8	Send an Operational State query.	Acceptable responses include: “Idle Normal” or “Running Normal”
9	Send a Return to Normal Operation request.	

Step	UECD	CWHP
10	Send an Operational State query.	Acceptable responses include: “Idle Normal” or “Running Normal”
11	For CWHP’s capable of receiving DR requests with a set duration or end time, send a General Curtailment request. Otherwise, end test. Start Time = Immediately Duration = 4 hours	The CWHP must acknowledge the request.
12	Send an Operational State query.	Acceptable responses include: “Idle Normal” or “Running Normal”
13		Remove connectivity and wait for the criteria described in section 4.D.c of the ENERGY STAR Specification to occur.
14		Re-establish connectivity and allow unit to perform any connection operations.
15	Send an Operational State query.	Acceptable responses include: “Running Curtailed Grid” or “Idle Grid”
16	Send a Return to Normal Operation request.	
17	Send an Operational State query.	Acceptable responses include: “Idle Normal” or “Running Normal”

Note: A commenter suggested adding further description of the time that the CWHP would be expected to wait before performing the actions described in section 4.D.c of the ENERGY STAR Specification when experiencing a loss of connectivity. DOE and EPA have added a description of the how long to wait before the CWHP should determine that a loss of connectivity has occurred. This time is calculated multiplying the number of polling events required by section 4.D.c of the ENERGY STAR Specification (i.e., 5 consecutive missed polls are required before a loss of connectivity is determined) and the polling interval which can be set while setting up the CWHP for test (e.g., if the polling interval was set to 5 minutes then the CWHP should know that a loss of connectivity event has occurred after 25 minutes), this time is used in steps 5 and 13. After a loss of connectivity event has been determined, the CWHP should operate as described in section 4.D.c of the ENERGY STAR Specification and when processing a DR event without a set duration or end time the product should return to normal operation within the time limit found in section 4.D.c.ii (i.e., 30 minutes). Therefore, in step 6 the instruction is to wait for 30 minutes before moving on to the next step.

The ENERGY STAR Specification now explicitly states that if the CWHP is capable of storing and operating with a time of use schedule, the unit may continue operating on that schedule during a loss of connectivity event. DOE and EPA have determined not to add steps to the loss of connectivity test to verify this option as it is very similar to the option allowing the CWHP to complete a DR event as planned when the DR event has a set end time.

6.5 Demand Response Requests and Responses

This section verifies the DR Requests and Responses of the CWHP as required by section 4.D.e of the ENERGY STAR Specification.

All communications between the UECD and CWHP must be logged. If any logged communications do not match the acceptable responses, then the CWHP fails.

Prior to the Load Shift (section 6.5.1) and Emergency Curtailment and Grid Emergency (section 6.5.2) tests perform the water heater preparation procedures from section 5.

Table 3 uses the Rated Draw Pattern to provide the flow rate used during the Load Shift and the Emergency Curtailment and Grid Emergency tests. The CWHP's Rated Draw Pattern is also used to determine the Load Shift Draw Pattern as described in section 3.

Table 3: Flow Rate Used in the Load Shift and Emergency Curtailment and Grid Emergency Tests

Rated Draw Pattern	Flow Rate
Very-Small-Usage	1.0 gpm ± 0.1 gpm
Low-Usage	1.7 gpm ± 0.1 gpm
Medium-Usage	1.7 gpm ± 0.1 gpm
High-Usage	3.0 gpm ± 0.25 gpm

During the Load Shift and Emergency Curtailment and Grid Emergency tests described in sections 6.5.1 and 6.5.2, respectively, instructions are given to allow the CWHP to settle. To "settle" in this test method is to allow the CWHP to operate without drawing water or recovering for an entire settling period after a cut-out. If a cut-in occurs before the end of the settling period, then the recovery should be allowed to continue until cut-out, at which time the settling period will begin again, and, if necessary, repeat until a full settling period is performed. A settling period is defined as the greater of 10 minutes or when a maximum mean tank temperature is observed as determined when the 60-second rolling average of mean tank temperature measurements, taken every 5 seconds, drops 0.05 °F below the previous 60-second rolling average.

Note: A commenter suggested adding the criteria found in the Air-Conditioning, Heating, & Refrigeration Institute's (AHRI) Operations Manual for the Residential Water Heaters Certification Program for determining when the CWHP has reached a maximum mean tank temperature during a test. The commenter also recommended that a minimum time length be included to avoid triggering a compressor lock out which is used to protect the compressor from short cycling. DOE and EPA have added the criteria from the AHRI Operations Manual for determining when a maximum mean tank temperature is observed mid-test and maintained the 10-minute period to avoid a compressor lock out.

6.5.1 Load Shift

The test steps described in Table 4 shall be performed to verify the requirements for the General Curtailment and either the Basic or Advanced Load Up requests from section 4.D.e of the ENERGY STAR Specification. The Load Shift test includes performing the Load Shift Draw Pattern with the CWHP in the Normal Mode of Operation, a load up (either a Basic or Advanced Load Up), and then performing the Load Shift Draw Pattern with the CWHP operating under a General Curtailment request. Only one load up request is required (i.e., if

the Basic Load Up is tested then verification of the Advanced Load Up is not required, and vice versa). Several steps in Table 4 use the flow rate that is determined using Table 3.

Record the mean tank temperature and energy usage at the beginning of the test and every 5 seconds afterward.

Table 4: Load Shift Test Steps

Step	UECD	CWHP
If verifying the Advanced Load Up request, first enable Advanced Load Up operation.		
1	Send a Return to Normal Operation request.	
2	Send an Operational State query.	Acceptable responses include: "Idle Normal" or "Running Normal"
3	Send a Device Type query.	CWHP must respond with Device Type.
4		If CWHP is undergoing a recovery, wait until cut-out and allow the CWHP to settle. If a recovery is not occurring, draw off water at the flow rate as determined using Table 3 until a cut-in occurs. Wait until cut-out and allow CWHP to settle.
Verification of Normal Mode of Operation		
5*	Send Power/Demand, Current Available Energy Storage Capacity, and if possible, Current Total Energy Storage Capacity queries.	CWHP must respond to all queries.
6		Perform the Load Shift Draw Pattern. If a recovery initiates during the first draw of the Load Shift Draw Pattern, record the volume drawn at the initiation of the recovery.
7		Wait until 4 hours from the start of step 5 have elapsed.
8*	Send Power/Demand, Current Available Energy Storage Capacity, and if possible, Current Total Energy Storage Capacity queries.	CWHP must respond to all queries.
9		If a recovery is occurring, wait until cut-out and allow the CWHP to settle.

Step	UECD	CWHP
		If a recovery is not occurring, draw off water at the flow rate as determined using Table 3 until a cut-in occurs. Wait until cut-out and allow CWHP to settle.
10*	Send Power/Demand, Current Available Energy Storage Capacity, and if possible, Current Total Energy Storage Capacity queries.	CWHP must respond to all queries.
Verification of the Basic Load Up or Advanced Load Up Request		
11		If a recovery initiated in the first draw of step 6, skip to step 12. If a recovery did not initiate in the first draw of step 6, draw off water at the flow rate as determined using Table 3. Stop drawing water when a cut-in occurs and wait for the CWHP to settle after cut-out.
12†		Draw off water at the flow rate as determined using Table 3. If a recovery initiated in the first draw of step 6, stop drawing water when 2 gallons less than the volume drawn in step 6 have been drawn. If a recovery did not initiate in the first draw of step 6, stop drawing water when 2 gallons less than the volume drawn in step 11 have been drawn. If a cut-in occurs at any time before step 14, wait for the CWHP to settle after cut-out, and restart this step. After a restart of this step (only when necessary) draw off 1 gallon less than the volume drawn immediately before cut-in during the previous iteration until a volume of water is drawn off and no cut-in occurs.
13*	Send Power/Demand, Current Available Energy Storage Capacity, and if possible, Current Total Energy Storage Capacity queries.	CWHP must respond to all queries.
14	Send either a Basic Load Up or Advanced Load up request. Start Time = Immediately Duration = Maximum	CWHP must acknowledge the request.

Step	UECD	CWHP
15*	Send Power/Demand, Current Available Energy Storage Capacity, and if possible, Current Total Energy Storage Capacity queries.	CWHP must respond to all queries.
16		If a cut-in does not occur within 5 minutes of sending the Basic Load Up or Advanced Load Up request, then the CWHP fails.
17*	If there was a delayed cut-in as described in step 16, perform this step. Send Power/Demand, Current Available Energy Storage Capacity, and if possible, Current Total Energy Storage Capacity queries.	CWHP must respond to all queries.
18	Send an Operational State query.	Acceptable responses include: "Running Heightened Grid"
19		Wait for the CWHP to settle after cut-out.
Verification of the General Curtailment Request		
20*	Send Power/Demand, Current Available Energy Storage Capacity, and if possible, Current Total Energy Storage Capacity queries.	CWHP must respond to all queries.
21	Send a General Curtailment request. Start Time = Immediately Duration = 4 hours. If the CWHP cannot accommodate a request of 4 hours, then the duration will be set to the shortest time greater than 4 hours or to a duration which does not end.	CWHP must acknowledge the request.
22	Send an Operational State query.	Acceptable responses include: "Running Curtailed Grid" or "Idle Grid"
23		Perform the Load Shift Draw Pattern.
24		Wait until 4 hours from the start of step 20 have elapsed.
25*	Send Power/Demand, Current Available Energy Storage Capacity, and if possible, Current Total Energy Storage Capacity queries.	CWHP must respond to all queries.

Step	UECD	CWHP
26	Send a Return to Normal Operation request.	
27	Send an Operational State query.	Acceptable responses include: “Idle Normal” or “Running Normal”
28*	Send Power/Demand, Current Available Energy Storage Capacity, and if possible, Current Total Energy Storage Capacity queries.	CWHP must respond to all queries.
29		Wait for the CWHP to settle after cut-out. If a recovery does not occur after 10 minutes, move on to the next step.
30*	Send Power/Demand, Current Available Energy Storage Capacity, and if possible, Current Total Energy Storage Capacity queries.	CWHP must respond to all queries.

* Calculate the energy content of the stored hot water in the CWHP as described in section 7.1.1.1.

† Step 12 is intended to force the CWHP to be in a completely depleted energy state to measure the maximum amount of energy that could be used when loading up the CWHP. While not being tested, if a load up request was sent when the CWHP was only partially depleted, the CWHP should still load up despite not being in a fully depleted energy state. The exact energy state at which the CWHP initiates a recovery when a load up request has been received is determined by the manufacturer.

Determine the total energy consumed during the normal operation, Basic Load Up or Advanced Load Up, and General Curtailment events:

Q_{Normal} = total energy consumption, including auxiliary energy use, between the start of step 5 and the end of step 8, Btu (Wh).

$Q_{Basic\ Load\ Up}$ = if applicable, total energy consumption, including auxiliary energy use, between step 13 and the end of step 20, Btu (Wh).

$Q_{Advanced\ Load\ Up}$ = if applicable, total energy consumption, including auxiliary energy use, between step 13 and the end of step 20, Btu (Wh).

$Q_{General\ Curtailment}$ = total energy consumption, including auxiliary energy use, between the start of step 20 and the end of step 25, Btu (Wh).

Q_{Reheat} = total energy consumption, including auxiliary energy use, between the start of step 25 to the end of step 30, Btu (Wh).

Verify that: $Q_{Normal} > Q_{General\ Curtailment}$

Verify that the maximum power draw or fossil-fuel supply measurement that occurred after the Basic Load Up or Advanced Load Up request was sent in step 14 and at or before the time limit described in step 16 is greater than the power draw or fossil-fuel supply measured in step 5.

6.5.2 Emergency Curtailment and Grid Emergency

Perform the test steps described in Table 5 to verify the Emergency Curtailment and Grid Emergency requirements from section 4.D.e of the ENERGY STAR Specification.

For CWHP that use heat pump technology along with resistance elements, if the resistance elements turn on at any point during an Emergency Curtailment event, then the CWHP fails. For CWHP that use only resistance heating elements, if any element but the top element turn on at any point during an Emergency Curtailment event, then the CWHP fails. For all CWHP, if any energy is used to heat water during a Grid Emergency event, then the CWHP fails.

Record the energy usage at the beginning of the test and every 5 seconds afterward. Measurements of the outlet temperatures shall be made 5 seconds after the draw is initiated and at every subsequent 3-second interval throughout the duration of each draw. Use Table 3 to determine the flow rate used in the Emergency Curtailment and Grid Emergency Verification Test.

Table 5: Emergency Curtailment and Grid Emergency Verification Test Steps

Step	UECD	CWHP
1	Send a Return to Normal Operation request.	
2	Send an Operational State query.	Acceptable responses include: “Idle Normal” or “Running Normal”
3		If CWHP is undergoing a recovery, wait for the CWHP to settle after cut-out.
4*	Send Power/Demand and Current Available Energy Storage Capacity queries.	CWHP must respond to all queries.
5	Send an Emergency Curtailment request Start Time = Immediately Duration = Maximum	CWHP must acknowledge the request.
6	Send an Operational State query.	Acceptable responses include: “Running Curtailed Grid” or “Idle Grid”
7		Draw off water at the flow rate as determined using Table 3. When the delivery temperature reaches 80 °F (26.7 °C) continue with the next step.
8	Send a Grid Emergency request Start Time = Immediately	CWHP must acknowledge the request.

Step	UECD	CWHP
	Duration = Maximum	
9*	Send Power/Demand and Current Available Energy Storage Capacity queries.	CWHP must respond to all queries.
10		Stop drawing water when delivery temperature drops below 60 °F (37.8 °C).
11	Send a Return to Normal Operation request.	
12	Send an Operational State query.	Acceptable responses include: “Idle Normal” or “Running Normal”
* Calculate the energy content of the stored hot water in the CWHP as described in section 6.6.3.		

If testing a CWHP that uses heat pump and electric resistance elements, verify through electrical supply measurements that the elements do not turn on between steps 5 and 7.

Verify through electrical and/or fossil fuel supply measurements that energy was not used to heat water between steps 8 and 10.

6.6 DR Information and Messaging

Sections 6.6.1 to 6.6.5 verify the appropriate responses required in section 4.D.d of the ENERGY STAR Specification.

6.6.1 Device Type

Verify that the device type recorded in step 3 of the Load Shift test described in Table 4 of section 6.5.1 is the correct device type.

6.6.2 Operational State

The Operational State messaging is verified in sections 6.3 through 6.5.

6.6.3 Current Available Energy Storage Capacity

Verify that a response is being received from the Current Available Energy Storage Capacity queries at each of the indicated steps in Table 4 of section 6.5.1 for the Load Shift test (i.e., steps 5, 8, 10, 13, 15, 17, 20, 25, 28, and 30) and Table 5 of section 6.5.2 for the Emergency Curtailment and Grid Emergency test (i.e., steps 4 and 9).

6.6.4 Current Total Energy Storage Capacity

Verify that a response is being received from the Current Total Energy Storage Capacity queries at each of the indicated steps in Table 4 of section 6.5.1 for the Load Shift test (i.e., steps 5, 8, 10, 13, 15, 17, 20, 25, 28, and 30) and Table 5 of section 6.5.2 for the Emergency Curtailment and Grid Emergency test (i.e., steps 4 and 9).

6.6.5 Power/Demand (Instantaneous)

Verify that a response is being received from the Power/Demand (Instantaneous) queries at each of the indicated steps in Table 4 of section 6.5.1 for the Load Shift test (i.e., steps 5, 8, 10, 13, 15, 17, 20, 25, 28, and 30) and Table 5 of section 6.5.2 for the Emergency Curtailment and Grid Emergency test (i.e., steps 4 and 9).

Verify that the Power/Demand (Instantaneous) CWHP responses in steps 5, 10, 13, 20, and 30 in the Load Shift test from section 6.5.1 and steps 4 and 9 for the Emergency Curtailment and Grid Emergency test from section 6.5.2 were less than the CWHP responses in step 15 (or step 17, if performed).

7 CALCULATIONS

7.1.1 Accuracy of Current Available Energy Storage Capacity

7.1.1.1 Energy Content of the Stored Water

Calculate the energy content of the stored water in the CWHP at each of the indicated steps in Table 4 of section 6.5.1 for the Load Shift test (i.e., steps 5, 8, 10, 13, 15, 17, 20, 25, 28 and 30).

$$E_{Step} = V_{st}\ \rho\ C_p\ \overline{T}_{Step}$$

Where,

E_{Step} = stored energy content of the CWHP during a specific step, Btu (Wh).

V_{st} = stored volume of the CWHP as found in section 5, gal (L).

ρ = density of the stored water at $\overline{T}_{Step}$, lb/gal (kg/L).

C_p = specific heat of stored water at $\overline{T}_{Step}$, Btu/(lb °F) (kJ/(kg °C)).

$\overline{T}_{Step}$ = mean tank temperature during a specific step, °F (°C).

7.1.1.2 Energy Content of the Stored Water after Cut-out during Normal Operation

Calculate the average energy content of the CWHP when the mean tank temperature reaches the maximum mean tank temperature after cut-out during normal operation, $\overline{E}_{Setpoint}$, by averaging the calculated energy content of the CWHP at steps 5 and 10 from the Load Shift test in Table 4. If the Basic Load Up request was verified then also include the calculated energy content at step 20 the calculation (i.e., average of 3 different energy content measurements if the Basic Load Up request was verified or 2 different energy content measurements if the Advanced Load Up request was verified).

7.1.1.3 Current Available Energy Storage Capacity

Calculate the Current Available Energy Storage Capacity at each of the indicated steps in Table 4 of section 6.5.1 for the Load Shift test (i.e., steps 5, 8, 10, 13, 15, 17, 20, 25, 28, and 30). Note, there are 10 Current Available Energy Storage Capacity values.

$$AE_{C,Step} = \frac{(\bar{E}_{Setpoint} - E_{\ Step})}{RE_{Rated}}$$

Where,

$AE_{C,\ Step}$ = calculated Current Available Energy Storage Capacity for a specific step, Btu (Wh).

RE_{Rated} = rated recovery efficiency, %.

7.1.1.4 Root-Mean-Square Difference (RMSD)

Calculate the RMSD between the calculated Current Available Energy Storage Capacity and the recorded Current Available Storage Energy Capacity values which were supplied by the CWHP during the Load Shift test from section 6.5.1.

$$RMSD_{AE} = \sqrt{\frac{\sum(AE_{C,Step} - AE_{R,Step})^2}{N}}$$

Where,

$RMSD_{AE}$ = root-mean-square-difference between the calculated Current Available Energy Storage Capacity and the recorded Current Available Energy Storage Capacity, Btu (Wh).

$AE_{R,\ Step}$ = recorded Current Available Energy Storage Capacity supplied by the CWHP for a specific step, as stated in section 7.1.1.3, Btu (Wh).

N = number of times the Current Available Energy Storage Capacity is measured during the Load Shift test (i.e., 10).

7.1.2 Accuracy of Current Total Energy Storage Capacity

These calculations are optional and only apply to CWHP capable of receiving and responding to Current Total Energy Storage Capacity requests.

7.1.2.1 Energy Content of the Stored Water at High Energy State

Determine the maximum mean tank temperature recorded between steps 10 and 21 of the Load Shift test found in Table 4 of section 6.5.1, $\overline{T}_{High}$, °F (°C).

Calculate the energy content of the stored water in the CWHP at the high energy state.

$$E_{\ High} = V_{st}\ \rho\ C_p\ \bar{T}_{High}$$

Where,

E_{High} = stored energy content of the CWHP at the high energy state, Btu (Wh).

V_{st} = stored volume of the CWHP as found in section 5, gal (L).

ρ = density of the stored water at $\overline{T}_{Low}$, lb/gal (kg/L).

C_p = specific heat of stored water at $\overline{T}_{Low}$, Btu/(lb °F) (kJ/(kg °C)).

7.1.2.2 Energy Content of the Stored Water at Low Energy State

Determine the minimum mean tank temperature recorded between steps 21 and 24 of the Load Shift test found in Table 4 of section 6.5.1, $\overline{T}_{Low}$, °F (°C).

Calculate the energy content of the stored water in the CWHP at the low energy state.

$$E_{Low} = V_{st}\,\rho\,C_p\,\overline{T}_{Low}$$

Where,

E_{Low} = stored energy content of the CWHP at the low energy state, Btu (Wh).

7.1.2.3 Current Total Energy Storage Capacity

Calculate the Current Total Energy Storage Capacity.

$$TE_C = \frac{(E_{High} - E_{Low})}{RE_{Rated}}$$

Where,

TE_C = calculated Current Total Energy Storage Capacity, Btu (Wh).

RE_{Rated} = rated recovery efficiency, %.

7.1.2.4 Root-Mean-Square Difference (RMSD)

Calculate the RMSD between the calculated Current Total Energy Storage Capacity and the recorded Current Total Storage Energy Capacity values which were supplied by the CWHP during the Load Shift test from section 6.5.1 (i.e., steps 5, 8, 10, 13, 15, 17, 20, 25, 28, and 30). Note, there are 10 Current Total Energy Storage Capacity values.

$$RMSD_{TE} = \sqrt{\frac{\sum(TE_C - TE_{R,Step})^2}{N}}$$

Where,

$RMSD_{TE}$ = root-mean-square-difference between the calculated Current Total Energy Storage Capacity and the recorded Current Total Energy Storage Capacity, Btu (Wh).

$TE_{R,\,Step}$ = recorded Current Total Energy Storage Capacity supplied by the CWHP for a specific step, Btu (Wh).

N = number of times the Current Total Energy Storage Capacity is measured during the Load Shift test (i.e., 10).

7.1.3 Load Shift

If the Basic Load Up request was verified during the Load Shift test, verify that the CWHP meets the requirements of a Basic Load Shift.

$$Q_{Basic\ Load\ Up} + (Q_{Normal} - Q_{General\ Curtailment}) \geq Basic\ Load\ Shift$$

Where,

Q_{Normal} = as defined in section 6.5.1.

$Q_{Basic\ Load\ Up}$ = as defined in section 6.5.1.

$Q_{General\ Curtailment}$ = as defined in section 6.5.1.

Basic Load Shift = as defined in section 4.D.d.i of the ENERGY STAR Specification.

If the Advanced Load Up request was verified during the Load Shift test, verify that the CWHP meets the requirements of an Advanced Load Shift.

$$Q_{Advanced\ Load\ Up} + (Q_{Normal} - Q_{General\ Curtailment}) \geq Advanced\ Load\ Shift$$

$Q_{Advanced\ Load\ Up}$ = as defined in section 6.5.1.

Advanced Load Shift = as defined in section 4.D.d.ii of the ENERGY STAR Specification.

8 REFERENCES

A) 10 CFR Part 430, Subpart E, Appendix B. Uniform Test Method for Measuring the Energy Consumption of Water Heaters (as of January 1, 2021).
B) ENERGY STAR Program Requirements Product Specification for Residential Water Heaters Version 4.0 (Rev. Feb-2021).