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

Test Method to Validate Demand Response
Draft 2
October 2020

## 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).

## 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.

> **Note**: The test method applies only to connected water heater products (CWHP) that are designed to meet the requirements of the ENERGY STAR Specification. This test method is being developed with non-ENERGY STAR water heaters with DR capabilities also in mind, and if possible, will be usable for these types of water heater as well. DOE and EPA request comment on any type of water heater with DR capabilities that cannot be tested to this test method.

## 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) LS: Load Shift
    8) 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.

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 may be installed in the outlet line where the elbow closest to the outlet is located. If there are no installation instructions for the mixing valve in the water heater or mixing valve manufacturer's instructions, then the mixing valve shall be installed on the outlet line, as shown in Figure 1 or Figure 2, and the cold water shall be supplied from the inlet line where a junction is installed after the location where $T_{IN}$ 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.

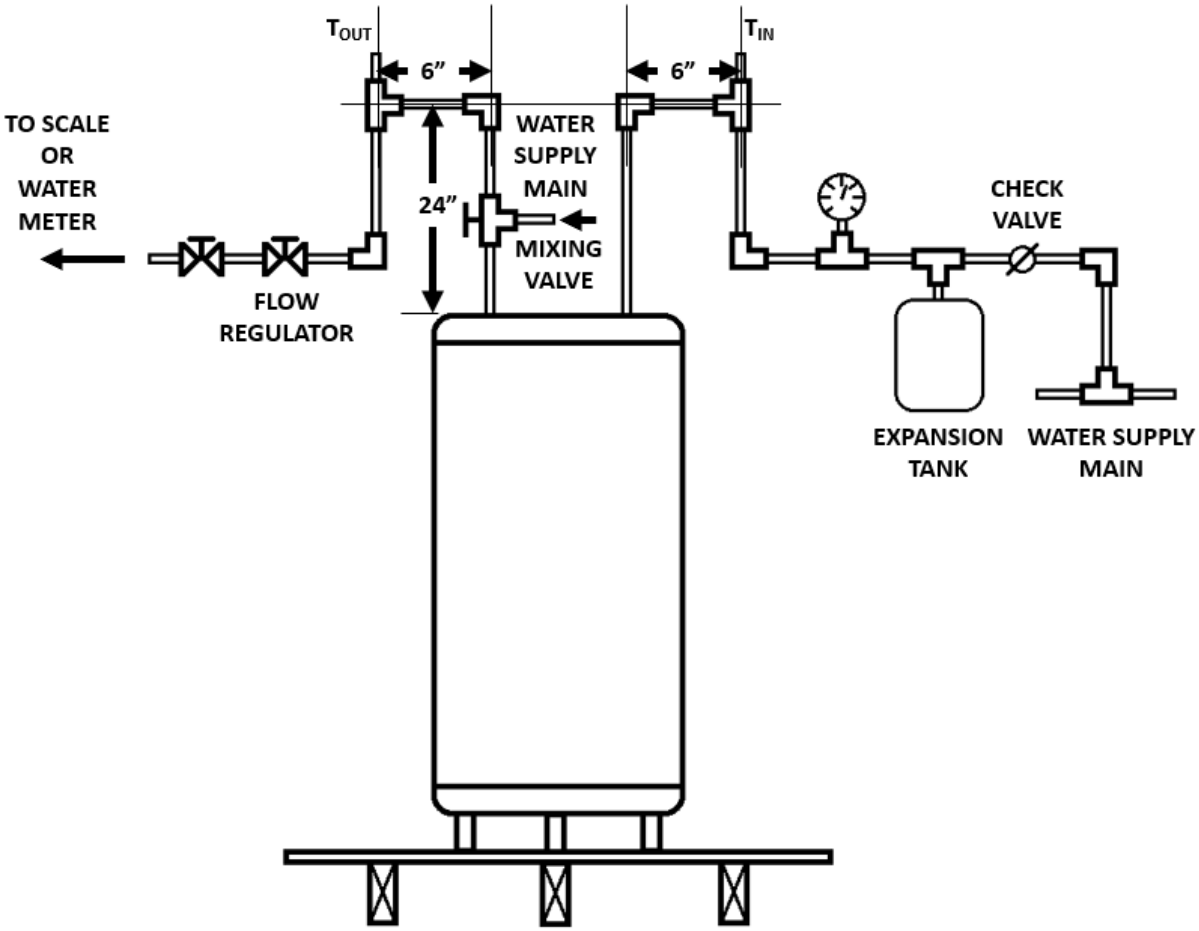


**Figure 1:** Mixing Valve location on a CWHP with top inlet and outlet connections

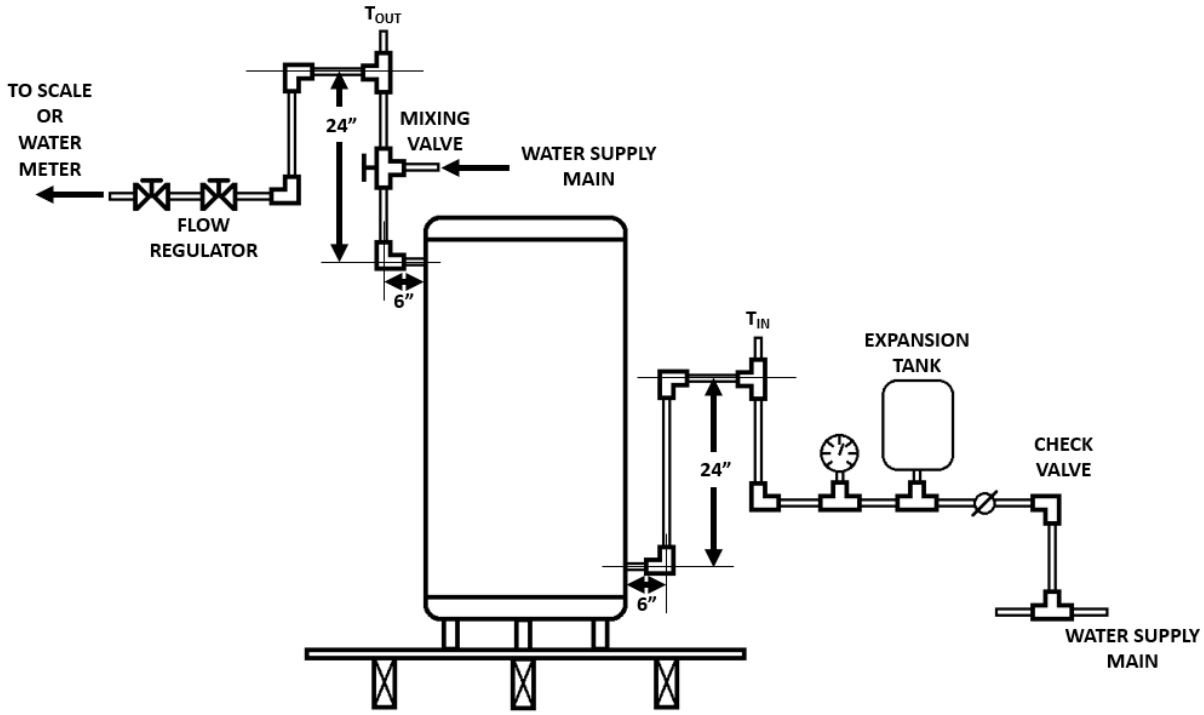


**Figure 2:** Mixing Valve location on a CWHP with side inlet and outlet connections

**Note**: A commenter suggested adding an inlet bypass loop to the test setup similar to AHRI's "Guideline for Testing Uniform Energy Factor for Electric, Gas, and Oil-Fired Residential and Residential-Duty Commercial Water Heaters." EPA and DOE have tentatively determined that this addition is not necessary and that while inlet bypass loops are commonly used by test labs to condition inlet water it is not required to run the test.

DOE and EPA request comment on the mixing valve installation instructions. Specifically, where should the inlet line tee be located and what default instructions are necessary when instruction is not provided in the water heater or mixing valve manufacturer's instructions?

# 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.

**Note**: A commenter stated that the outlet water temperature used in the DOE Test Procedure and this test method may not align with the settings required in California's Title 24 Joint Appendix 13 (JA 13), which states that the water heater setting is "as shipped." It is DOE and EPA's understanding that most models are shipped set to deliver water between 120°F and 125°F, which would be within the outlet water temperature tolerance required in the DOE Test Procedure and this test method. EPA and DOE adjusted the language in section 5 to address this but acknowledge that if the criteria in section 5.2 of the DOE Test Procedure cannot be met with the setpoint "as shipped" then then setpoint will need to be set according to the DOE Test Procedure. This change allows for CWHP to be compared in a consistent manner and helps to align the ENERGY STAR Specification and test method requirements with JA 13.

EPA and DOE note that the soak-in period from section 5.2.4 of the DOE Test Procedure is required to be greater than or equal to 12 hours. Therefore, if desired, the soak-in period could be longer than 12 hours.

# 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.

## 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.

**Note**: A commenter recommended aligning the user interface requirements with those under consideration in JA 13, including: product connectivity status, DR event status, active control strategy (if any), demand management mode, time-of-use schedule (if applicable), and confirmation of setting changes. If user interface changes are proposed in the Final Draft of the ENERGY STAR Specification, then this test method will be updated to account for those changes.

## 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.<br>Start Time = Immediately<br>Duration = Maximum | The CWHP must acknowledge the request. |
| 4 | Send an Operational State query. | Acceptable responses include: “Running Curtailed Grid” or “Idle Grid” |
| 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.<br>Start Time = Immediately<br>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. | CWHP must acknowledge the request. |

| Step | UECD | CWHP |
|---|---|---|
| | Start Time = Shortest possible duration allowing for time to complete Step 11<br><br>Duration = Maximum | |
| 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. EPA and DOE have tentatively determined that waiting for this set time period will unduly increase the test time and burden, as the CWHP will be sitting on the test stand not running for an extended period of time.

A commenter suggesting adding a calculation to determine that the CWHP returns to Normal Operation when the Consumer Override is initiated. EPA and DOE have tentatively determined that a calculation in the Consumer Override test is unnecessary as the CWHP response to DR requests is checked in the Load Shift and Emergency Curtailment and Grid Emergency tests found in sections 6.5.1 and 6.5.2, respectively.

## 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.

**Table 2: Loss of Connectivity Verification Test Steps**

| Step | UECD | CWHP |
|---|---|---|
| 1 | Send a Return to Normal Operation request. | |

| Step | UECD | CWHP |
|---|---|---|
| 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.<br>Start Time = Immediately<br>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. | |
| 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.<br>Start Time = Immediately<br>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. |

| Step | UECD | CWHP |
|---|---|---|
| 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” |

## 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 10 minutes after a cut-out. If a cut-in occurs before 10 minutes have elapsed after cut-out, then the recovery should be allowed to continue until cut-out, at which time the 10-minute settling period will begin again, and, if necessary, repeat until a full 10-minute settling period is performed.

### 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.f 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.<br>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.<br>If the Basic Load Up request will be verified and 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 | CWHP must respond to all queries. |

| Step | UECD | CWHP |
|---|---|---|
| | Energy Storage Capacity queries. | |
| 9 | | If a recovery is occurring, wait until cut-out and allow the CWHP to settle.<br><br>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.<br><br>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. |

| Step | UECD | CWHP |
|---|---|---|
| 14 | Send either a Basic Load Up or Advanced Load up request.<br><br>Start Time = Immediately<br><br>Duration = Maximum | CWHP must acknowledge the request. |
| 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.<br><br>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.<br><br>Start Time = Immediately<br><br>Duration = Maximum. If the CWHP cannot accommodate a request without an end time, then | CWHP must acknowledge the request. |

| Step | UECD | CWHP |
|---|---|---|
| | the duration will be set to greater than or equal to 4 hours. | |
| 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. |
| 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. | | |

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 through electrical and/or fossil fuel supply measurements that the CWHP began heating water 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.

**Note**: EPA and DOE are proposing a Load Shift test to verify functionality of CWHP in the DR modes that are likely to be used the most (i.e., Basic or Advanced Load Up and General Curtailment) with a test that is intended to be representative of actual use in the field, while also minimizing test burden. A separate test for each DR request is not being proposed to further reduce test burden.

During the Load Shift test, a 4-hour General Curtailment evaluation period is being proposed. This 4-hour General Curtailment period is being compared to a 4-hour period of operation in Normal Mode to determine whether the CWHP operates as required in General Curtailment mode. In Draft 1 of this test method, EPA and DOE requested feedback on whether a 4-hour General Curtailment period adequately represents the typical use of CWHP. Commenters generally supported the 4-hour General Curtailment period and one commenter asked for clarification on why the 4-hour period was chosen. The 4-hour period was discussed and generally accepted as a reasonable length during in-person meetings, it corresponds to the peak time range (i.e., 5:00 pm to 9:00 pm) which was evaluated to determine the Basic and Advanced Load Shift values, and when examining the available test data for heat pump water heaters, the data showed that the water heater could fully recover from the first draw cluster of the DOE Test Procedure within a 4-hour period. For these reasons, the 4-hour General Curtailment period was proposed.

The energy used values, which are used to determine whether the CWHP meets the minimum Basic or Advanced Load Shift specified in the ENERGY STAR Specification section 4.D.d, are currently found immediately at the end of the 4-hour period regardless of whether a recovery is occurring. In other words, if a recovery is occurring at the end of the 4-hour period, the energy used after hour 4 is not currently used in the energy use calculations. Section 4.A of the ENERGY STAR Specification states that, “A load shift operation moves energy that would have been used by the CWHP under normal operating conditions within an interval to outside that interval.” Therefore, the intervals under normal operation and General Curtailment should be the same and will not be if the intervals can be extended past hour 4.

In Draft 1 of this test method, EPA and DOE requested comment on whether the CWHP would operate differently when the end time of the General Curtailment period is known in advance, as opposed to when the end time is unspecified (e.g., would a unit delay a recovery

until after General Curtailment if it knows the end of the period is near). In response, one commenter stated that the CWHP would not operate differently and another commenter stated that depending on the complexity of the control system, knowing the end time of the event could impact the behaviour of the CWHP. EPA and DOE have tentatively determined to send the General Curtailment request with no end time, if possible, for the CWHP being tested. The CWHP will likely not delay a recovery that would occur near the end of the 4-hour period if it is not aware that the General Curtailment will soon be ending.

DOE and EPA have proposed the addition of a reheat period after the end of the General Curtailment period to help determine whether a CWHP will immediately initiate a recovery. DOE and EPA request comment on the usefulness of this information and how it can be incorporated into this test method and the ENERGY STAR Specification. This reheat period does not affect the load shift calculations found in section 7.1.3.

In Draft 1 of the test method no draw was required prior to sending the Advanced Load Up request, therefore the Draft 1 test method captured the energy use to bring the CWHP from the normal operation setpoint energy state to a higher energy state. In this document a draw is required prior to the Advanced Load Up and captures the energy use to bring the CWHP from a depleted energy state to a higher energy state. This draw is the same as the draw required when verifying the Basic Load Up. During the testing of an 80-gallon high-usage CWHP, the Basic Load Shift was observed to be greater than the Advanced Load Shift. The Advanced Load Shift should be higher than the Basic Load Shift for the same CWHP, therefore, DOE and EPA have proposed adding a draw prior to the Advanced Load Up request to capture the energy use to bring the CWHP from a depleted energy state to the normal operation setpoint energy state. The energy use to bring the CWHP from the normal operation energy state to the higher energy state is still being captured. DOE and EPA request comment on this revision.

DOE and EPA observed once that a CWHP did not immediately cut-in after receiving a Basic Load Up request. The CWHP cut-in about 3 minutes after the Basic Load Up request was sent. Prior to the Basic Load Up request being sent a draw was performed to get the CWHP into a depleted energy state. DOE and EPA believe this could have occurred due to internal tank stratification and that some time may be required for some CWHP to recognize that they are in a depleted energy state and capable of loading up. Therefore, DOE and EPA have proposed to allow the CWHP 5 minutes to initiate a cut-in after a Basic or Advanced Load Up request is sent. If a cut-in does not occur within 5 minutes of sending the Basic or Advanced Load Up request, then the CWHP would fail. DOE and EPA request comment on whether 5 minutes is an appropriate length of time to wait for a cut-in after a Basic or Advanced Load Up request is sent.

DOE and EPA have removed language indicating that electric resistance elements cannot turn on during a General Curtailment event. Per the revised ENERGY STAR Specification language, the water heater shall avoid use of electric resistance elements during and immediately after the event, but electric resistance elements can turn on if user needs cannot be met.

### 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.f 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<br>Start Time = Immediately<br>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.<br>When the delivery temperature reaches 80 °F (26.7 °C) continue with the next step. |
| 8 | Send a Grid Emergency request<br>Start Time = Immediately<br>Duration = Maximum | CWHP must acknowledge the request. |
| 9* | Send Power/Demand and Current Available Energy Storage Capacity queries. | CWHP must respond to all queries. |

| Step | UECD | CWHP |
|---|---|---|
| 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.e 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).

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

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).

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

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

$\bar{T}_{Step}$ = 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, $\bar{E}_{Setpoint}$, 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.

$$AE_{C,Step} = \frac{100\ (\bar{E}_{Setpoint} - E_{Step})}{RE_{Rated}}$$

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.

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

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).

$\rho$ = 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.

$$TE_C = \frac{100\ (E_{High} - E_{Low})}{RE_{Rated}}$$

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).

**Note**: A commenter requested that optional procedures and calculations be added to determine the accuracy of the Current Total Energy Storage Capacity responses. DOE and EPA request comment on whether the inclusion of these procedures and calculations should

be maintained in the Final Draft of this test method. Further, comments are requested on whether the accuracy of the Current Total Energy Storage Capacity is adequately captured.

### 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.

**Note**: A commenter requested that load shift test data be published. DOE and EPA have tentatively determined not to publish actual test data but will comment on the testing and results. Testing started with an amended version the Draft 1 test method with updates that were recommended by commenters. As the test lab worked through the test method, areas that required further clarification or direction were identified and amended. The amended test method was then run. A 50-gallon medium-usage and an 80-gallon high-usage CWHP were tested to verify both the Basic and Advanced Load Up requests. In all tests, the measured load shift was greater than the required load shift from 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, 2020).
B) ENERGY STAR Program Requirements Product Specification for Residential Water Heaters Version 4.0 (Rev. Jan-2020).