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

Test Method to Validate Demand Response
Draft 1
November-2019

1 OVERVIEW

2 The following test method shall be used for determining product compliance with requirements for
3 Demand Response (DR) functionality in the ENERGY STAR Program Requirements Product
4 Specification for Residential Water Heaters Eligibility Criteria Version 3.3 (ENERGY STAR Specification).

2 APPLICABILITY

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

8 **Note**: The test procedure applies only to connected water heater products (CWHP) that are designed to
9 meet the requirements of the ENERGY STAR Specification. This test procedure is being developed with
10 non-ENERGY STAR water heaters with DR capabilities also in mind and if possible, will be usable for
11 these types of water heater as well.

3 DEFINITIONS

13 Unless otherwise specified, all terms used in this document are consistent with the definitions in both the
14 ENERGY STAR Specification and in the U.S. Department of Energy (DOE) Test Procedure in Title 10 of
15 the Code of Federal Regulations (CFR) Part 430, Appendix E to Subpart B, as of January 1, 2019 (DOE
16 Test Procedure).

17 A) <u>Acceptable Response</u>: The appropriate signal response from the connected water heater product
18 (CWHP) after an operational state query is sent by the utility equivalent communication device
19 (UECD).
20 B) <u>Appliance Communication Module</u>: A built-in or external device that enables bi-directional
21 communication between the CWHP and the UECD. The CWHP and appliance communication
22 module (ACM) are included in the CWHP test boundary as specified in Figure 1 of the ENERGY
23 STAR Specification.
24 C) <u>Load Shift Draw Pattern</u>: The first draw cluster of the Rated Draw Pattern (i.e., draws 1 through 5 for
25 the very small draw pattern, draws 1 through 3 for the low draw pattern, draws 1 through 3 for the
26 medium draw pattern, and draws 1 through 4 for the high draw pattern).
27 D) <u>Normal Mode of Operation</u>: The operational state in which the device would be operating independent
28 of the information exchanged through the open communication link, as set by the consumer.
29 E) <u>Operation State Query</u>: Request from the UECD for the operation state of the CWHP.
30 F) <u>Rated Draw Pattern</u>: Draw pattern in which the CWHP was certified (i.e., either very small, low,
31 medium, or high).
32 G) <u>User Interface</u>: A means for a user to control the operation of the water heater, which may be a
33 remote and/or local user interface, such as a web-based portal, a mobile device application, or an
34 interface directly on the CWHP.
35 H) <u>Utility Equivalent Communication Device</u>: Self-contained or Personal Computer (PC)-based device or
36 devices capable of communicating with the CWHP and simulating signals sent from a utility. The
37 utility equivalent communication device or devices will be controlled by the technician during the

38   conduct of this test procedure, allowing the technician to execute and deliver the DR requests and
39   queries and receive necessary feedback from the CWHP.
40   I) Acronyms:
41   1) ACM: Appliance Communication Module
42   2) API: Application Programming Interface
43   3) CWHP: Connected Water Heating Product
44   4) DR: Demand Response
45   5) GPM: Gallons Per Minute
46   6) ICD: Interface Control Document
47   7) LS: Load Shift
48   8) UECD: Utility Equivalent Communication Device

49 **4 TEST SETUP**

50 Unless otherwise specified, all test setup and condition requirements shall be identical to sections 2, 3,
51 and 4 of the DOE Test Procedure.

52 **4.1 Connected Water Heater Product (CWHP) System Setup**

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

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

60 For CWHP designed to raise the temperature of water in the tank above the temperature of the water
61 after all thermostats are satisfied at the user setpoint under normal operation, as specified in section 5.2.2
62 of the DOE Test Procedure, and that do not have a self-contained mixing valve, a mixing valve shall be
63 installed. The outlet temperature, liquid flow rate, and/or mass measuring instrumentation, if installed on
64 the outlet side of the CWHP, shall be installed after the mixing valve.

65 **Note**: EPA and DOE request feedback on what test setup considerations must be made to appropriately
66 install a mixing valve. In particular, what piping lengths are required from the water heater to the mixing
67 valve and from the mixing valve to the thermocouple measuring the outlet temperature? Further, are
68 CWHP being developed that do not increase the temperature of water in the tank beyond the temperature
69 of the water after all thermostats are satisfied at the user setpoint?

70 **5 WATER HEATER PREPARATION**

71 Perform the procedures found in section 5.2 of the DOE Test Procedure. These include the determination
72 of storage tank volume, V_{st}, setting the outlet discharge temperature, power input determination, and a
73 soak-in period.

74 If the DOE Test Procedure was performed prior to this test procedure and the CWHP has not been
75 unplugged, then the soak-in period from section 5.2.4 of the DOE Test Procedure does not need to be
76 conducted.

77 **6 DEMAND RESPONSE TESTS**

78 **6.1 CWHP Initialization**

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

81 ## 6.2 User Interface

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

84 | **Note**: EPA and DOE request feedback on what other features of the user interface might need to be
85 | verified.

86 ## 6.3 Consumer Override

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

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

91 *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""
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.	

92 | **Note**: EPA and DOE are proposing this Consumer Override test to verify that DR requests can be opted
93 | out of if desired by the user. Verification of only one DR request is being proposed in an effort to reduce
94 | test burden. We welcome feedback on this procedure.

95 6.4 Loss of Connectivity

96 Reserved.

97 | **Note**: EPA and DOE are proposing to not verify the CWHP's ability to appropriately respond to a loss of
98 | connectivity event.

99 6.5 Demand Response Requests and Responses

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

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

104 Table 2 provides the flow rates used during the Load Shift test, if verifying the Basic Load Up, and the
105 Emergency Curtailment and Grid Emergency test.

106 *Table 2: Flow Rate Used in the Basic Load Up Verification and Emergency Curtailment*
107 *and Grid Emergency Test*

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

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109 6.5.1 Load Shift

110 The test steps described in Table 3 shall be performed to verify the requirements for the General
111 Curtailment and either the Basic or Advanced Load Up requests from section 4.C.e of the ENERGY
112 STAR Specification. The Load Shift test includes performing the Load Shift Draw Pattern with the CWHP
113 in the Normal Mode of Operation, a load up (either a Basic or Advanced Load Up), and then performing
114 the Load Shift Draw Pattern with the CWHP operating under a General Curtailment request. Only one
115 load up request is required (i.e., if the Basic Load Up is tested then verification of the Advanced Load Up
116 is not required, and vice versa).

117 Record the mean tank temperature and energy usage at the beginning of the test and every 5 seconds
118 afterward. If verifying the Basic Load Up request, use Table 2 to determine the flow rate used.

Table 3: 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 a maximum mean tank temperature is observed after cut-out.
Normal Mode of Operation Verification		
5*	Send Power/Demand and Current Available Energy Storage Capacity queries.	CWHP must respond to all queries.
6		Perform the Load Shift Draw Pattern. 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 and Current Available Energy Storage Capacity queries.	CWHP must respond to all queries.
9		If a recovery is occurring, wait until a maximum mean tank temperature is observed after cut-out. If a recovery is not occurring, draw off water until a cut-in occurs. Wait until a maximum mean tank temperature is observed after cut-out.
10*	Send Power/Demand and Current Available Energy Storage Capacity queries.	CWHP must respond to all queries.

Step	UECD	CWHP
If verifying the Basic Load Up request, continue to step 11.		
If verifying the Advanced Load Up request, skip to step 18.		
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 2. Stop drawing water when a cut-in occurs and wait until a maximum mean tank temperature is observed after cut-out.
12		Draw off water at the flow rate as determined using Table 2. If a recovery initiated in the first draw of step 6, stop drawing water when 1 gallon less than the volume drawn in step 6 is drawn. If a recovery did not initiate in the first draw of step 6, stop drawing water when 1 gallon less than the volume drawn in step 11 is drawn. If a cut-in occurs at any time before step 14, wait until a maximum mean tank temperature is observed 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 and Current Available Energy Storage Capacity queries.	CWHP must respond to all queries.
14	Send a Basic Load Up request. Start Time = Immediately Duration = Maximum	CWHP must acknowledge the request.
15*	Send Power/Demand and Current Available Energy Storage Capacity queries.	CWHP must respond to all queries.
16	Send an Operational State query.	Acceptable responses include: "Running Heightened Grid"
17		Wait until a maximum mean tank temperature is observed after cut-out.
If verifying the Basic Load Up request, skip to step 22.		

Step	UECD	CWHP
If verifying the Advanced Load Up request, continue to step 18.		
18	Send an Advanced Load Up request. Start Time = Immediately Duration = Maximum	CWHP must acknowledge the request.
19*	Send Power/Demand and Current Available Energy Storage Capacity queries.	CWHP must respond to all queries.
20	Send an Operational State query.	Acceptable responses include: "Running Heightened Grid"
21		Wait until a maximum mean tank temperature is observed after cut-out.
General Curtailment Verification		
22*	Send Power/Demand and Current Available Energy Storage Capacity queries.	CWHP must respond to all queries.
23	Send a General Curtailment request. Start Time = Immediately Duration = 4 hours. If the CWHP cannot accommodate a request with an end time, then the duration will be set to the maximum.	CWHP must acknowledge the request.
24	Send an Operational State query.	Acceptable responses include: "Running Curtailed Grid" or "Idle Grid"
25		Perform the Load Shift Draw Pattern.
26		Wait until 4 hours from the start of step 24 have elapsed.
27*	Send Power/Demand and Current Available Energy Storage Capacity queries.	CWHP must respond to all queries.
28		If a recovery is occurring, wait until a maximum mean tank temperature is observed after cut-out.
29*	Send Power/Demand and Current Available Energy Storage Capacity queries.	CWHP must respond to all queries.
30	Send a Return to Normal Operation request.	

Step	UECD	CWHP
31	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 6.7.1.1.		

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

122
123 Q_{Normal} = total energy consumption, including auxiliary energy use, between the start of step 6 and the end of step 7, Btu (Wh).

124
125 $Q_{Basic\ Load\ Up}$ = if applicable, total energy consumption, including auxiliary energy use, between step 14 and the end of step 17, Btu (Wh).

126
127 $Q_{Advanced\ Load\ Up}$ = if applicable, total energy consumption, including auxiliary energy use, between step 18 and the end of step 21, Btu (Wh).

128
129 $Q_{General\ Curtailment}$= total energy consumption, including auxiliary energy use, between the start of step 25 and the end of step 26, Btu (Wh).

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

131
132 If testing a CWHP which uses heat pump and electric resistance elements, verify that the elements do not turn on in step 27.

133
134 If verifying the Basic Load Up request, verify that the CWHP began heating water after the Basic Load Up request was sent in step 14.

135
136 If verifying the Advanced Load Up request, determine the mean tank temperature at steps 9 and 21 and verify that the mean tank temperature at step 21 is greater than the mean tank temperature at step 9.

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140 **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 in an effort to further reduce test burden.

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145 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. EPA and DOE request feedback on whether a 4-hour General Curtailment period adequately represents the typical use of CWHP.

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154 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.C.b, 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. Draft 2 of version 3.3 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 the designated 4-hours.

155 EPA and DOE further request comment on when the General Curtailment request should have an end
156 time. The duration of the General Curtailment request is currently 4 hours, at which time the CWHP would
157 return to the Normal Mode of Operation. Would the CWHP operate differently when the end time of the
158 General Curtailment period is known in advance, as opposed to when the end time is unspecified (e.g.,
159 would a unit delay a recovery until after General Curtailment if it knows the end of the period is near)?

160 **6.5.2 Emergency Curtailment and Grid Emergency**

161 The test steps described in Table 4 shall be performed to verify the Emergency Curtailment and Grid
162 Emergency requirements from section 4.C.e of the ENERGY STAR Specification.

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

168 Record the energy usage at the beginning of the test and every 5 seconds afterward. Measurements of
169 the outlet temperatures shall be made 5 seconds after the draw is initiated and at every subsequent 3-
170 second interval throughout the duration of each draw. Use Table 2to determine the flow rate used in the
171 Emergency Curtailment and Grid Emergency Verification Test.

172 *Table 4: 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 until a maximum mean tank temperature is observed 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 2. When the delivery temperature reaches 80 °F (26.7 °C) continue with the next step.

Step	UECD	CWHP
8	Send a Grid Emergency request Start Time = Immediately Duration = Maximum	CWHP must acknowledge the request.
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.

6.6 DR Information and Messaging

174 Sections 6.6.1 to 6.6.4 verify the appropriate responses required in section 4.C.d of the ENERGY STAR
175 Specification.

6.6.1 Device Type

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

6.6.2 Operational State

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

6.6.3 Current Available Energy Storage Capacity

182 Verify that a response is being received from the Current Available Energy Storage Capacity queries at
183 each of the indicated steps in Table 3 of section 6.5.1 for the Load Shift test (i.e., steps 5, 8, 10, 22, 27,
184 and 29; if verifying the Basic Load Up request then also steps 13 and 15; if verifying the Advanced Load
185 Up request then also step 19) and Table 4 of section 6.5.2 for the Emergency Curtailment and Grid
186 Emergency test (i.e., steps 4 and 9).

6.6.4 Power/Demand (Instantaneous)

188 Verify that the CWHP responses in steps 5, 10, 13, 22, and 29 in the Load Shift test from section 6.5.1
189 and steps 4 and 9 for the Emergency Curtailment and Grid Emergency test from section 6.5.2 indicated
190 that the CWHP was not heating water. If verifying the Advanced Load Up request, then step 13 does not
191 need to be verified.

192 Verify that the CWHP responses indicated that the CWHP was heating water in step 15 if verifying the
193 Basic Load Up request or step 19 if verifying the Advanced Load Up request from the Load Shift test from
194 section 6.5.1.

6.7 CWHP Metrics

6.7.1 Accuracy of Current Available Energy Storage Capacity

6.7.1.1 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 3 of section 6.5.1 for the Load Shift test (i.e., steps 5, 8, 10, 13, 15, 19, 22, 27, and 29; if verifying the Basic Load Up request then do not calculate for step 19; if verifying the Advanced Load Up request then do not calculate for steps 13 or 15).

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

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).

6.7.1.2 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 3. If the Basic Load Up request was verified then also include the calculated energy content at step 22 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).

6.7.1.3 Current Available Energy Storage Capacity

Calculate the Current Available Energy Storage Capacity at each of the indicated steps in Table 3 of section 6.5.1 for the Load Shift test (i.e., steps 5, 8, 10, 13, 15, 19, 22, 27, and 29; except that if verifying the Basic Load Up request then do not calculate for step 19 and if verifying the Advanced Load Up request then do not calculate for steps 13 or 15). Note, there are 8 Current Available Energy Storage Capacity values if verifying the Basic Load Up request and 7 Current Available Energy Storage Capacity values if verifying the Advanced Load Up request.

$$AE_{C,Step} = \overline{E}_{Setpoint} - E_{Step}$$

Where,

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

6.7.1.4 Root-Mean-Square Difference (RMSD)

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

230
$$RMSD_{AE} = \sqrt{\frac{\sum(AE_{C,Step} - AE_{R,Step})^2}{N}}$$

231　Where,

232　$RMSD_{AE}$ = root-mean-square-difference between the calculated Current Available Energy Storage
233　Capacity and the recorded Current Available Energy Storage Capacity, Btu (Wh).

234　$AE_{R,\ Step}$ = recorded Current Available Energy Storage Capacity supplied by the CWHP for a specific step,
235　as stated in section 6.7.1.3, Btu (Wh).

236　N = number of times the current available energy storage capacity is measured during the Load Shift test
237　(i.e., 8 if verifying the Basic Load Up request or 7 if verifying the Advanced Load Up request).

238　**6.7.2　Load Shift**

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

241
$$Q_{Basic\ Load\ Up} + \left(Q_{Normal} - Q_{General\ Curtailment}\right) \geq Basic\ Load\ Shift$$

242　Where,

243　Q_{Normal} = as defined in section 6.5.1.

244　$Q_{Basic\ Load\ Up}$ = as defined in section 6.5.1.

245　$Q_{General\ Curtailment}$ = as defined in section 6.5.1.

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

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

249
$$Q_{Advanced\ Load\ Up} + \left(Q_{Normal} - Q_{General\ Curtailment}\right) \geq Advanced\ Load\ Shift$$

250　$Q_{Advanced\ Load\ Up}$ = as defined in section 6.5.1.

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

252　# 7　REFERENCES

253　A)　10 CFR Part 430, Subpart E, Appendix B. Uniform Test Method for Measuring the Energy
254　　　Consumption of Water Heaters (as of January 1, 2019).
255　B)　ENERGY STAR Program Requirements Product Specification for Residential Water Heaters Version
256　　　3.3 (Rev. Jan-2020).

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