ENERGY STAR Connected Water Heaters Test Procedure Kick-Off

May 21, 2019
Kick-Off Meeting Schedule

• 10:00AM – 12:30PM
  – Opening Remarks
  – Agenda
    • Introduction/History
    • Scope
    • Criteria to be Tested
    • Current Water Heater Test Procedure

• 12:30PM – 1:15PM: Lunch

• 1:15PM – 3:00PM
  – Agenda
    • Possible Test Procedures
  – Open Discussion
Agenda

1. Introduction/History
2. Scope
3. Criteria to be Tested
4. Current Water Heater Test Procedure
5. Possible Test Procedures
6. Wrap-Up
Goal of the Test Procedure Kick-Off Meeting

- To establish a framework to address the needs of all stakeholders

- Expected stakeholder benefits and uses of the Connected Water Heater Specification and Test Procedure:
  - Verification of specification
  - Guaranteed hot water and energy supply, lower energy bills
  - Quantifiable metric of how much energy storage is available, ability to manage load.
  - Reduce overall energy use, increase in renewable energy use
  - Quantifiable metric to validate policy goals

- **What other goals might exist?**
History of Specification/Test Procedure Development

- March 20, 2018 – Specification Kick-Off Meeting (Portland, OR)

- February 14, 2019 – Large Load Products Discussion Guide
  - Comment Deadline March 18, 2019

- March 7, 2019 – Large Load Product Discussion Guide Webinar

- March 27, 2019 – Specification Workshop (ACEEE Nashville, TN)

- April 16, 2019 – Draft Specification 1 of Version 3.3 published
  - Comment Deadline May 17, 2019
Anticipated Timeline

• Specification (EPA) and Test Procedure (DOE) developed concurrently
  – Specification finalizes when test method is mostly done
• Anticipated Q3-2019: Specification Draft 2
• Stakeholder meeting ENERGY STAR Products Partner Meeting, September 10-12, Charlotte, NC
• Anticipated Q4-2019: Specification and Test Method Draft 1
• Anticipated Q1-2020: Specification and Test Method Draft Final; not necessarily at exactly the same time
• Anticipated Q2-2020: Test Method Final
Agenda

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Connected Water Heater Test Procedure Scope

• Must be an ENERGY STAR water heater
  – Included
    • Electric Heat Pump Water Heaters (HPWH)
    • Gas Storage & Instantaneous Water Heaters
  – Excluded:
    • Electric Resistance Water Heaters (ERWH), including DOE Grid-Enabled Water Heaters
    • Products intended only for commercial applications
    • Combination space-heating and water-heating appliances
    • Add on heat pump water heaters
    • 3rd party water heater controllers
  – Meet the criteria as stated in ENERGY STAR Product Specification for Residential Water Heaters Version 3.3, Sections 1-3
    • Criteria typically include UEF rating, warranty, and safety certifications
Connected Criteria in the Draft Specification

• **Connected criteria = User Amenity + Demand Response (DR)** (as appropriate for product type)
  – Electric Heat Pump Water Heaters: Full DR requirements
  – Gas Storage Water Heaters: Limited DR requirements
    • As per current gas curtailment programs (*e.g.*, during a polar vortex)
  – Gas Instantaneous Water Heaters: Exempt from DR
    • Connected if meets non-DR requirements (*i.e.*, user amenity requirements)

• The test procedure under development only applies to the DR part of the connected criteria and NOT the user amenity portion
Connected Water Heater

A connected water heater includes the ENERGY STAR certified water heater, integrated or separate communications hardware, and additional hardware and software required to enable connected functionality.
Discussion Topics: Scope

• Keep in mind that the specification and test procedure apply to all ENERGY STAR water heaters, not just HPWH
  – Should the test procedure be applicable to non-ENERGY STAR water heaters as well (e.g., ERWH)?
Agenda

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How are Connected Criteria organized in the Spec?

- **Communications**: Open standard(s) and API or interface docs

- **Functionality**:
  - Remote Management and Consumer Feedback (User Amenity): Services for homeowners and for home energy management integration
  - Demand Response: Specific choices of communication protocols, responses to specific messages and requests
    - Let manufacturer protect user experience; avoid prescriptive requirements (e.g. reduce tank temp by X °F)
    - Let manufacturers compete on optimal logic/control strategies to provide grid services

- **Testing**: Refer to test requirements section

- **Appendix**: details on how a given open standard implementation would look (e.g. OpenADR 2.0 / CTA 2045-A).
Functionality: Demand Response

a. Communications: CTA-2045-A and/or OpenADR 2.0

b. Consumer Override: Easily accessible means for consumers to override DR events
   – Except for Grid Emergency/Off Mode events
   – When DR event is overridden, CWHP shall return to its previous operating mode.

c. Loss of Connectivity
   – On loss of connectivity, CWHP will revert to either the stored schedule, continue with DR events (in progress or planned), or continue with normal operation
d. DR Information and Messaging
   
   Required
   
   - Device Type
     - ERWH, HPWH, Gas Storage, Gas Instantaneous, etc.
   
   - Operational State
     - Current CWHP running state and DR event status
   
   - Current Available Energy Storage Capacity (kWh or Btu)
     - Energy capacity available for load up, in current conditions
   
   - Power / Demand (Instantaneous) (kW or Btu/h)
     - Measured or Estimated
   
   Optional
   
   - Energy Use (kWh or Btu)
     - Measured or estimated cumulative energy use
   
   - Current Total Energy Storage Capacity (kWh or Btu)
     - Energy storage capacity available over and above the hot water stored to provide user service at the moment.
Functionality: Demand Response - Required Requests

e. **DR Requests and Responses**
   - **General Curtailment (Shed)**
     - Reduce energy consumption, allowing the stored thermal energy in the tank to reduce moderately
     - HPWH: on recovery, should not use resistance elements
   - **Emergency Curtailment (Critical Curtailment)**
     - Reduce energy consumption substantially and urgently, allowing the stored thermal energy in the tank to reduce more than general curtailment
   - **Grid Emergency (Off Mode)**
     - Stop using power immediately if safe to do so
   - **Load Up**
     - Increase energy consumption allowing the stored thermal energy to increase within product’s safety limits
     - HPWH: Avoid resistance element usage to satisfy Load Up
   - **Return to Normal Operation**
     - Event cancellation (in progress and/or advance event)
     - Return to normal pre-event operation
Functionality: Demand Response - Optional Requests

e. DR Requests and Responses (continued)

- Set Point Adjustment
  • Adjust product thermostat set point up or down

- Relative Price Signals
  • Information to CWHP
    - Current energy cost
    - Upcoming pricing changes (e.g., relative price)
  • Allows product control logic to react to data
    - E.g. Shed / Load Up
Discussion Topics: Criteria to be Tested

• How are connected water heaters currently used in the field?
  • What distinguishes better performers?
  • What do DR programs look for in a connected water heater now?

• Loss of Connectivity: Are all DR events time limited?
  • If connectivity is lost during a DR event, could the unit be put into a permanent shed?

• Load Up: “Avoid” electric resistance is used.
  • How should we test for this ambiguity?
Agenda

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### UEF Test Procedure: Test Conditions

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Temperature</td>
<td>67.5°F ± 2.5°F</td>
</tr>
<tr>
<td>Supply Water Temperature</td>
<td>58°F ± 2°F</td>
</tr>
<tr>
<td>Outlet/Setpoint Water Temperature</td>
<td>125°F ± 5°F</td>
</tr>
</tbody>
</table>

- Accuracy and precision of the instruments are specified for all measurements necessary to measure and calculate the stored energy, energy delivered, and energy received by the water heater.

- The outlet/setpoint water temperature is initially set between 120°F to 130°F but over the entire test there is no requirement for the outlet water to be between 120°F to 130°F.
UEF Test Procedure: Test Setup (Storage Water Heater)

Dip Tube

Thermocouple Tree

Plywood with 2x4” runners
UEF Test Procedure: Overview

- Storage Volume Measurement

- Preconditioning
  - 12 hour soak-in for water heaters with rated storage volumes ≥2 gallons

- Delivery Capacity Tests [First-Hour Rating (FHR) or Max GPM]
  - FHR: Max gallons of hot water a storage CWHP can deliver in 1 hour
  - Max GPM: Max flow rate of hot water an instantaneous CWHP can deliver continuously at the test conditions

- 24hr Simulated-Use Test
  - Designed to approximate the actual use of water heaters in the field for a typical day
UEF Test Procedure: First-Hour Rating (FHR)

- Maximum gallons of hot water a storage water heater can deliver in 1 hour

- Procedure:
  - Start with a fully heated tank.
  - Initiate a draw and continue until the outlet temperature drops to 15°F below the initial outlet temperature
    - Unit will be in recovery at the end of the draw.
    - Ideally, initial outlet temperature is 125°F and the lowest temperature that hot water is delivered at 110°F.
  - After cut-out (recovery end), initiate another draw and end with the criteria stated above. Repeat for 1 hour.
  - FHR is the sum total of all the gallons of hot water delivered
UEF Test Procedure: 24-Hour Simulated Use Test

• Designed to approximate the actual use of water heaters in the field

• Results of the delivery capacity tests (FHR and Max GPM) are used to determine the appropriate draw pattern (usage pattern)
  – 4 draw patterns (Very Small, Low, Medium, and High)
  – A draw pattern specifies the volume, flow rate, and start time of the draw

• Typically, there are 3 draw clusters to simulate early morning use, use after work, and late night use.

• Important variables
  – Recovery Efficiency (RE)
  – Standby Loss Coefficient (UA)
  – UEF
UEF Test Procedure: High Draw Pattern

![Graph showing the阳光 Delivered Volume, gallons vs Time of Day](image)

- **Delivered Volume, gallons**
- **Time of Day**
- **Sunshine**

**Key Points**:
- **Draw Cluster 1**: 5:00 to 7:00
- **Draw Cluster 2**: 11:00 to 13:00
- **Draw Cluster 3**: 17:00 to 19:00
- **Recovery Draw**: 21:00 to 23:00
- **Standby Period**: 5:00 to 7:00, 11:00 to 13:00, 17:00 to 19:00, 21:00 to 23:00

**Legend**:
- Green line: Volume
- Red line: DC Summer Solstice
- Blue line: DC Winter Solstice
UEF Test Procedure: 24-Hour Simulated Use Test Cont.

- **Recovery Efficiency (RE)**
  - The ratio of energy delivered to the water to the energy content of the fuel consumed by the water heater.
  - Calculated during the initial draw of the test
    - Initial draw is large and removes a significant amount of energy from the tank allowing for a long recovery where efficiency could be calculated with repeatability

- **Standby Loss Coefficient (UA)**
  - Calculated from period between the 1\textsuperscript{st} and 2\textsuperscript{nd} draw clusters
  - Energy input to heat water minus standby losses, scaled with time, mean tank temperature and ambient temperature

- **UEF**
  - Energy delivered through hot water / energy input into the unit from burners/elements/heat pump
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Possible TP’s: Energy Consumption

• Water Heater Control Options
  – HPWH: Heat pump On/Off and/or Elements On/Off
    • Resistive elements should not be used during Curtailments and avoided during Load Ups
  – Gas Storage: Burner On/Off (Modulating is possible but not currently used in products on the market)
  – Gas Instantaneous: Burner On/Off, Modulating is predominant

• Methods to Measure/Compare Energy Consumption
  – No specifically defined limits between energy consumption states
  – Energy in, out, and stored can be measured throughout the test with the full test setup from UEF test procedure
  – Comparing specific values at a recovery start could reduce test length
    • E.g., delivered volume, outlet temperature, or mean tank temperature
Possible TP’s: What should be checked?

• Signals and responses
  – To verify open standards are being used appropriately

• Verify reaction of the connected water heater
  – Energy consumption during different DR events

• Measure energy capacity of the connected water heater
  – At different times before, during, and after DR events
  – Compare to message values provided by the connected water heater
    • What tolerances should be specified?

• Measure efficiency during different DR events

• Price responsiveness
  • Currently lack data and market conditions
  • What factors should be considered to estimate market conditions?
    • Relative high and low prices?
Possible TP’s: What metrics are most helpful and necessary?

Which metrics are most useful in verifying performance while minimizing burden?

- kWh used during different curtailments before cut-in
  - Difference in energy storage between normal operation and curtailment states
- kWh available for Load Up
  - Instantaneous (e.g., Max Energy State - Current Energy State)
  - As a reported metric (e.g., Max Energy State - Baseline Energy State at Normal Operation)
- Gallons of hot water available to consumer at different states
  - Normal operation (rated FHR)
  - Normal operation → Curtailment (less than rated FHR since there is less recovery)
  - After being loaded up (greater than rated FHR)
  - Depleted (CWHP has not fully recovered, Less than rated FHR)
- $ used after receiving a simulated pricing signal
Possible TP’s: Ideas for Procedures

• After receiving different DR requests (to verify connected water heater response and/or measure energy content of the tank)
  • What should the baseline look like (draw patterns, FHR, etc.)?
  • What order should the DR requests arrive in?
    • Normal Operation → General Curtailment → Emergency Curtailment → Normal Operation
  • Could have an issue with stacking (mean tank temperature steadily rises after repeated draws and recoveries)

• Simulated-Use Tests (not necessarily those in the UEF TP)
  • Will a connected water heater always be loaded up before a shed?
  • How often would a shed occur after no load up?
  • How long will a shed typically last?
    • Set length or until another DR request is received?

• Others Ideas?
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Anticipated Timeline

- Specification and Test Procedure (DOE) developed concurrently
- **Mid July: Test Procedure Check-In 1**
  - Anticipated Q3-2019: Specification Draft 2
  - Stakeholder meeting ENERGY STAR Products Partner Meeting, September 10-12, Charlotte, NC (**Test Procedure Check-In 2**)
- **Mid November: Test Procedure Check-In 3**
  - Anticipated Q4-2019: Specification and Test Method Draft 1
  - Anticipated Q1-2020: Specification and Test Method Draft Final; not necessarily at exactly the same time
  - Anticipated Q2-2020: Test Method Final
Ways to Work Together: Future TP Check-In Calls

• An initial draft of the CWHP Test Procedure is planned for Quarter 4 of 2019

• Stakeholder check-ins about every 2 months would allow for 3 by the end of 2019
  – Check-In 1: Mid-July
  – Check-In 2: September Product Partner Meeting (Charlotte, NC)
  – Check-In 3: Mid-November

• Check-in’s would be open to anyone who is interested and would be held via webinar (and possibly in person at the Partner Meeting)
Contact Information

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Agenda

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NEEA’s: Northern Climate Uniform Energy Factor

• Northern Climate Uniform Energy Factor (UEF_{NC}) is representative of water heater performance for equipment installed in semi-conditioned (e.g., basements, unheated utility rooms) and unconditioned (e.g., garages, crawl spaces) locations in northern climates.

• Two 24-hour Simulated Use Tests and a bin weighted calculation
  • Based on the Heating Seasonal Performance Factor (HSPF) for space conditioning heat pumps

• Test Conditions:
  • UEF_{67}: to the DOE’s 24-hour Simulated Use Test
  • UEF_{50}: 50°F dry bulb, 43.5°F wet bulb (58% RH), 50°F inlet water
NEEA’s: Northern Climate Uniform Energy Factor

\[ UEF_{NC} = \sum_{j=1}^{10} UEF_j \times f_j \]

where:
- \( j \) is the bin number from Table 2
- \( f_j \) is the fraction of hours for that bin

If no ER is used in either UEF_{67} or UEF_{50}

\[
UEF_j = (T_j - 50) \times m_{UEF} + UEF_{50}
\]

\[
m_{UEF} = (UEF_{67} - UEF_{50}) / (67.5 - 50)
\]

If ER is used in either UEF_{67} or UEF_{50}

For bin temperatures <50°F

\[
UEF_j = (T_j - 50) \times m_{compT50} + UEF_{50}
\]

\[
m_{compT50} = (UEF_{50} - UEF_{R,Cutoff}) / (50 - C_{Cutoff})
\]

For bin temperatures \geq 50°F and \leq 67.5°F

\[
UEF_j = (T_j-50) \times m_{UEF} + UEF_{50}
\]

For bin temperatures >67.5°F

\[
UEF_j = UEF_{67}
\]

\[
UEF_{R,j} = Q_{wtr} / (Q_{wtr} + Q_{stdby,j})
\]

\[
Q_{wtr} = m \times c_p \times \Delta T / \eta_{elem}
\]

\[
Q_{stdby,j} = UA \times (T_{tank} - T_j) \times 24 \text{ hrs}
\]

### Table 2. Temperature Bins

<table>
<thead>
<tr>
<th>j</th>
<th>( T_j ) (°F)</th>
<th>( f_j )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>77</td>
<td>0.021</td>
</tr>
<tr>
<td>2</td>
<td>72</td>
<td>0.121</td>
</tr>
<tr>
<td>3</td>
<td>67</td>
<td>0.124</td>
</tr>
<tr>
<td>4</td>
<td>62</td>
<td>0.131</td>
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<tr>
<td>5</td>
<td>57</td>
<td>0.132</td>
</tr>
<tr>
<td>6</td>
<td>52</td>
<td>0.141</td>
</tr>
<tr>
<td>7</td>
<td>47</td>
<td>0.121</td>
</tr>
<tr>
<td>8</td>
<td>42</td>
<td>0.096</td>
</tr>
<tr>
<td>9</td>
<td>37</td>
<td>0.071</td>
</tr>
<tr>
<td>10</td>
<td>32</td>
<td>0.04</td>
</tr>
</tbody>
</table>
NEEA’s: Northern Climate Uniform Energy Factor

Figure 1. UEF_{NC} vs Temperature
## Functionality: Demand Response - Operational States

<table>
<thead>
<tr>
<th>Running State</th>
<th>DR Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Idle</strong></td>
<td>Normal</td>
<td>In normal mode of operation</td>
</tr>
<tr>
<td>(Water heater IS NOT heating)</td>
<td>Grid</td>
<td>In grid service operational mode</td>
</tr>
<tr>
<td></td>
<td>Heightened</td>
<td>Processing a Load Up request</td>
</tr>
<tr>
<td></td>
<td>Opted Out</td>
<td>DR is overridden (no/insignificant energy use)</td>
</tr>
<tr>
<td><strong>Running</strong></td>
<td>Normal</td>
<td>In normal mode of operation</td>
</tr>
<tr>
<td>(Water heater IS heating)</td>
<td>Curtailed</td>
<td>In grid service operational mode</td>
</tr>
<tr>
<td></td>
<td>Grid</td>
<td>In grid service operational mode</td>
</tr>
<tr>
<td></td>
<td>Heightened</td>
<td>In grid service operational mode and processing a Load Up request.</td>
</tr>
<tr>
<td></td>
<td>Opted Out</td>
<td>DR is overridden (significant energy use)</td>
</tr>
<tr>
<td><strong>Cycling</strong></td>
<td>On</td>
<td>Is heating</td>
</tr>
<tr>
<td>(grid service event)</td>
<td>Off</td>
<td>Is not heating</td>
</tr>
<tr>
<td><strong>SGD Error</strong></td>
<td>-</td>
<td>Device is malfunctioning</td>
</tr>
</tbody>
</table>
Other Connected Criteria Specifications

- California’s Title 24
  - Joint Appendices 13 (JA13)

- Consortium for Energy Efficiency (CEE)
  - Residential Water Heating Initiative (March 16, 2018)
  - https://library.cee1.org/content/cee-residential-water-heating-initiative/

- Northwest Energy Efficiency Alliance (NEEA)
  - Advanced Water Heating Specification V6.0

- Air-Conditioning, Heating, & Refrigeration Institute (AHRI)
  - AHRI Standards 1380 (I-P/2019), Demand Response through Variable Capacity HVAC Systems in Residential and Small Commercial Applications

- Others we should be aware of?
Discussion Topics: Current Test Procedure

• What other instruments and test equipment would be useful and/or necessary?

• Should other test conditions be used?
  – Region specific values probably won’t work since this test applies to the entire nation, but would a CWHP in a DR program experience different conditions in the field?

• When is wind power most available?
  – What other renewable energy sources might we want to account for?

• Would a recovery efficiency and/or UEF during different DR events be useful?