AHRI Standard 1430-2022 (I-P)
with Addendum 1

2022 Standard for

Demand Flexible Electric Storage Water Heaters

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2311 Wilson Boulevard, Suite 400
Arlington, VA 22201, USA
www.ahrinet.org
PH 703.524.8800
FX 703.562.1942

AHRI STANDARD 1430-2022 (I-P) (WITH ADDENDUM 1)

DEMAND FLEXIBLE ELECTRIC STORAGE WATER HEATERS

September – 2023

Addendum 1 of AHRI Standard 1430-2022 (I-P) is provided as follows. The following change has been incorporated (deletions are shown by ~~strikethrough~~ and additions by shading) into the already published 2022 edition of AHRI Standard 1430 (I-P) to prevent confusion.

1. Revision to Table 4

12.	Send an Operational State query.	Acceptable responses include: "Running Curtailed Grid" or "Idle Grid" ~~"Idle Normal" or "Running Normal"~~

IMPORTANT

SAFETY DISCLAIMER

AHRI does not set safety standards and does not certify or guarantee the safety of any products, components or systems designed, tested, rated, installed or operated in accordance with this standard/guideline. It is strongly recommended that products be designed, constructed, assembled, installed and operated in accordance with nationally recognized safety standards and code requirements appropriate for products covered by this standard/guideline.

AHRI uses its best efforts to develop standards/guidelines employing state-of-the-art and accepted industry practices. AHRI does not certify or guarantee that any tests conducted under its standards/guidelines will be non-hazardous or free from risk.

ICS Code: 91.140.65

Note:

This is a new Standard.

AHRI CERTIFICATION PROGRAM DISCLAIMER

AHRI Standards are developed independently of AHRI certification activities and can have scopes that include products that are not part of the AHRI Certification Program. The scope of the applicable AHRI Certification Program can be found on AHRI's website at http://www.ahrinet.org.

Intent

This standard sets forth a harmonized specification for demand flexible electric resistance storage and *electric heat pump water heaters (HPWH)s* capable of load management that can be used by policymakers, state government, electric utilities, authorized third parties, manufacturers, designers, installers, contractors, and users. By providing standardized requirements *for Demand Flexible Electric Storage Water Heater (DFWH)*s, utilities and load management program managers can be assured the *DFWHs* are enabled to communicate using standard hardware and software.

Review and Amendment

This standard is subject to review and amendment as technology advances in both water heating equipment and communication protocols.

2022 Edition

This edition of AHRI Standard 1430 (I-P), *Demand Flexible Electric Storage Water Heaters*, was prepared by Water Heater Standards Technical Committee. The standard was published by the Heating Standards Subcommittee in December 2022.

Origin and Development of AHRI Standard 1430

This is the initial publication of AHRI Standard 1430 (I-P), *Demand Flexible Electric Storage Water Heaters*.

This first edition of AHRI Standard 1430-2022 (I-P) was created to develop:

- Demand Flexible Electric Storage Water Heater application definitions
- Methods of testing and verification
- Operating and physical requirements
- Minimum data requirements for published ratings
- Marking and labeling data
- Conformance conditions
- Values of load shifting minimum requirements
- Product literature requirements

The purpose and scope include requirements and conformance conditions to confirm that equipment communicates in standardized messages and communication protocols using CTA-2045-B.

Committee Personnel

AHRI 1430 Standard Working Group

Participant	Interest Category Classification	Voting Member Role	State / Country
Julian Ferrante Bradford White Corp.	Product Manufacturer	Chair	PA, USA
Joe Boros Rheem Sales Company, Inc.	Product Manufacturer	Vice Chair	AL, USA
James Abraham Bosch Thermotechnology Corp	Product Manufacturer	Primary	NH, USA
John Bade 2050 Partners, Inc.	General Interest	Primary	CA, USA
Brian Branecky A.O. Smith Corporation	Product Manufacturer	Primary	WI, USA
Abigail Daken U.S. Environmental Protection Agency (Energy Star Program)	Regulatory Agency	Primary	DC, USA
Renee Eddy Rinnai America Corporation	Product Manufacturer	Primary	GA, USA
George Gurlaskie Duke Energy	General Interest	Primary	NC, USA
Byron Horak Intertek	Testing Laboratory	Primary	NY, USA
Brian Pickett Ariston Thermo USA LLC	Product Manufacturer	Primary	MA, USA
Alice Rosenberg Consortium for Energy Efficiency	General Interest	Primary	MA, USA
Judd Smith CSA America Testing & Certificate LLC	Testing Laboratory	Primary	OH, USA
Chuck Thomas Electric Power Research Institute	General Interest	Primary	TN, USA
Craig Tsai GE Appliances, a Haier Company	Product Manufacturer	Primary	KY, USA
Joe Vukovich Natural Resources Defense Council	General Interest	Primary	CA, USA
Geoff Wickes Norwest Energy Efficiency Alliance	General Interest	Primary	OR, USA
Pierre Delforge Natural Resources Defense Council	General Interest	Alternate to Joe Vukovich	CA, USA
Joshua Goncalves Ariston Thermo USA LLC	Product Manufacturer	Alternate to Brian Pickett	MA, USA
Paul Hikspoors (A.O. Smith Corporation) Usines GIANT Factories Inc	Product Manufacturer	Alternate to Brian Branecky	QC, Canada
Amber Humphries A.O. Smith Corporation	Product Manufacturer	Alternate to Brian Branecky	WI, USA
Kim Katz Consortium for Energy Efficiency	General Interest	Alternate to Alice Rosenberg	MA, USA
Jeff Kleiss (A.O. Smith Corporation) Lochinvar, LLC	Product Manufacturer	Alternate to Brian Branecky	TN, USA

Participant	Interest Category Classification	Voting Member Role	State / Country
Bob Krmpotich Rheem Sales Company, Inc.	Product Manufacturer	Alternate to Joe Boros	GA, USA
James Phillips Rheem Sales Company, Inc.	Product Manufacturer	Alternate to Joe Boros	GA, USA
John Schlafer GE Appliances, a Haier Company	Product Manufacturer	Alternate to Craig Tsai	KY, USA
Tyler Styles Intertek	Testing Laboratory	Alternate to Byron Horak	NY, USA
John Taylor Consortium for Energy Efficiency	General Interest	Alternate to Alice Rosenberg	MA, USA
Brian Teeter CSA America Testing & Certificate LLC	Testing Laboratory	Alternate to Judd Smith	OH, USA
Alex Ussery Intertek	Testing Laboratory	Alternate to Byron Horak	NY, USA
James York Rheem Sales Company, Inc.	Product Manufacturer	Alternate to Joe Boros	GA, USA
Jacob (Cobi) Waxman	AHRI Staff Liaison		

Water Heater Standards Working Group Scope:

To develop all sections of an ANSI Water Heater Standard for Demand Flexible Electric Storage Water Heater application definitions; test requirements, methods of testing and verification, operating and physical requirements, minimum data requirements for published ratings, marking and labeling, and data and conformance conditions, values of load shifting minimum requirements, and product literature requirements.

The above purpose and scope include requirements and conformance conditions to confirm that equipment is enabled to communicate in standardized messages and communication protocols using CTA-2045-B.

Standards Working Groups (SWG) are temporary and are formed by and report to the Standards Technical Committee (STC). The work of the SWG shall be within the scope of the STC as defined by the Standards Subcommittee (SSC).

Water Heater Standards Technical Committee

Participant	Interest Category Classification	Voting Member Role	State / Country
Jeff Kleiss Lochinvar, LLC	Product Manufacturer	Chair	TN, USA
James Abraham Bosch Thermotechnology Corp	Product Manufacturer	Primary	NH, USA
John Bade 2050 Partners, Inc.	General Interest	Primary	CA, USA
Joe Boros Rheem Sales Company, Inc.	Product Manufacturer	Primary	AL, USA
Abigail Daken U.S. Environmental Protection Agency (Energy Star Program)	Regulatory Agency	Primary	DC, USA
Renee Eddy Rinnai America Corporation	Product Manufacturer	Primary	GA, USA
George Gurlaskie Duke Energy	General Interest	Primary	NC, USA
Byron Horak Intertek	Testing Laboratory	Primary	NY, USA
Behrooz Mohebbi Pentair Aquatic Systems	Product Manufacturer	Primary	NC, USA
John O'Hare Hayward Industries, Inc.	Product Manufacturer	Primary	NC, USA
Brian Pickett Ariston Thermo USA LLC	Product Manufacturer	Primary	MA, USA
Judd Smith CSA America Testing & Certificate LLC	Testing Laboratory	Primary	OH, USA
Eric Truskoski Bradford White Corp.	Product Manufacturer	Primary	PA, USA
Craig Tsai GE Appliances, a Haier Company	Product Manufacturer	Primary	KY, USA
Greg Beaty Hayward Industries, Inc.	Product Manufacturer	Alternate to John O'Hare	TN, USA
Brian Branecky (Lochinvar, LLC) A. O. Smith Corporation	Product Manufacturer	Alternate to Jeff Kleiss	WI, USA
Julian Ferrante Bradford White Corp.	Product Manufacturer	Alternate to Eric Truskoski	PA, USA
Joshua Goncalves Ariston Thermo USA LLC	Product Manufacturer	Alternate to Brian Pickett	MA, USA
Paul Hikspoors (Lochinvar, LLC) Usines GIANT Factories Inc	Product Manufacturer	Alternate to Jeff Kleiss	QC, Canada
Amber Humphries (Lochinvar, LLC) A. O. Smith Corporation	Product Manufacturer	Alternate to Jeff Kleiss	WI, USA
Bob Krmpotich Rheem Sales Company, Inc.	Product Manufacturer	Alternate to Joe Boros	GA, USA
James Phillips Rheem Sales Company, Inc.	Product Manufacturer	Alternate to Joe Boros	GA, USA
Bill Roy Hayward Industries, Inc.	Product Manufacturer	Alternate to John O'Hare	NC, USA

Participant	Interest Category Classification	Voting Member Role	State / Country
John Schlafer GE Appliances, a Haier Company	Product Manufacturer	Alternate to Craig Tsai	KY, USA
Tyler Styles Intertek	Testing Laboratory	Alternate to Byron Horak	NY, USA
Brian Teeter CSA America Testing & Certificate LLC	Testing Laboratory	Alternate to Judd Smith	OH, USA
Alex Ussery Intertek	Testing Laboratory	Alternate to Byron Horak	NY, USA
James York Rheem Sales Company, Inc.	Product Manufacturer	Alternate to Joe Boros	GA, USA
Jacob (Cobi) Waxman	AHRI Staff Liaison		

Water Heater Standards Technical Committee Scope:

The Water Heater Standards Technical Committee is responsible for the development and maintenance of AHRI standards and guidelines pertaining to residential and commercial water heaters and pool heaters.

Out of scope for this STC are indirect water heaters which are part of a hydronic system.

Heating Standards Subcommittee

Participant	Interest Category Classification	Voting Member Role	State / Country
Robert Glass Daikin Comfort Technologies	Manufacturer	Chair	AL, USA
Diane Jakobs Rheem Manufacturing Company	Manufacturer	Vice Chair	AR, USA
Bryan Ahee Bradford White Corp.	Manufacturer	Primary	IL, USA
Martin Brice Gas-Fired Products, Inc.	Manufacturer	Primary	NC, USA
Jeff Kleiss Lochinvar, LLC	Manufacturer	Primary	TN, USA
Tom Neill Smith Cast Iron Boilers	Manufacturer	Primary	MA, USA
Paul Sohler Crown Boiler Co.	Manufacturer	Primary	PA, USA
Karl Best	AHRI Staff Liaison		

Heating Standards Subcommittee Scope:

The scope of the Heating Standards Subcommittee is standards and guidelines related to the end products that are part of the AHRI Heating Industry Sector. (The definition of and list of products associated with each sector are found on the AHRI website.)

This list represents the membership at the time the Standards Technical Committee and Standards Subcommittee were balloted on the final text of this edition. Since that time, changes in the membership may have occurred. Membership on these committees shall not in and of itself constitute an endorsement by the committee members or their employers of any document developed by the committee on which the member serves.

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DEMAND FLEXIBLE ELECTRIC STORAGE WATER HEATERS

Section 1. Purpose

1.1 Purpose

This standard establishes specifications for *demand flexible water heaters* (*DFWH*) as defined in Section 3. This standard includes applicable definitions, test requirements, methods of testing and verification, operating and physical requirements, minimum data requirements for published ratings, marking and nameplate data, conformance conditions, values of load shifting minimum requirements, and product literature requirements. The standard provides two pathways for compliance. Both pathways include a *demand response* (*DR*) only compliance pathway and the second additionally includes locally stored *time-of-use* (TOU) compliance pathway.

1.2 Requirements

This standard establishes requirements for *DFWHs* that are capable of supporting *load management strategies* to benefit the electric grid in a predictable manner, and to facilitate end users to participate in *DR*, *TOU scheduling*, price response, or incentive programs offered by electric utilities or *consumer authorized third parties*. The requirements described in this standard include the following:

- Specification for standardized communication pathways and protocols to be utilized by *DFWHs* to communicate with electric utilities or *consumer authorized third parties* operating load management programs.
- Specifications for communication connections to *DFWHs*
- Specifications for standardized communication signals between electric utilities or *consumer authorized third parties* and *DFWHs*
- Specifications for responses taken by *DFWHs* in response to requests from electric utilities or *consumer authorized third parties*, based on instructions pre-configured in the system and entered during the enrollment processor otherwise by the end user
- Specifications for transmittal to and from *DFWHs* to facilitate enrollment in *load management* programs

Section 2. Scope

2.1 Scope

This standard applies to communication, infrastructure, and system functionality as these relate to the implementation of energy management strategies for *DFWHs*, with a nominal storage capacity greater than or equal to forty gallons and less than or equal to 120 gallons, installed in residential and small commercial applications as defined in Section 3.

- Standardized communication required to enable participation in *load management programs* of electric utilities and *consumer authorized third parties*.
- Infrastructure including the physical layer, to enable direct communication between *DFWHs* and electric utilities and *consumer authorized third parties*.
- *DFWH* functionality including the control modes and how the system responds to signals to adjust operation.

2.2 Exclusions

This standard does not apply to any electric storage water heater with an input rate greater than 12 kW or any heat pump water heater with a maximum current rating greater than 24 amps at a voltage not greater than 250 volts. This standard does not apply to any electric storage or heat pump water heater with a nominal storage capacity less than 40 gal or greater than 120 gal, nor to any water heater that uses fuel other than electricity.

Section 3. Definitions

All terms in this document shall follow the standard industry definitions in the ASHRAE Terminology website unless otherwise defined in this section.

3.1 Expression of Provisions

Terms that provide clear distinctions between requirements, recommendations, permissions, options, and capabilities.

3.1.1 "Can" or "cannot"

Express an option or capability.

3.1.2 "May"

Signifies a permission expressed by the document.

3.1.3 "Must"

Indication of unavoidable situations and does not mean that an external constraint referred to is a requirement of the document.

3.1.4 "Shall" or "shall not"

Indication of mandatory requirements to strictly conform to the standard and where deviation is not permitted.

3.1.5 "Should" or "should not"

Indication of recommendations rather than requirements. In the negative form, a recommendation is the expression of potential choices or courses of action that is not preferred but not prohibited.

3.2 Standard Specific Definitions

3.2.1 Communication Link

The mechanism for bi-directional data transfers between the *DFWH* and one or more external applications, devices, or systems.

3.2.2 Consumer Authorized Third Party

Any entity the consumer has provided explicit permission to access the *DFWH* functionality, in whole or in part, through a *communication link*.

3.2.3 Demand Flexible Water Heater (DFWH)

An *electric resistance storage water heater* or *HPWH* with the capability to reduce, shed, shift, load up, and modulate energy consumption.

3.2.4 Demand Response (DR)

Changes in electricity usage by an end-use device from the consumption pattern in response to short-term electricity price changes, to incentive payments designed to induce lower electricity use at times of high electricity prices, or to improve the reliability of electric distribution systems.

3.2.5 Electric Heat Pump Water Heater (HPWH)

Electric storage water heaters with a maximum current rating of 24 amps at a voltage not greater than 250 volts that are designed to transfer thermal energy from one temperature level to a higher temperature level for the purpose of heating water, including all ancillary equipment such as fans, storage tanks, pumps, or controls necessary for the device to perform. These include split-system heat pump water heaters tested with a specific tank.

3.2.6 Electric Resistance Storage Water Heater

A water heater that uses electricity as the energy source, has a nameplate input rating of 12 kW or less, and contains more than one gallon of water per 4000 Btu per hour of input.

3.2.7 Load Management Programs

Programs that incentivize temporary adjustments in the use of electricity.

3.2.8 Load Management Strategies

Strategies that can include but are not limited to concepts such as direct load control, *TOU scheduling*, and price response programs.

3.2.9 Load Shift

An operation that moves energy used by a device within a time interval under *normal mode of operation* to occur outside that time interval. It can be performed by a combination of load up and curtailment requests.

3.2.10 Load Shift Draw Pattern

The first draw cluster of the *rated draw pattern* (meaning, draws one through five for the very-small-usage draw pattern, draws one through three for the low-usage draw pattern, draws one through three for the medium-usage draw pattern, and draws one through four for the high-usage draw pattern).

3.2.11 Loss of Connectivity Event

A communication state when the *DFWH* can no longer send or receive signals to or from an outside source.

3.2.12 Normal Mode of Operation

The operational state that the device operates independent of the information exchanged through the open *communication link*, as set by the consumer.

3.2.13 On-premises

A function that relies only on equipment present at the physical installed location of the *DFWH*.

3.2.14 Operation State Query

A request from the *UCM* for the operation state of the *DFWH*.

3.2.15 Rated Draw Pattern

Draw pattern that the *DFWH* was certified (meaning, either very-small-usage, low-usage, medium-usage, or high-usage).

3.2.16 Rated Recovery Efficiency

Recovery efficiency that the *DFWH* was certified.

3.2.17 Settling Period

The greater of ten minutes or when a maximum mean tank temperature is observed as determined when the sixty second rolling average of mean tank temperature measurements, taken every five seconds, drops 0.05°F below the previous sixty second rolling average.

3.2.18 Time-of-use (TOU) Scheduling

A method of adjusting the electricity consumption of a water heater based on published pricing information provided by the utility or *consumer authorized third party* or by using a locally entered schedule.

3.2.19 Time-of-use (TOU)-capable Water Heater

A *DFWH* with the capability of *TOU scheduling* through either a data connection meeting the requirements of this standard or a local schedule.

3.2.20 Universal Communication Module (UCM)

A device that enables bi-directional communication between utility or *consumer authorized third party* and the port compliant with CTA-2045. The device sends and receives a signal to and from an outside source through means such as, FM, Cellular, Wi-Fi, and Power line carrier, and exchanges the information with the *DFWH* through the CTA-2045 port.

3.2.21 User Interface

A means for a user to control the operation of the water heater, that can be remote or local, or both, such as a web-based portal, a mobile device application, or an interface directly on the *DFWH*.

3.2.22 Utility Equivalent Communication Device (UECD)

A *UCM* configured for testing that is capable of communicating with the *DFWH* and simulating signals sent from a utility or *consumer authorized third party*.

Section 4. Test Requirements

Configuration requirements, communication requirements, and equipment performance requirements shall be verified in accordance with the test method described in Appendix C and utilizing the communication protocols in Section 9 and Section 11.

Section 5. Rating Requirements

5.1 Rating Conditions

To comply with this standard, rating conditions shall comply with requirements established in Appendix C of this standard.

5.2 Values of Load Shifting

Published standard measures of *load shift* shall be expressed to the nearest 0.01 kWh.

5.3 Verification Testing Acceptance Criteria

To comply with this standard (see Section 6), measured test results shall not be less than 95% of the published rating for *load shift*.

Section 6. Minimum Data Requirements for Published Rating

As a minimum, published ratings shall include all standard ratings. All claims to ratings within the scope of this standard shall include the statement "Rated in accordance with AHRI Standard 1430 – 2022 (I-P)". All claims to ratings for products excluded by Section 2.2 of this standard that meet all other requirements of this standard shall include the statement "Outside the scope of but rated in accordance with AHRI Standard 1430 – 2022 (I-P)". Application ratings within the scope of the standard shall include a statement of the conditions under which the ratings apply.

At a minimum, manufacturers shall provide the following data for *DFWHs*.

6.1 General

Brand Name, Model Number or Designation, *Rated Draw Pattern*, Nominal Storage Capacity (gallons), U.S. Department of Energy (DOE) Rated Storage Volume (gallons), Input (kW), *Rated Recovery Efficiency* (%).

For split-system *DFWHs* include the model number of the tank.

6.2 DR Communication Protocol(s) Supported by the Equipment

1) CTA-2045-B
2) CTA-2045-B and other communication protocols supported by the equipment

6.3 Control Strategy

1) *DR*
2) *DR* and *TOU-capable*

6.4 Load Shift Value

The *load shift* value and either the Basic Load Up or Advanced Load Up that was used when performing the tests described in Appendix C. The published *load shift* rating value shall be less than or equal to the average of at least two *load shift* test results conducted on separate water heaters with the same type of load up.

The *load shift* value is based on the result of the *load shift* test that shall be used in published ratings. This value is not a minimum *load shift* value but shall be used to verify minimum *load shift* values that are established in Appendix D.

6.5 Hardware Requirements

Record the following CTA-2045-B form factor utilized:

1) AC Form Factor
2) DC Form Factor

Section 7. Marking and Labeling Data

7.1 Mandatory

Manufacturers' descriptive and technical literature for *DFWHs* shall reference this standard number and designate the *DR* communication protocol(s) the system can support, using the following designations depending upon the system capability. The label or marking shall be located to be visible to the end user after installation.

7.1.1 DR Pathway

To comply with the *DR* pathway, the water shall show one of the two markings below:

1) *DR*-ready: CTA-2045-B
2) *DR*-ready: CTA-2045-B and other communication protocols supported by the equipment

7.1.2 DR and TOU Pathway

To comply with the *DR* and TOU pathway, the water shall show one of the two markings below:

1) *DR* and TOU-ready: CTA-2045-B
2) *DR* and TOU-ready: CTA-2045-B and other communication protocols supported by the equipment

7.2 CTA-2045-B

Manufacturers' descriptive and technical literature shall designate the CTA Form Factor utilized:

1) AC form factor, or
2) DC form factor

Section 8. Conformance Conditions

While conformance with this standard is voluntary, conformance shall not be claimed or implied for products or equipment within the standard's Purpose (Section 1) and Scope (Section 2) unless such product claims meet all of the requirements of the standard and all of the testing and rating requirements are measured and reported in complete compliance with the standard. Any product that has not met all the requirements of the standard shall not reference, state, or acknowledge the standard in any written, oral, or electronic communication.

Section 9. Physical and Communication Requirements

9.1 Physical Requirements

All *DFWHs* shall meet the physical requirements of the *DR* communication protocol in Section 11.

9.2 Communication Requirements

9.2.1 Required Communication, Discovery, Management Functions and Equipment Responses

Table 1 outlines the communication, discovery, management functions and equipment responses that are required for the following two compliance pathways:

- *DR*: This compliance pathway shall meet the requirement specified in Section 9.
- *DR +TOU*: This compliance pathway shall meet the requirements specified in Section 9 and includes optional *TOU scheduling* specified in Section 10.

9.2.2 Consumer Override DR Events

The *DFWH* shall provide an accessible means for the consumers to override *DR* events during or ahead of an event. When the event is overridden, the *DFWH* shall return to the operation set by the consumer. Temporary overrides shall be limited to a duration up to seventy-two hours without additional input from the consumer. After this time, the *DFWH* shall return to the *normal mode of operation*.

9.2.3 Response to a Request

The response to a request shall be based upon the product state not older than sixty seconds from request.

Note: This period is not relevant to the overall response of the water heater to the request, meaning a *DFWH* getting to a specific state in response to a request.

9.2.4 Loss of Connectivity Event

The *DFWH* shall experience a *loss of connectivity event* when the *DFWH* has not received from the *UCM* a CTA-2045-B Outside Comm Connection Status equal to Good Connection for fifteen continuous minutes. If the *DFWH* experiences a *loss of connectivity event* lasting fifteen minutes, it shall respond as follows:

1) If a *loss of connectivity event* occurs while processing a *DR* event with a set duration or end time, product shall complete the *DR* event as planned, returning to *normal mode of operation* set by the customer afterwards, or if over-ridden.
2) If a *loss of connectivity event* occurs while processing a *DR* event without a set duration or end time, product shall resume *normal mode of operation* within thirty minutes.
3) For *TOU-capable water heaters*, the unit shall continue operating on that schedule during a *loss of connectivity event*.

9.2.5 Verification

Verification of the functions listed as required for the intended compliance pathway in Table 1 shall be conducted using the procedures found in Appendix C.

Table 1 Communication, Discovery, and Management Required

Function	Explanation and Requirement	DR	DR+TOU
Verifying Connectivity	A recurring signal verifying that there is a successfully connection.	Required	Required
System Type	Information request sent from the communication module to determine the *DFWH* characteristics and feature set such as the ability to perform an Advanced Load Up.	Required	Required
Operational State Query and Response	*Operational state query* and response enables remote systems to monitor the present state of the *DFWH* and to verify that curtailment events are acted upon and in effect. Responses include: 1) Idle Normal – Water heater is not under grid control and water is not being heated. 2) Running Normal – Water heater is not under grid control and water is being heated. 3) Running Curtailed Grid – Water heater is running a grid service curtailment mode of operation and the water heater is presently being heated. 4) Running Heightened Grid – Water heater is in a grid Basic Load Up/Advanced Load Up operational mode and water is being heated. 5) Idle Grid – Water heater is in a grid service curtailment operational model and the water heater is not heating water. 6) Water Heater Error – Device is malfunctioning. 7) Idle Heightened – Water heater is in a grid Basic Load Up/Advanced Load Up operational mode and water is not being heated. 8) Idle Opted Out – Water Heater is overridden, and water is not being heated. 9) Running, Opted Out – Water heater is overridden and is water is being heated.	Required	Required
Energy Storage Capacity	Present Energy Storage/Take Capacity: The amount of grid energy that the *DFWH* can take now (kWhs).	Required	Required
	Total Energy Storage/Take Capacity: The total amount of grid energy that the *DFWH* represents (kWhs).	Optional	Optional
Power/Demand	Electricity Consumed: The estimated power consumption in current conditions.	Required	Required
General Curtailment (Shed/Light Shed)	General curtailment directs the water heater to prevent using energy that the device otherwise uses under *normal mode of operation* by using stored thermal energy in the tank to supplement. For *DFWHs* with multiple efficiency heating modes, the *DFWHs* shall use the most efficient heating mode, during and immediately after the event unless user needs cannot be met. The *DFWH* shall verify receipt and support of the request.	Required	Required
Critical Curtailment (Deep Shed)	Critical curtailment directs the water heater to prevent using energy that the device uses under *normal mode of operation* by using stored thermal energy in the tank to supplement up to a lower depleted level than for General Curtailment. For *DFWHs* with multiple efficiency heating modes, the *DFWH* shall use the most efficient heating mode during and immediately after the event unless user needs cannot be met. The *DFWH* shall verify receipt and support of the request.	Required	Required

Function	Explanation and Requirement	DR	DR+TOU
Grid Emergency (Off mode)	Grid emergency directs the *DFWH* to immediately, stop using energy for water heating when it is safe to do so. For *DFWHs* with multiple efficiency heating modes, the *DFWH* shall use the most efficient heating mode during and immediately after the event unless user needs cannot be met. The *DFWH* shall verify receipt and support of the request.	Required	Required
Basic Load Up	Basic Load Up directs the *DFWH* to use or store, or both additional thermal energy that the device does not use or store under *normal mode of operation*. Basic Load Up allows the stored thermal energy to increase, within the parameters set by the manufacturer up to user set point. For *DFWHs* with multiple efficiency heating modes, the default shall use or store, or both additional thermal energy using the most efficient mode The *DFWH* shall verify receipt and support of the request.	Required	Required
Advanced Load Up	Advanced Load Up directs the *DFWH* to use or store, or both additional thermal energy that the device does not use or store under *normal mode of operation*. Advanced Load Up allows the stored thermal energy to increase within the parameters set by the manufacturer beyond user set point. The Advanced Load Up function requires additional installations steps, see Appendix E. The *DFWH* shall verify receipt and support of the request.	Optional	Required
Return to Normal Operation	When an ongoing event is cancelled for any reason, the *DFWH* shall return to the operational state as set by the consumer. The *DFWH* shall verify receipt and support of the request.	Required	Required
Consumer Override	Consumer override is sent by the *DFWH* to the *UCM* to notify that a consumer override has occurred.	Required	Required
Price Stream	Price Stream sends the *TOU-capable DFWH* a sequence of time-price pairs for use in a *TOU schedule*.	Not Required	Optional
TOU scheduling	See Section 10 for full description.	Not Required	Required

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Section 10. Locally Stored TOU Scheduling

10.1 General

Section 10 is only applicable to *TOU-capable water heaters*. The TOU function is accomplished through setup and execution phases; see Section 10.1.1 and Section 10.1.2.

10.1.1 Local and Remote Setup

The setup phase downloads and stores the *TOU schedule* as defined in Section 10.1 into the *TOU-capable* water heater. The *TOU-capable water heater* shall support both local and remote setup, selection, and update of *TOU schedules*. Local and remote setup, selection, and update shall be achieved through a *user interface* (such as an app).

10.1.2 Local Execution

The phase executes the *TOU schedule* using a local real-time clock as defined in Section 10.3.

The storage of a *TOU schedule* shall be built into the *TOU-capable water heater* as shown in Figure 1 or reside within the *UCM* as shown in Figure 2. The *TOU-capable water heater* shall be capable of performing the *TOU schedule* during a *loss of connectivity event* as described in Section 9.2.4.

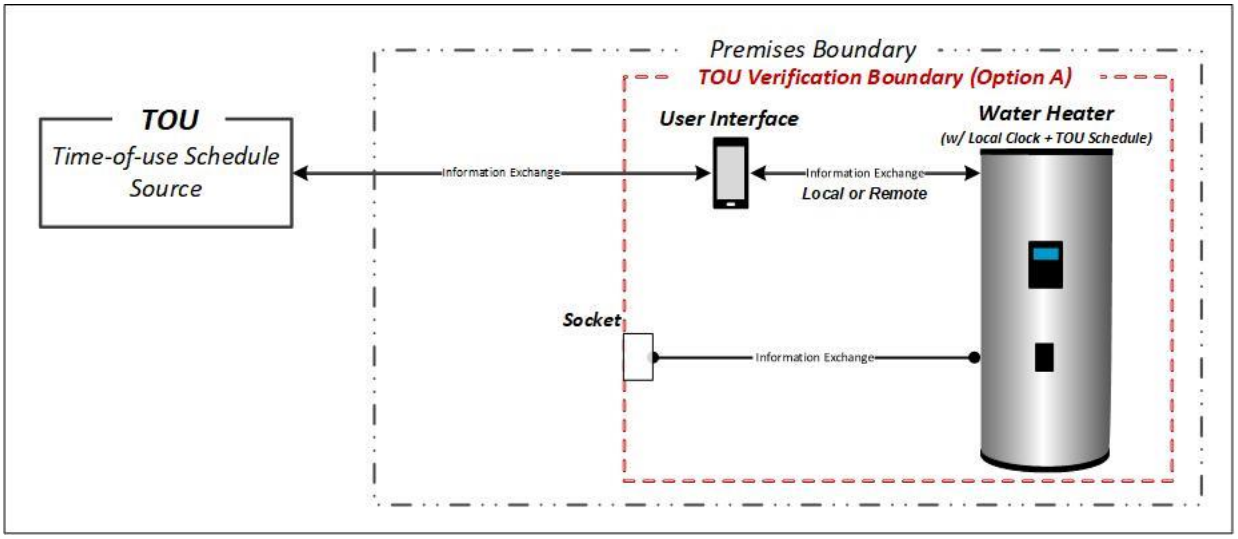

Figure 1 TOU Schedule Built Into TOU-Capable Water Heater

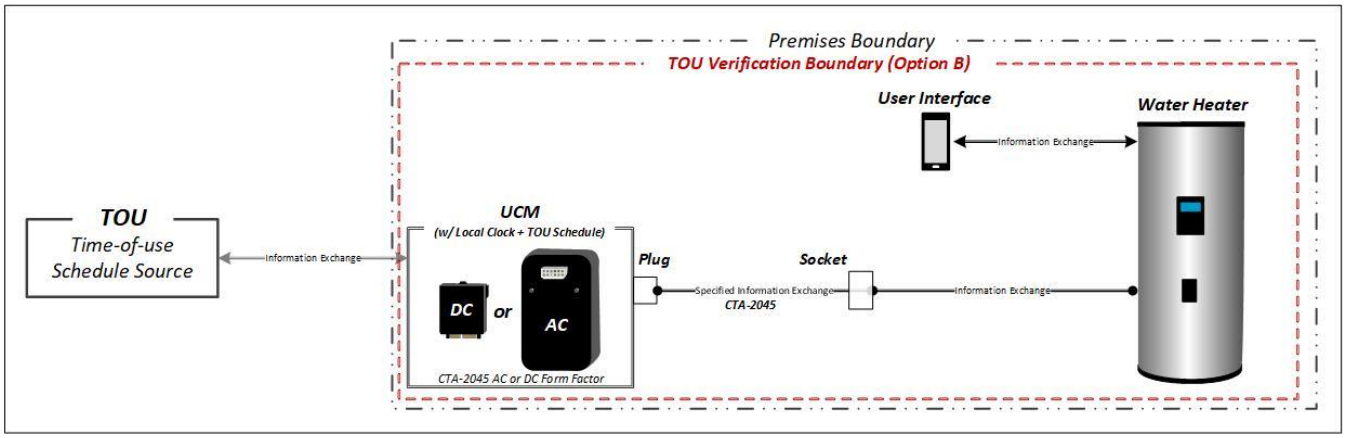

Figure 2 TOU Schedule Built Into UCM

10.2 Time-of-use Scheduling Requirements

A *TOU-capable water heater* shall have the capability of locally storing and responding to at least five *TOU schedules*. At a minimum, each *TOU schedule* shall be able to support three distinct seasons that rotate based on date. Each season of the *TOU schedule* shall support at a minimum five distinct time periods for each weekday and weekend. The *TOU schedule* shall follow daylight savings time changes if necessary.

10.3 Local Clock Requirement

In the event of a loss of power, the *TOU-capable water heater* settings, including operating mode, *TOU schedules*, and local clock, shall be retained, or reacquired, for at least three months. The local clock shall be designed to have a maximum drift of five minutes or less per year under standard operating conditions and without requiring remote connectivity.

Section 11. DR Communication Protocols

11.1 General Requirements

Any approved *DR* communication protocol shall be an open standard, as described below, and have physical and communication requirements clearly defined.

Open standards are designed to communicate with entities outside the *DFWH* that use, for all communication layers, any, or all of the following standards:

- included in the Smart Grid Interoperability Panel (SGIP) Catalog of Standards
- included in the National Institute of Standards and Technology (NIST) Smart Grid Framework Table 4.1 and Table 4.2
- adopted by the American National Standards Institute (ANSI) or another accredited international standards organization such as the International Organization for Standardization (ISO), International Electrotechnical Commission (IEC), International Telecommunication Union (ITU), Institute of Electrical and Electronics Engineers (IEEE) or Internet Engineering Task Force (IETF).

Open standards that are compliant with this document are described in Section 11.2.

11.2 CTA-2045-B

11.2.1 Physical Requirements

All *DFWHs* with CTA-2045-B compatibility shall have a port compliant with CTA-2045-B.

TOU-capable water heaters shall have the ability to input a locally stored *TOU schedule* (see Section 10).

11.3 Communication Requirements

Table 2 Communication, Discovery, and Management with CTA-2045-B

Function	Message	Reference
Verifying Connectivity	Outside Comm Connection Status Message	Table 10-2
System Type	Info request sent from the communication module to the water heater. Responses include electric resistance (0x0002) or heat pump water heater (0X0003). Included in the information request response is the Capability Bitmap that indicates the support for Advanced Load Up (Bit6).	Section 11.1.1
Operational State Query and Response	Operational State Query and Response Messages	Table 10-2 and Section 10.4.4
Energy Storage Capacity	Get CommodityRead sent from the communication module to the water heater for energy storage info	Section 11.2.2
Power/Demand	Get CommodityRead sent from the communication module to the water heater for power consumption info	Section 11.2.2
General Curtailment (Shed/Light Shed)	Shed (request) and Light Shed (request) and Basic Application acknowledgement (ACK) (response)	Table 10-2
Critical Curtailment (Deep Shed)	Critical Peak Event (request) and Basic Application ACK (response)	Table 10-2
Off Mode (Grid Emergency)	Grid Emergency (request) and Basic Application ACK (response)	Table 10-2
Basic Load Up	Basic Load Up (request) and Basic Application ACK (response)	Table 10-2
Advanced Load Up	Advanced Load Up (request) and Basic Application ACK (response)	Table 11-2
Return to Normal Operation	End Shed/Run Normal Operation (request) and Basic Application ACK (response)	Table 10-2
Consumer Override	Consumer Override Message (initiated by the water heater) and Basic Application ACK. In accordance with the CTA-2045-B standard, the *DFWH* shall send this message when override is first initiated and following incoming energy management messages while override is in effect.	Table 10-2
Price Stream	Price Stream	Table 11-2
TOU scheduling	Not done through *DR* communication.	N/A

APPENDIX A. REFERENCES – NORMATIVE

Listed here are all standards, handbooks, and other publications essential to the formation and implementation of the standard. All references in this appendix are considered as part of the standard.

A.1. ANSI/CTA-2045-B, *Modular Communications Interface for Energy Management*, February 2021, Consumer Technology Association, 1919 S. Eads Street, Arlington, VA 22202, USA.

A.2. ASHRAE Terminology. ASHRAE. Accessed May 4, 2022. https://www.ashrae.org/technicalresources/free-resources/ashrae-terminology**.**

A.3. Uniform Test Method for Measuring the Energy Consumption of Water Heaters, Appendix E to Subpart B of Part 430, Title 10. Accessed July 8, 2022. https://www.ecfr.gov/current/title-10/chapter-II/subchapter-D/part-430/subpart-B/appendix-Appendix%20E%20to%20Subpart%20B%20of%20Part%20430

APPENDIX B. REFERENCES - INFORMATIVE

Listed here are standards, handbooks and other publications which may provide useful information and background but are not considered essential. References in this appendix are not considered part of the standard.

B.1. ANSI/ASSE 1017-2009, *Performance Requirements For Temperature Actuated Mixing Valves For Hot Water Distribution Systems*. Westlake, Ohio, USA.

B.2. ENERGY STAR®, *Connected Residential Water Heaters Test Method to Validate Demand Response*, Version 1.2 (Rev. July-2022).

APPENDIX C. METHODS OF TESTING AND VERIFICATION - NORMATIVE

C.1. Purpose

This appendix prescribes a method of testing for demand flexible and *TOU-capable water heaters* to verify the equipment response to *DR* signals through the communication protocols as defined in Section 9 and Section 11.

Testing shall occur at a facility where consumer water heaters are tested for capacity and energy efficiency according to the 1 January 2021, revision of the DOE Test Procedure in Title 10 of the Code of Federal Regulations (CFR) Part 430, Appendix E to Subpart B (DOE Test Procedure).

C.2. Test Setup

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

The instrumentation that measures water volume, mass, or flow rate, or all of these can 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 one measurement every five seconds.

C.2.1. DFWH System Setup

The *UECD* and water heater shall be set up in accordance with Figure 3 and manufacturer instructions. Confirm that the *UECD* is connected and can both receive and send data to the water heater.

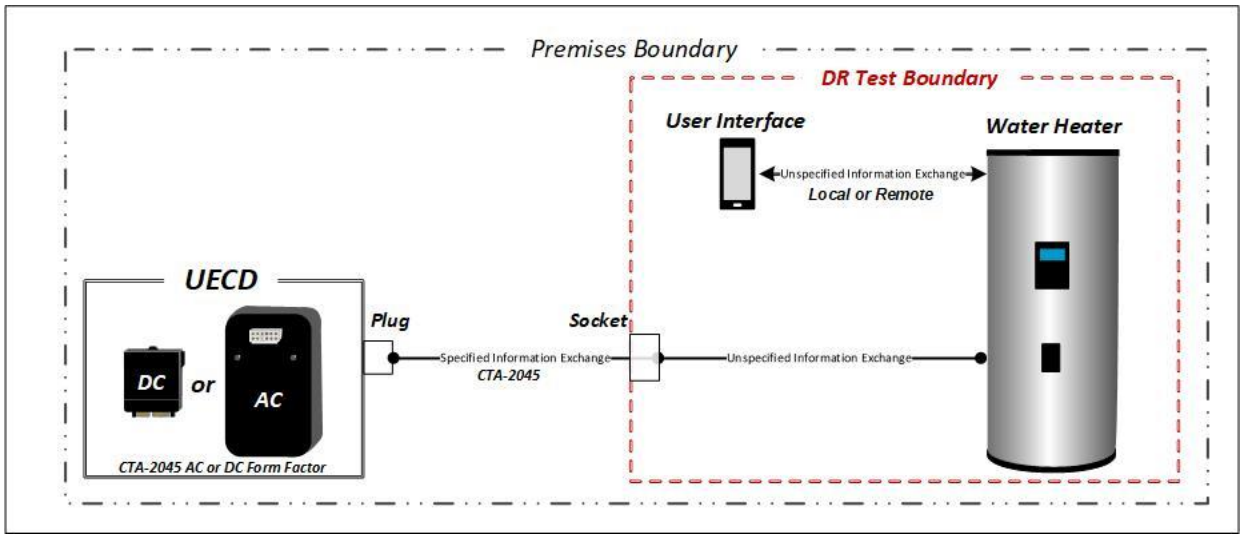

Figure 3 Demand Flexible Water Heater

For *DFWHs* designed to be used with a mixing valve (meaning the *DFWH* 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 4 or Figure 5. If permitted by the water heater and mixing valve manufacturer's instructions, the mixing valve and junction that supplies the cold water to the mixing valve can be installed where the elbows are in the outlet and inlet water lines, respectively. If installation instructions for the mixing valve in the water heater or mixing valve manufacturer's instructions are not provided, then the mixing valve shall be installed on the outlet water line, as shown in Figure 4 or Figure 5, 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, or mass measuring instrumentation, or all of these shall be installed after the mixing valve if installed on the outlet side of the *DFWH*.

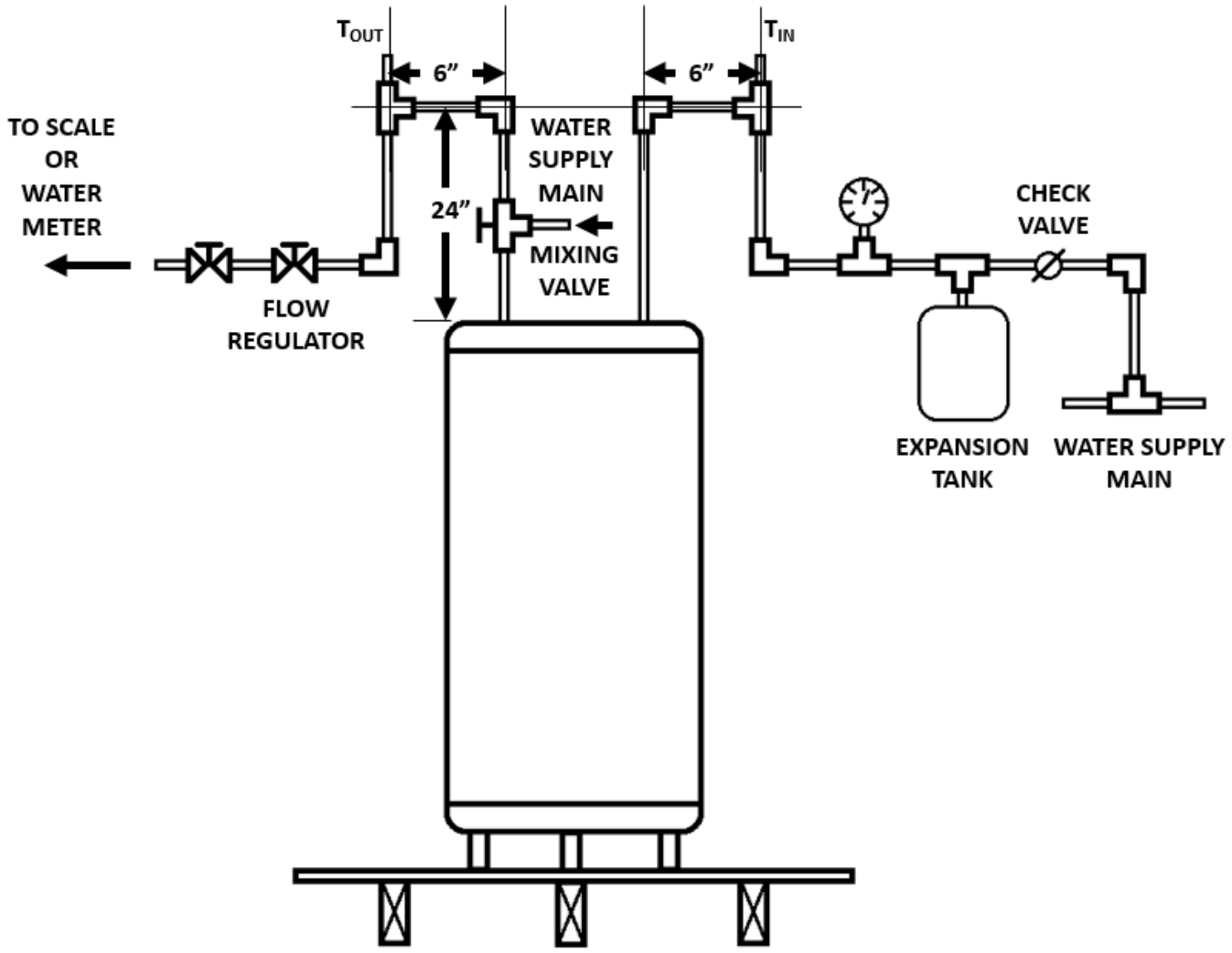

Figure 4 Mixing Valve Location on a DFWH with Top Inlet and Outlet Connections

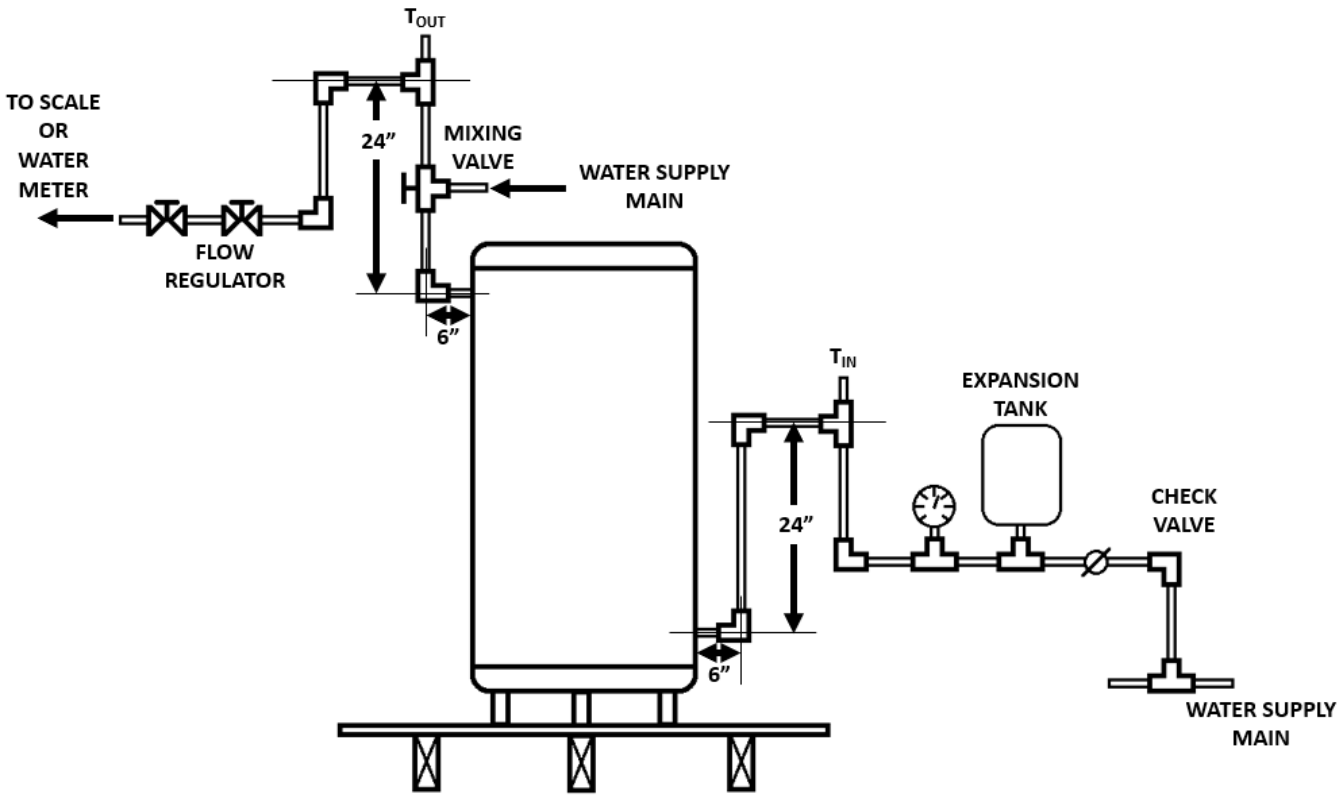

Figure 5 Mixing Valve Location on a DFWH with Side Inlet and Outlet Connections

C.3. Water Heater Preparation

Prior to the *load shift* (Section C.4.5.1) and Emergency Curtailment and Grid Emergency (Section C.4.5.2) tests, perform the procedures found in Section 5.1 and Section 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 has not been removed from the *DFWH*, then the soak-in period from Section 5.2.4 of the DOE Test Procedure does not need to be conducted.

This section does not need to be performed to complete the *DFWH* Initialization (Section C.4.1), *User Interface* (Section C.4.2), Consumer Override (Section C.4.3), and Loss of Connectivity (Section C.4.4) tests.

C.4. Demand Response Tests

In Section C.4.3 through Section C.4.5 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 (meaning as soon as the request is received by the *DFWH*) or at a certain time after the request is received by the *DFWH*. Durations are stated as either Maximum or other durations (such as four hours). For all tests except the Loss of Connectivity test in Section C.4.4, a Maximum duration in the context of this test method means that the *DR* request does not end, and if the *DFWH* is incapable of receiving a *DR* request that does not end, then the *DR* request shall last at least four hours.

C.4.1. DFWH Initialization

Verify that the *DFWH* communicates using an open standard as described in Section 11.1.

C.4.2. User Interface

Verify that the manufacturer literature supplied with the *DFWH* or *UCM*, or both includes instructions for the user to override *DR* requests.

C.4.3. Consumer Override

The test steps described in Table 3 shall be performed to verify the consumer override requirement described in Section 9.2.2.

All communications between the *UECD* and *DFWH* shall be logged. If any logged communications do not match the acceptable responses listed in Table 3, then the *DFWH* fails.

Table 3 Consumer Override Verification Test Steps

Step	UECD	DFWH
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 *DFWH* shall 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	The *DFWH* 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 an Operational State query.	Acceptable responses include: “Idle Normal” or “Running Normal”

C.4.4. Loss of Connectivity

The test steps described in Table 4 shall be performed to verify the loss of connectivity requirement of Section 9.2.4.

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 *DFWH* shall be logged. If any logged communications do not match the acceptable responses listed in Table 4, then the *DFWH* fails.

The time *DFWH* experiences a loss of connectivity is defined in 9.2.4. This time is used in steps 5 and 13 of Table 4.

Table 4 Loss of Connectivity Verification Test Steps

Step	UECD	DFWH
1.	Send a Return to Normal Operation request.	—
2.	Send an Operational State query.	Acceptable responses include: “Idle Normal” or “Running Normal”
3.	For *DFWHs* 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	The *DFWH* shall 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 9.2.4 to occur.
6.	—	Wait for the time specified in Option 2 of Section 9.2.4
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 *DFWHs* 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 *DFWH* shall acknowledge the request.
12.	Send an Operational State query.	Acceptable responses include: “Running Curtailed Grid” or “Idle Grid” ~~“Idle Normal” or “Running Normal”~~
13.	—	Remove connectivity and wait for the criteria described in Section 9.2.4 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”

C.4.5. Demand Response Requests and Responses

This section verifies the *DR* Requests and Responses of the *DFWH* as required by Section 9.2.5.

All communications between the *UECD* and *DFWH* shall be logged. If any logged communications do not match the acceptable responses, then the *DFWH* fails.

Prior to the *load shift* (Section C.4.5.1) and Emergency Curtailment and Grid Emergency (Section C.4.5.2) tests perform the water heater preparation procedures from Section C.3.

Table 5 uses the *rated draw pattern* to provide the flow rate used during the *load shift* and the Emergency Curtailment and Grid Emergency tests. The *DFWHs rated draw pattern* is used to determine the *load shift draw pattern* as defined in Section 3.

Table 5 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 Section C.4.5.1 and Section C.4.5.2, respectively, instructions are given to allow the *DFWH* to settle. To settle in this test method the *DFWH* shall operate without drawing water or recovering for an entire *settling period* after a cut-out.

Note: If a cut-in occurs before the end of the *settling period*, then the recovery should be allowed to continue until cut-out, at this time the *settling period* can begin again, and, if necessary, repeat until a full *settling period* is performed.

C.4.5.1. Load Shift

The test steps described in Table 6 shall be performed to verify the requirements for the General Curtailment and either the Basic or Advanced Load Up requests from Section 9. The *load shift* test includes performing the *load shift draw pattern* with the *DFWH* 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 *DFWH* operating under a General Curtailment request. Only one load up request is required for example, if the Basic Load Up is tested then verification of the Advanced Load Up is not required. Steps in Table 6 use the flow rate that is determined using Table 5.

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

Table 6 Load Shift Test Steps

Step	UECD	DFWH
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.	The *DFWH* shall respond with Device Type.
4.	—	If the *DFWH* is undergoing a recovery, wait until cut-out and the *DFWH* settles. If a recovery is not occurring, draw off water at the flow rate as determined using Table 5 until a cut-in occurs. Wait until cut-out and the *DFWH* settles.
Verification of *Normal Mode of Operation*		
5.	Send Power/Demand, Current Available Energy Storage Capacity, and if possible, Current Total Energy Storage Capacity queries.	The *DFWH* shall 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 four 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.	The *DFWH* shall respond to all queries.
9.	—	If a recovery is occurring, wait until cutout and the *DFWH* settles. If a recovery is not occurring, draw off water at the flow rate as determined using Table 5 until a cut-in occurs. Wait until cut-out and the *DFWH* settles.
10.	Send Power/Demand, Current Available Energy Storage Capacity, and if possible, Current Total Energy Storage Capacity queries.	The *DFWH* shall 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 5. Stop drawing water when a cut-in occurs and wait for the *DFWH* to settle after cut-out.
12.	—	Draw off water at the flow rate as determined using Table 5. If a recovery initiated in the first draw of step 6, stop drawing water when two 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 two 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 *DFWH* to settle after cut-out, and restart this step. After a restart of this step (only when necessary) draw off one gallon less than the volume drawn immediately before cut-in during the previous iteration until a volume of water is drawn off and cut-in does not occur. Wait five minutes for each verification of no cut-in occurring.[1]

Step	UECD	DFWH
13.	Send Power/Demand, Current Available Energy Storage Capacity, and if possible, Current Total Energy Storage Capacity queries.	The *DFWH* shall respond to all queries.
14.	Send either a Basic Load Up or Advanced Load up request. Start Time = Immediately Duration = Maximum	The *DFWH* shall acknowledge the request.
15.	Send Power/Demand, Current Available Energy Storage Capacity, and if possible, Current Total Energy Storage Capacity queries.	The *DFWH* shall respond to all queries.
16.	—	If a cut-in does not occur within five minutes of sending the Basic Load Up or Advanced Load Up request, then the *DFWH* 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.	The *DFWH* shall respond to all queries.
18.	Send an Operational State query.	Acceptable responses include: “Running Heightened Grid”
19.	—	Wait for the *DFWH* 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.	The *DFWH* shall respond to all queries.
21.	Send a General Curtailment request. Start Time = Immediately Duration = four hours. If the *DFWH* cannot accommodate a request of four hours, then the duration will be set to the shortest time greater than four hours or to a duration that does not end.	The *DFWH* shall 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 four 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.	The *DFWH* shall respond to all queries.
26.	Send a Return to Normal Operation request.	—

Step	UECD	DFWH
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.	The *DFWH* shall respond to all queries.
29.	—	Wait for the *DFWH* to settle after cut-out. If a recovery does not occur after ten 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.	The *DFWH* shall respond to all queries.

Note:

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

Requirement for Table 6:

Calculate the energy content of the stored hot water in the *DFWH* as described in Section C.5.1.1.

Determine the total energy consumed during the *normal mode of 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.
- $Q_{Basic\ Load\ Up}$ = if applicable, total energy consumption, including auxiliary energy use, between step 13 and the end of step 20, Btu.
- $Q_{Advanced\ Load\ Up}$ = if applicable, total energy consumption, including auxiliary energy use, between step 13 and the end of step 20, Btu.
- $Q_{General\ Curtailment}$ = total energy consumption, including auxiliary energy use, between the start of step 20 and the end of step 25, Btu.
- Q_{Reheat} = total energy consumption, including auxiliary energy use, between the start of step 25 to the end of step 30, Btu.

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

Verify that the maximum power draw measured 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 measured in step 5.

C.4.5.2. Emergency Curtailment and Grid Emergency

Perform the test steps described in Table 7 to verify the Critical Curtailment and Grid Emergency requirements from Section 9.

For *DFWHs* 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 *DFWH* fails. For *DFWHs* that use only resistance heating elements, if any element but the top element turns on at any point during an Emergency Curtailment event, then the *DFWH* fails. For all *DFWHs*, if any energy is used to heat water during a Grid Emergency event, then the *DFWH* fails.

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

Table 7 Emergency Curtailment and Grid Emergency Verification Test Steps

Step	UECD	DFWH
1.	Send a Return to Normal Operation request.	—
2.	Send an Operational State query.	Acceptable responses include: “Idle Normal” or “Running Normal”
3.	—	If the *DFWH* is undergoing a recovery, wait for the *DFWH* to settle after cut-out.
4.	Send Power/Demand and Current Available Energy Storage Capacity queries.	The *DFWH* shall respond to all queries.
5.	Send an Emergency Curtailment request Start Time = Immediately Duration = Maximum	The *DFWH* shall 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 5. When the delivery temperature reaches 80°F continue with the next step.
8.	Send a Grid Emergency request Start Time = Immediately Duration = Maximum	The *DFWH* shall acknowledge the request.
9.	Send Power/Demand and Current Available Energy Storage Capacity queries.	The *DFWH* shall respond to all queries.
10.	—	Stop drawing water when delivery temperature drops below 60°F.
11.	Send a Return to Normal Operation request.	—
12.	Send an Operational State query.	Acceptable responses include: “Idle Normal” or “Running Normal”

Requirement for Table 7:

Calculate the energy content of the stored hot water in the *DFWH* as described in Section C.4.6.3.

If testing a *DFWH* 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 measurements that energy was not used to heat water between steps 8 and 10.

C.4.6. DR Information and Messaging

Section C.4.6.1 through Section C.4.6.5 verify the appropriate responses required in Section 9.2.

C.4.6.1. Device Type

Verify that the device type recorded in step 3 of the *load shift* test described in Table 6 of Section C.4.5.1 is the correct device type.

C.4.6.2. Operational State

The Operational State messaging is verified in Section C.4.3 through Section C.4.5

C.4.6.3. Current Available Energy Storage Capacity

Verify that a response is being received from the Current Available Energy Storage Capacity queries at steps 5, 8, 10, 13, 15, 17, 20, 25, 28, and 30 in Table 6 of Section C.4.5.1 for the *load shift* test and steps 4 and 9 in Table 7 of Section C.4.5.2 for the Emergency Curtailment and Grid Emergency test.

C.4.6.4. Current Total Energy Storage Capacity

Verify that a response is being received from the Current Total Energy Storage Capacity queries at steps 5, 8, 10, 13, 15, 17, 20, 25, 28, and 30 in Table 6 of Section C.4.5.1 for the *load shift* test and steps 4 and 9 in Table 7 of Section C.4.5.2 for the Emergency Curtailment and Grid Emergency test.

C.4.6.5. Power/Demand (Instantaneous)

Verify that a response is being received from the Power/Demand (Instantaneous) queries at steps 5, 8, 10, 13, 15, 17, 20, 25, 28, and 30 in Table 6 of Section C.4.5.1 for the *load shift* test and steps 4 and 9 in Table 7 of Section C.4.5.2 for the Emergency Curtailment and Grid Emergency test.

Verify that the Power/Demand (Instantaneous) *DFWH* responses in steps 5, 10, 13, 20, and 30 in the *load shift* test from Section C.4.5.1 and steps 4 and 9 for the Emergency Curtailment and Grid Emergency test from Section C.4.5.2 were less than the *DFWH* responses in step 15 (or step 17 in Table 6, if performed).

C.4.7. Time-of-use Scheduling

For *TOU-capable water heaters*, *TOU scheduling* instructions shall be verified using the manufacturer's product literature.

C.5. Calculations

C.5.1. Accuracy of Current Available Energy Storage Capacity

C.5.1.1. Energy Content of the Stored Water

Calculate the energy content of the stored water in the *DFWH* at steps 5, 8, 10, 13, 15, 17, 20, 25, 28, and 30 in Table 6 of Section C.4.5.1 for the *load shift* test. See Equation 1:

$$E_{Step} = V_{st}\rho C_p \bar{T}_{Step} \quad \textbf{1}$$

Where:

E_{Step} = stored energy content of the *DFWH* during a specific step, Btu.

V_{st} = stored volume of the *DFWH* as found in Section C.3, gal.

ρ = density of the stored water at $\bar{T}_{Step}$, lb/gal.

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

$\bar{T}_{Step}$ = mean tank temperature during a specific step, °F.

C.5.1.2. Energy Content of the Stored Water after Cut-out during Normal Operation

Calculate the average energy content of the *DFWH* 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 *DFWH* at steps 5 and 10 from the *load shift* test in Table 6. If the Basic Load Up request was verified, then include the calculated energy content at step 20 in the calculation. This means it is the average of three different energy content measurements if the Basic Load Up request was verified, or of two different energy content measurements if the Advanced Load Up request was verified.

C.5.1.3. Current Available Energy Storage Capacity

Calculate the Current Available Energy Storage Capacity at steps 5, 8, 10, 13, 15, 17, 20, 25, 28, and 30 in Table 6 of Section C.4.5.1 for the *load shift* test. See Equation 2. There are ten Current Available Energy Storage Capacity values.

$$AE_{C,Step} = \frac{(\bar{E}_{Setpoint} - E_{Step})}{RE_{Rated}} \quad \textbf{2}$$

Where:

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

RE_{Rated} = *rated recovery efficiency*, %.

C.5.1.4. 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 that were supplied by the *DFWH* during the *load shift* test from Section C.4.5.1. See Equation 3:

$$RMSD_{AE} = \sqrt{\frac{\sum(AE_{C,Step} - AE_{R,Step})^2}{N}} \quad \textbf{3}$$

Where:

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

$AE_{R,Step}$ = recorded Current Available Energy Storage Capacity supplied by the *DFWH* for a specific step, as stated in Section C.5.1.3, Btu.

N = number of times the Current Available Energy Storage Capacity is measured during the *load shift* test (ten times).

C.5.2. Accuracy of Current Total Energy Storage Capacity

The calculations in Section C.5.2.1, Section C.5.2.2, Section C.5.2.3, and Section C.5.2.4 are optional and only apply to *DFWH* capable of receiving and responding to Current Total Energy Storage Capacity requests.

C.5.2.1. 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 6 of Section C.4.5.1, $\bar{T}_{High}$, °F.

Calculate the energy content of the stored water in the *DFWH* at the high energy state. See Equation 4:

$$E_{High} = V_{st}\rho C_p \bar{T}_{High} \quad \textbf{4}$$

Where:

E_{High} = stored energy content of the *DFWH* at the high energy state, Btu.
V_{st} = stored volume of the *DFWH* as found in Section C.3, gal.
ρ = density of the stored water at $\overline{T}_{Low}$, lb/gal.
C_p = specific heat of stored water at $\overline{T}_{Low}$, Btu/(lb °F).

C.5.2.2. 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 6 of Section C.4.5.1, $\overline{T}_{Low}$, °F.

Calculate the energy content of the stored water in the *DFWH* at the low energy state. See Equation 5:

$$E_{Low} = V_{st}\rho C_p \overline{T}_{Low} \quad \textbf{5}$$

Where:

E_{Low} = stored energy content of the *DFWH* at the low energy state, Btu.

C.5.2.3. Current Total Energy Storage Capacity

Calculate the Current Total Energy Storage Capacity. See Equation 6:

$$TE_C = \frac{(E_{High} - E_{Low})}{RE_{Rated}} \quad \textbf{6}$$

Where:

TE_C = calculated Current Total Energy Storage Capacity, Btu.
RE_{Rated} = *rated recovery efficiency*, %.

C.5.2.4. 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 that were supplied by the *DFWH* during the *load shift* test from Section C.4.5.1 in steps 5, 8, 10, 13, 15, 17, 20, 25, 28, and 30. There are ten Current Total Energy Storage Capacity values. See Equation 7:

$$RMSD_{TE} = \sqrt{\frac{\sum(TE_C - TE_{R,Step})^2}{N}} \quad \textbf{7}$$

Where:

$RMSD_{TE}$ = root-mean-square-difference between the calculated Current Total Energy Storage Capacity and the recorded Current Total Energy Storage Capacity, Btu.
$TE_{R,Step}$ = recorded Current Total Energy Storage Capacity supplied by the *DFWH* for a specific step, Btu.
N = number of times the Current Total Energy Storage Capacity is measured during the *load shift* test (ten times).

C.5.3. Load Shift

Record whether the Basic Load Up or Advanced Load Up was performed when conducting the *load shift* test in Section C.4.5.1.

Calculate the adjustment to the energy used between the start of step 5 and the end of step 8 of the *load shift* test described in Section C.4.5.1. See Equation 8:

$$Q_{Normal,Adjustment} = \frac{E_{Step\ 8} - E_{Step\ 5}}{RE_{Rated}} \quad \textbf{8}$$

Where:

$Q_{Normal,Adjustment}$ = adjustment to the total energy consumption due to differences in the thermal energy content of the *DFWH*, between the start of step 5 and the end of step 8, Btu.

$E_{Step\ 5}$ = the energy content of the tank at the start of step 5 of the *load shift* test described in Section C.4.5.1, as calculated in Section C.5.1.1, Btu.

$E_{Step\ 8}$ = the energy content of the tank at the end of step 8 of the *load shift* test described in Section C.4.5.1, as calculated in section C.5.1.1, Btu.

RE_{Rated} = *rated recovery efficiency*, %.

If the Basic Load Up request was verified during the *load shift* test, calculate the *load shift* using Equation 9:

$$Load\ Shift = \frac{Q_{Basic\ Load\ Up} + \left(Q_{Normal} - Q_{Normal,Adjustment} - Q_{General\ Curtailment}\right)}{3412} \quad \textbf{9}$$

Where:

Q_{Normal} = as defined in Section C.4.5.1, Btu.

$Q_{Basic\ Load\ Up}$ = as defined in Section C.4.5.1, Btu.

$Q_{General\ Curtailment}$ = as defined in Section C.4.5.1, Btu.

If the Advanced Load Up request was verified during the *load shift* test, calculate the *load shift* using Equation 10:

$$Load\ Shift = \frac{Q_{Advanced\ Load\ Up} + \left(Q_{Normal} - Q_{Normal,Adjustment} - Q_{General\ Curtailment}\right)}{3412} \quad \textbf{10}$$

Where:

$Q_{Advanced\ Load\ Up}$ = as defined in Section C.4.5.1, Btu.

Note: The load shift adjustment factor does not appear in the ENERGY STAR® Connected Residential Water Heaters Test Method to Validate Demand Response, because the factor addresses accuracy associated with electric resistance water heaters. The factor is expected to be negligible for products able to meet other requirements of the ENERGY STAR® specification.

APPENDIX D. VALUES OF LOAD SHIFTING MINIMUM REQUIREMENTS – NORMATIVE

DFWHs shall be able to load shift at or above the following when tested under the conditions in Appendix C:

1) 0.25 kWh for nominal storage capacities greater than or equal to forty gallons and less than fifty gallons
2) 0.50 kWh for nominal storage capacities greater than or equal to fifty gallons and less than or equal to 120 gallons

APPENDIX E. DFWH PRODUCT LITERATURE REQUIREMENTS – NORMATIVE

DFWHs capable of performing Advanced Load Up shall provide instructions in product literature for user action required to initially enable the Advanced Load Up function.

Before advanced load up is enabled, installation instructions for *DFWHs* without a built-in thermostatic mixing valve shall prominently state that a thermostatic mixing valve certified to ASSE 1017 shall be installed. The instructions shall include, at a minimum, the following text:

> If the water heater is enrolled in a utility DR program that allows the utility to temporarily increase the storage temperature setpoint higher than set by the user, a thermostatic mixing valve shall be installed. If used, the thermostatic mixing valve shall:
>
> - Be certified to ASSE 1017 - Performance Requirements for Temperature Actuated Mixing Valves in Hot Water Distribution Systems
> - Be installed according to the manufacturer's installation instructions.
> - Be configured to limit the delivered water temperature to that required by the user.

The Advanced Load Up *DR* functionality shall not be enabled if the thermostatic mixing valve is not installed.

APPENDIX F. MIXING VALVE INSTALLATION VERIFICATION – INFORMATIVE

The utility or *consumer authorized third party* should verify that a thermostatic mixing valve certified to ASSE 1017 is installed on the hot water supply line following all manufacturer installation instructions.