

Appendix A (informative)

SOLAR UNIFORM ENERGY FACTOR PROCEDURE FOR SOLAR WATER HEATING SYSTEMS

1. **INTRODUCTION:** The U.S. Department of Energy sets uniform test methods for measuring the energy consumption of water heaters in 10 CFR 430, Subpart B, Appendix E, *Uniform Test Method for Measuring the Energy Consumption of Water Heaters* (“DOE Test Procedure”). It produces two performance values, First-Hour Rating or Maximum GPM and Uniform Energy Factor (UEF) utilizing the data collected during the prescribed tests. The DOE Test Procedure addresses water heaters utilizing electricity, natural gas, propane, and fuel oil sources. The UEF values resulting from the DOE Test Procedure permit the performance of water heaters utilizing different fuels and heating technologies to be compared on a consistent basis.
 - 1.1 The current DOE Test Procedure does not address water heaters utilizing solar energy. Therefore, this document details the additional specifications required to produce a UEF value for solar water heaters, permitting the direct comparison of the performance of water heaters utilizing solar energy with other water heating fuels and technologies.
 - 1.2 This specification defines the conditions, assumptions, methodologies and metrics for the determination of Uniform Energy Factor for water heaters directly utilizing solar energy. It does not establish minimum safety and durability requirements, which are addressed by the ICC 900/SRCC 300 standard, which is referenced by the International Building Code (IBC).
 - 1.3 Performance ratings derived per this specification are intended to provide an indicator of relative system performance under consistent installation and operating conditions. They are not intended to accurately predict actual performance, which will vary with installation, load, weather and operating conditions.
2. **REFERENCES:** This specification shall augment the information provided in 10 CFR 430, Subpart B, Appendix E, *Uniform Test Method for Measuring the Energy Consumption of Water Heaters* (79 FR 40542; July 11, 2014) (“DOE Test Procedure”).
 - 2.1 The following standards are also referenced in this specification:
 - ICC 900/SRCC 300, Solar Thermal System Standard
 - ICC 901/SRCC 100, Solar Thermal Collector Standard
 - ISO 9806-2017, Solar energy - Solar thermal collectors – Test methods

2.2 Where a conflict or difference between the DOE Test Procedure exists, this specification shall prevail.

3. DEFINITIONS: Terms associated with solar water heaters shall be as defined in ICC 901/SRCC 100, *Solar Thermal Collectors* and ICC 900/SRCC 300, *Solar Thermal Systems*.

4. SCOPE: Solar Uniform Energy Factor ratings apply to water heating systems utilizing solar energy as a source of energy in conjunction with a fueled backup (auxiliary) energy source to heat water to meet a hot water load. Auxiliary water heaters used as part of a solar water heating system shall be fueled by natural gas, propane, fuel oil or electricity.

4.1 Solar water heating systems that do not incorporate a backup heat source are outside the scope of this specification. Since they rely exclusively on solar radiation, their Uniform Energy Factor will always be infinite. Such solar water heaters may be unable to meet the hot water load, depending on local weather conditions.

5. APPROACH: Uniform Energy Factor ratings for solar water heaters may be determined either by means of laboratory testing or computer modeling as established in this specification.

5.1 ADDITIONAL TEST REQUIREMENTS: The current DOE Test Procedure assumes the test subject to be a unitary device installed within conditioned space, drawing from a constant and limitless energy source (e.g. gas, fuel oil or electricity). Solar water heaters, by definition, include a solar collector or module that is directly exposed to solar radiation outdoors and is often separated from a storage tank and/or backup water heater located indoors. Because of these differences, several assumptions made by the DOE Test Procedure must be addressed to permit the consistent rating of solar water heaters, as listed in Table 4.1.

DOE 10 CFR 430, SUBPART B, APPENDIX E	SOLAR WATER HEATERS
Constant and infinite energy supply	Time-dependent energy supply based on solar time and its relationship to the hot water draws.
Unitary equipment	Distributed equipment connected by piping (in some cases).
Insensitive to orientation	System performance is a function of collector tilt and orientation, vertical distance from collector to tanks.

Installation in controlled space	One or more components installed outdoors (e.g. solar collector/module). Tank may be installed indoors or outdoors.
Fixed efficiency	Efficiency varies with irradiance, weather, season, and time of day.

TABLE 5.1: VARIATIONS FROM DOE TEST PROCEDURE ASSUMPTIONS

5.2 Computer Simulation. Software and routines used to determine UEF ratings per this specification shall be validated against measured laboratory data.

5.3 Laboratory Testing. In addition to the measurements prescribed in the DOE Test Procedure, the additional measurements listed in Table 5.3 shall be made during the period of any testing incorporating solar as an energy source, as applicable for the type of collector used in the system. Instrumentation type, configuration and accuracy shall comply with the requirements of ISO 9806, *Solar energy – Solar thermal collectors – Test methods, Second edition* (“ISO 9806”). All other instrumentation prescribed in the DOE Test Procedure shall comply with Section 3, *Instrumentation* of the DOE Test Procedure.

5.3.1 Where testing is conducted in an indoor solar simulator, the setup, sensors, accuracy and operation of the test equipment shall comply with ISO 9806.

ITEM MEASURED	PROCEDURE & SENSORS	NOTES
Outdoor ambient air speed (u)	ISO 9806, Section 21.5	Measured in the vicinity and in the plane of the solar collector
Hemispherical irradiance (G)	ISO 9806, Section 21.1.1	Usually measured using a pyranometer.
Long-wave irradiance (E _L)	ISO 9806, 21.2	Necessary for certain types of solar thermal collectors. Usually measured using a pyrgeometer.
Outdoor ambient air temperature (T _a)	ISO 9806, Section 21.3.4	Measured in the vicinity of the collector.

TABLE 5.3: ADDITIONAL MEASUREMENTS FOR SOLAR WATER HEATERS

6. INSTALLATION: Unlike the water heaters addressed in the DOE Test Procedure, solar water heaters must be installed in whole or in part outdoors and are sensitive to orientation. Therefore, the requirements for installation in this specification have been expanded to accommodate exterior components and systems as given below. The solar water heater shall comply with all other requirements in the DOE Test Procedure, Section 4, *Installation*.

6.1 Solar collectors and modules shall be installed in accordance with manufacturer’s instructions and utilizing mounting hardware specified by the

manufacturer. When subject to system testing, collector backing shall be utilized in accordance with ISO 9806, Section 20, and the collector shall be oriented to achieve the incidence angles indicated in Table 7.4.2 of this document.

- 6.2** Solar water heating system components designed for installation indoors shall be subject to an ambient temperature of 67.5 °F (19.7 °C) for computer modeling. Where the system is subject to testing, ambient indoor air temperature shall be controlled as specified in the DOE Test Procedure.
- 6.3** The length of the piping between separable collector(s) and tank(s) shall be 25 feet (6.75 m) in each direction, with a vertical head from the solar loop pump to the top of the collector(s) of 16 feet (4.9 m). The piping type and insulation shall be as specified by the manufacturer.
- 6.4** For laboratory testing, a wind generator shall be used to produce the airspeed conditions required in this specification and shall be configured as specified in ISO 9806.
- 6.5** Supply water temperature, outlet water temperature, set point temperature, supply water pressure, and any fuel supplies shall be configured as specified in the DOE Test Procedure, Section 2, *Test Conditions*.

7. SOLAR WATER HEATER TEST PROCEDURES

7.1 Operational Mode Selection. Operational modes shall be selected per DOE Test Procedure, Section 5.1.

7.2 Solar Water Heater Preparation.

7.2.1 Determination of Storage Tank Volume. Storage volume shall be determined per the DOE Test Procedure, Section 5.2.1, with the following exceptions for solar water heaters:

7.2.1.1 Where the system includes multiple storage tanks, all storage shall be included in the storage volume determination.

7.2.1.2 Except for Integrated Collector Storage (ICS) collectors, the volume enclosed within the solar collector shall not be included in the storage volume determination.

7.2.1.3 The volume enclosed in piping between solar collectors and tanks shall not be included in the storage volume determination.

7.2.2 Setting the Outlet Discharge Temperature. Outlet discharge temperature shall be set per the DOE Test Procedure, Section 5.2.2, with the following exception:

7.2.2.1 When tested in a laboratory, solar water heaters shall be operated, exposed to the solar irradiance and weather conditions described in this specification for 24 hours before setting the outlet discharge temperature, per the DOE Test Procedure, Section 5.2.2.

7.2.3 Power Input Determination. When tested in a laboratory, the power input for auxiliary water heaters utilizing natural gas, propane, or fuel oil, shall be determined in accordance with the DOE Test Procedure, Section 5.2.3.

7.2.4 Soak-In Period for Solar Water Heaters. Solar water heaters shall be operated for at least 24 hours while exposed to the solar irradiance and weather conditions described in this specification and connected to any other power source, to achieve the nominal temperature setpoint. During this time, no hot water draws shall be conducted.

7.3 Delivery Capacity Tests.

7.3.1 Maximum GPM Rating Test for Flow-Activated Water Heaters. Maximum GPM Rating Testing per Section 5.3.2 of the DOE Test Procedure is not required for solar water heaters incorporating flow-activated water heaters.

7.3.2 First-Hour Rating Test. First-Hour Rating Testing per Section 5.3.3 of the DOE Test Procedure is not required for solar water heaters incorporating storage-type water heaters.

7.4 24-Hour Simulated Use Test.

7.4.1 Selection of Draw Pattern. Solar water heaters shall be tested or modeled using a draw pattern that is dependent on the total area of all solar thermal collectors or all photovoltaic modules supplying energy to heat water in the system. For solar thermal water heaters, the gross area of each solar thermal collector shall be determined in accordance with ICC 901/SRCC 100 and added to obtain the total gross area to be used in Table 7.4.1(a) to select the draw pattern.

For photovoltaic water heaters, the total area of all photovoltaic modules in Table 7.4.1(b) shall be used to select the draw pattern to be used.

Total solar thermal collector gross area greater than or equal to:	... and total gross area less than:	Draw pattern to be used in simulated-use test or modeling
0 square feet	24 square feet	Very-Small-Usage (DOE Test Procedure Table III.1)
24 square feet	48 square feet	Low-Usage (DOE Test Procedure Table III.2)
48 square feet	84 square feet	Medium-Usage (DOE Test Procedure Table III.3)
84 square feet	No upper limit	High-Usage (DOE Test Procedure Table III.4)

TABLE 7.4.1(a) DRAW PATTERN TO BE USED BASED ON TOTAL GROSS SOLAR THERMAL COLLECTOR AREA

Total photovoltaic module gross area greater than or equal to:	... and total gross area less than:	Draw pattern to be used in simulated-use test or modeling
0 square feet	84 square feet	Very-Small-Usage (DOE Test Procedure Table III.1)
84 square feet	168 square feet	Low-Usage (DOE Test Procedure Table III.2)
168 square feet	294 square feet	Medium-Usage (DOE Test Procedure Table III.3)
294 square feet	No upper limit	High-Usage (DOE Test Procedure Table III.4)

TABLE 7.4.1(b) DRAW PATTERN TO BE USED BASED ON TOTAL GROSS PHOTOVOLTAIC MODULE AREA

7.4.2 24-Hour Rating Test. The 24-Hour Simulated Use Test shall be conducted for solar water heaters in accordance with the requirements of the DOE Test Procedure, Section 5.4.2 or 5.4.3, as applicable, with the exceptions below:

7.4.2.1 The solar collectors or modules and any other components installed outdoors shall be subjected to the irradiance and weather profile described in Table 7.4.2. Hour 0:00 in the applicable draw profile established by the DOE Test Procedure shall correspond to a solar time of 07:00 AM in the weather profile in Table 7.4.

7.4.2.2 Solar angles should be based on a latitude of 29.5 degrees and with a collector slope of 25.6 degrees at the center of the time zone based on the autumnal equinox.

7.4.2.3 The soak-in period described above shall be completed immediately prior to the start of the 24-Hour Test. The

test shall begin at the solar time of 0:00 AM with the first draw occurring at 07:00 AM. The other prescribed draws shall occur using the same 7-hour offset between the solar time and the draw time scales.

7.4.2.4 The incidence angle of the solar irradiance on fixed solar collectors or modules shall be as described in Table 7.4. If the solar water heater incorporates a tracking mechanism designed to actively alter the orientation of the solar collector or module, it shall be operated during testing or modeling. In that case, the incident angle of the solar radiation shall be set by the solar tracker, rather than Table 7.4.

HOUR	INCIDENCE ANGLE* (degrees)	OUTDOOR TEMP.		WIND** (m/s)	SOLAR RADIATION		
		AMBIENT AIR	SKY		BEAM	DIFFUSE	GROUND DIFFUSE
		(°C)			(kJ/m ²)		
0	-	18.0	8.2	1.34	0	0	0
1	-	17.4	7.7	1.34	0	0	0
2	-	17.2	7.5	1.34	0	0	0
3	-	17.2	7.5	1.34	0	0	0
4	-	17.4	7.7	1.34	0	0	0
5	-	18.0	8.1	1.34	0	0	0
6	90.0	18.7	8.8	1.34	0	0	0
7	75.1	19.6	9.6	1.34	126	241	6
8	60.1	20.6	10.5	1.34	671	465	11
9	45.1	21.6	11.4	1.34	1158	658	15
10	30.2	22.6	12.3	1.34	1538	806	18
11	15.4	23.5	13.1	1.34	1781	899	21
12	3.3	24.3	13.8	1.34	1865	930	21
13	15.2	24.8	14.2	1.34	1781	899	21
14	30.0	25.1	14.5	1.34	1538	806	18
15	44.9	25.1	14.5	1.34	1158	658	15
16	59.8	24.8	14.2	1.34	671	465	11
17	74.8	24.3	13.8	1.34	126	241	6
18	90.0	23.6	13.1	1.34	0	0	0
19	-	22.7	12.3	1.34	0	0	0
20	-	21.7	11.4	1.34	0	0	0
21	-	20.6	10.5	1.34	0	0	0
22	-	19.6	9.6	1.34	0	0	0
23	-	18.7	8.8	1.34	0	0	0
24	-	18.0	8.2	1.34	0	0	0

TABLE 7.4 24-HOUR TEST WEATHER AND IRRADIANCE PROFILES

* Incidence angle indicates the angle of the solar radiation incident on the tilted surface of the solar collector or module.

***Wind speed is assumed to be constant and omnidirectional, in the transverse direction parallel to the plane of the collector or module as established in ISO 9806 for solar thermal performance testing.*

8. COMPUTATIONS

8.1 GENERAL

- 8.1.1** The properties of water and glycol fluids for all modeling and computations shall be as given in Table 8.1.1
- 8.1.2** Measurements for irradiance, ambient air temperature at the collector, and wind speed are conducted in order to confirm compliance with the specification established for irradiance and weather shown above and are not included in rating calculations.
- 8.1.3** Modeling of the 24-Hour Test allows the UEF to be readily calculated for each of the draw patterns established in the DOE Test Procedure. While only the determination of the UEF for the draw profile determined by solar collector or module area is required, the UEF at the other draw patterns may be determined. Where this is done, the UEF associated with the draw pattern prescribed by Table 7.4.1 shall be clearly identified as such and are the only results suitable for comparison with UEF values for other water heater types.

FLUID PROPERTY	WATER	GLYCOL
Density (ρ)	8.28 lbm/gal	8.38 lbm/gal
Specific Heat (C_p)	1.0 BTU/lb _m °F	0.8957 BTU/lb _m °F
Coefficient of Thermal Expansion	0.0003 /°F	0.0005 /°F
Absolute Viscosity	1.0692 lbm/ft-h	3.6286 lbm/ft-h
Thermal Conductivity	0.2377 BTU/h-ft-°F	0.208 BTU/h-ft-°F

TABLE 8.1.1 FLUID PROPERTIES