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Standard Guide for On-Site Inspection and Verification of Operation of Solar Domestic Hot Water Systems[1]

This standard is issued under the fixed designation E1160; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers procedures and test methods for conducting an on-site inspection and acceptance test of an installed domestic hot water system (DHW) using flat plate, concentrating-type collectors or tank absorber systems.

1.2 It is intended as a simple and economical acceptance test to be performed by the system installer or an independent tester to verify that critical components of the system are functioning and to acquire baseline data reflecting overall short term system heat output.

1.3 This guide is not intended to generate accurate measurements of system performance (see ASHRAE standard 95-1981 for a laboratory test) or thermal efficiency.

1.4 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E823 Practice for Nonoperational Exposure and Inspection of a Solar Collector (Withdrawn 2010)[3]

E1056 Practice for Installation and Service of Solar Domestic Water Heating Systems for One- and Two-Family Dwellings

2.2 *ASHRAE Standards:*

93-1986 (ANSI B198.1-1977) Method of Testing to Determine the Thermal Performance of Solar Collectors[4]

95-1981 Method of Testing to Determine the Thermal Performance of Domestic Water Heating System[4]

2.3 *NIST Standard:*

76-1137 Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program[5]

2.4 *ISO Standard:*[6]

9806 Test Methods for Solar Collectors

3. Summary of Guide

3.1 This guide recommends inspection procedures and tests for: general system inspection, collector efficiency, freeze protection, and controller and pump/blower operation.

3.1.1 Verification of satisfactory operation of these components indicates that the system is functioning. Tests are designed to take a minimum of time in preparation, testing and restoration of the system. They may use relatively inexpensive, nonintrusive instrumentation which system installers can reasonably be expected to have on hand.

3.2 Recommended tests for each component or subsystem fall into categories according to the level of complexity and cost (Note 1).

3.2.1 *Category A*—The most rudimentary tests, such as visual inspection.

3.2.2 *Category B*—Tests that require minimal instrumentation and skill.

3.2.3 *Category C*—Tests that require most expensive or sophisticated instrumentation or more time to perform.

NOTE 1—Category B tests should include Category A tests as prerequisite, etc.

3.2.4 Selection of the appropriate test is at the discretion of the tester and purchaser, who should be aware of the tradeoffs between cost and accuracy at each level of testing. The tester

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[1] This guide is under the jurisdiction of ASTM Committee E44 on Solar, Geothermal and Other Alternative Energy Sources and is the direct responsibility of Subcommittee E44.05 on Solar Heating and Cooling Systems and Materials.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from ASHRAE, 1791 Tullie Circle, N.E., Altanta, GA 30329.

[5] Available from National Institute of Standards and Technology, Gaithersburg, MD 20899.

[6] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

should make these clearly known to the purchaser of the system who may wish to assume the costs of more sophisticated testing (Note 2). Preferably there should be a part of the installation contract between the tester and purchaser spelling out test specifics (for example, Category A, B or C for each subtest).

NOTE 2—Consult your local National Balancing Bureau or Associated Air Balance Council.

3.3 Instrumentation includes sensors to monitor some or all of the following conditions:

3.3.1 Total incident solar radiation (in the plane of the collector array),

3.3.2 Outdoor ambient temperature,

3.3.3 Internal building temperature near storage system,

3.3.4 Collector loop flow rate and temperatures, and

3.3.5 Storage temperature.

3.3.6 Each system should be instrumented to the practical level required for calculation (see NIST standard 76-1137 for another method to instrument and evaluate solar systems). Some sites may need additional instrumentation as a result of their unique requirements. Fig. 1 shows a typical closed loop system with the instrumentation required for the various tests.

3.4 The various types of available instrumentation are listed in Tables 1-4. Approximate cost ranges, accuracy and application information are given. Most of the necessary instruments are presently used in conventional heating and air conditioning work except the pyranometer or solar radiation flux-measuring instruments.

4. Significance and Use

4.1 This guide is intended for on-site assessment of in-service operation by short term measurement of appropriate system functions under representative operating conditions.

4.2 Primary application is for residential systems and medium-size multi-family units or commercial buildings. Use of back-up conventional DHW heating system is assumed to augment solar heating.

4.3 This guide is intended for use by suppliers, installers, consultants and homeowners in evaluating on-site operation of an installed system. Emphasis is placed on simplified measurements that do not require special skills, intrusive instrumentation, system modification or interruption of service to the purchaser.

4.4 The purpose of this guide is to verify that the system is functioning. Copies of all data and reports must be submitted by the testing group to the owner or his or her designated agent.

4.5 Data and reports from these procedures and tests may be used to compare the system performance over time, but should not be used to compare different systems or installations.

4.6 Test is for a newly installed system and also for periodic checking.

5. Procedures

5.1 *Preparation:*

5.1.1 Install and operate components and controls in accordance with manufacturer's instructions.

5.1.2 Use temporary portable instrumentation or any permanent instruments installed for continuous monitoring to evaluate system performance as long as accuracy is ±2 % of full scale and reproducibility is ≥5 % and instrumentation is installed properly in accordance with manufacturer's instruction.

5.1.3 Operate the system in a normal and satisfactory manner for several days before the on-site performance test. Operate the entire system at a nearly steady-state condition for

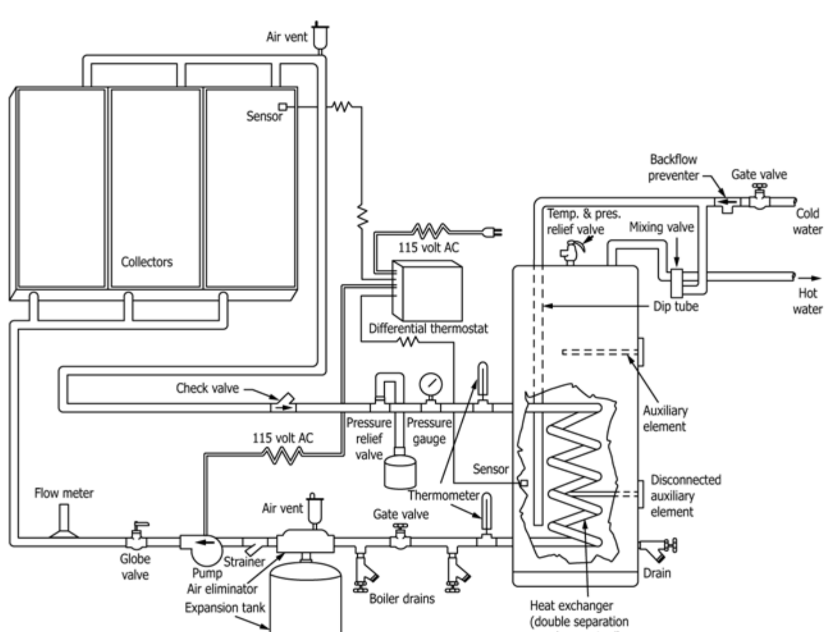

FIG. 1 Closed Loop System—One Tank

TABLE 1 Solar Radiation Probes

Type of Sensor	Approximate Cost (dollars)	Accuracy	Type of Output	Special Comments
Pyranometer	150 to 1000	1–3 % of instantaneous value	Analog electrical millivolt output, may need amplifier	Mounting point must be unshaded; some models increase error increase error by tilting
Integrating pyranometer	150 to 1000	5 % of integrated value	Mechanical totalizer (and analog electrical on some models)	Some models provide instantaneous reading
Photovoltaic solar cell	25 to 150	±5 % of instantaneous value	Analog	Drift or degradation over long periods

TABLE 2 Thermal Sensors

Type of Sensor	Approximate Cost (dollars)	Accuracy	Convenience	Type of Output	Special Comments
Bi-metallic thermometer	25 to 50	High; 1 % or less of full scale	Good, when installed correctly	Visual	Not reliable for differential temperatures, time lag present; clip on type available
Bulb type thermometer	25	High	Difficult to read because of small scale	Visual	Very fragile
Digital thermometer	100 +	Depends on type of probe(s), typically 0.5°C (1°F)	Excellent, one indicator can serve several locations (probes)	Visual (digital)	Probes typically cost $50
Thermocouple	25 to 30	Fair, 1°C (2°F)	Excellent when coupled with indicator	Analog (electrical)	Not reliable for measuring temperature differences; requires special wire for installation
Resistance temperature detectors (HTD)	60	High 0.25°C (0.5°F) or better	Excellent when coupled with indicator	Analog (electrical)	Especially suited for measuring temperature differences
Thermistors	1 to 30	Good, 0.5°C (1°F)	Excellent when coupled with indicator	Analog (electrical)	Not available in proper housing; can be damaged
Tapes	2 to 3	Fair, 1–3°C (2–5°F) steps	Excellent, reusable	Visual	Inexpensive

TABLE 3 Liquid Flow Sensors and Indicators

Type of Sensor	Approximate Cost (dollars)	Accuracy	Convenience	Type of Output
Pressure gages	50	Strictly a flow indicator	Low	Visual
Float type	30	Fair, + 5 % full scale accuracy	Moderate	Visual

TABLE 4 Air Flowmeters

Type of Sensor	Approximate Cost (dollars)[A]	Accuracy	Type of Output	Special Comments
Hot wire anemometer	600 to 1000	Moderate, 2 % of full scale; recalibration necessary	Analog (electrical)	Some models easily damaged by debris and improper handling; must be properly located in order to determine mean flow
Turbine	300	Good, 1 % of flow	Analog (electrical)	Must be properly located in order to determine mean flow
Pitot tube	300	Fair, 1 to 5 %	Visual or analog (electrical)	Standard for measuring duct velocities

[A]Includes readout device or transmitter.

at least a 2-h period before testing. Conduct tests for collector effectiveness under clear, sunny conditions.

5.2 *General Inspection:*

5.2.1 The ability to perform as intended for the specified period of time defines system durability and reliability. System performance depends on the proper operation of each of the subsystems. The manual containing drawings, specifications, and engineering data shall serve as a benchmark for the inspection.

5.2.2 The following components should be inspected for proper installation (see Practice E1056) and operation to check for any malfunctions, leaks or improper adjustments. See Ref (1) for an Installation Checklist.

5.2.2.1 Collectors and connections,

5.2.2.2 Controls and sensors,

5.2.2.3 Insulation,

5.2.2.4 Interconnections—mechanical and electrical,

5.2.2.5 Pumps and motors,

5.2.2.6 Valves and fittings,

5.2.2.7 Storage containers and media,

5.2.2.8 Heat exchangers,

5.2.2.9 Dampers and ducting,

5.2.2.10 Air or liquid systems leaks,

5.2.2.11 Interrelated support systems, including other air handlers, chillers, heaters, or heat pumps, and

5.2.2.12 Fans and air handlers.

5.2.3 Most of the failures reported have been in the collector subsystem and connections and controls with considerably fewer failures reported for valves and pump subsystems. There has been a high incidence of improper system operation due to controls improperly connected or adjusted.

5.2.4 A visual inspection should be made of all connections (see Practice E1056, 6.7.6) to check for evidence of leaks or potential future corrosion due to improper use of materials (Practice E1056, 6.7.2), improper joining of dissimilar metals (Practice E1056, 6.7.14), or improper fluids (Practice E1056, 6.5). See Ref (**2**) for a leak check on air systems. A pressure check on liquid systems should be done to see if it meets manufacturer's recommendations.

5.2.5 Check pumps for noise (most pumps are very quiet). Noisy fluid flow almost always indicates a bad pump, cavitation or air in the system and is symptomatic of further problems. In an open or drainback system noisy fluid flow will occur if there is water loss due to leakage. If a pump problem is suspected, one way to determine if the pump is seized or has other electrical problems is to touch the assembly to see if it is hotter than the fluid circulating through it. Also any burning odors may indicate electrical problems.

5.3 *Collector Operation and Effectiveness* (See Practice E823, ISO 9806, and ASHRAE Standard 93-1986 for other tests). Table 5 gives the typical operating ranges of the test parameters for various collector system configurations.

6. Test Level A—Visual Inspection

6.1 *Procedure*—Turn on system, observe the pump or blower comes on with sunshine available. Temperature on return line from collector should be slightly warmer (about 5°C (10°F)) than the supply line to the collector. This can be determined by feel or by temperature gages (see Table 2) if installed. The return temperature should also show a gradual increase during daylight hours (will fluctuate depending on water usage).

6.2 *Interpretation and Report of Results*—If temperature rise is unreasonable (too little or too much—see 6.1) check pump or blower for proper operation and fluid level in system.

7. Test Level B—Estimation of Flow Rates

7.1 *Procedures:*

7.1.1 In indirect system, record total head (discharge pressure-suction pressure), and establish flow rate using intersection of system curve with blower curve provided by manufacturer (see Fig. 2 correct for antifreeze percentage). See Ref (**2**) for more information.

7.1.2 In-direct or open system measure discharge pressure with drain valve and makeup valve closed. Then open makeup valve, turn on pump and adjust the drain valve until the pressure is the same as in 7.1.1 (see Fig. 3 for operating point).

7.2 *Instrumentation*—A pressure gage (see Fig. 4 and Table 3), a stopwatch, and a container may be needed for this test.

7.3 *Interpretation and Report of Results*—The system should be providing 7 to 27 cm^3/m^2s (0.01 to 0.04 gpm/ft^2) of collector or as specified in operating manual.

8. Test Level C—Measure Radiation and Temperature Changes (See Ref (**3**) for similar test)

8.1 *Procedure:*

8.1.1 Measure radiation (q) with pyranometer. To get steady state, read every 15 min until two consecutive values are the same within 5 %. Record readings, once at steady state, every 15 min for 2 h. Measure collector inlet (T_{in}) and outlet temperatures (T_{out}) every 15 min for 2 h (may need to close off makeup water and backup heater for duration of test. Use flow rates from Test Level B or use flow meters for fluid flow rate (Q).

8.2 *Instrumentation:*

8.2.1 Use pyranometer or solar cell (see Table 1).

8.2.2 Use thermometer or other device in accordance with Table 2. Probes or strap-on sensors should be at collector inlet and outlet as close to collectors as possible.

8.2.3 Use flow meters or data from Level B test (see Table 3 or Table 4).

8.3 *Interpretation and Report of Results:*

8.3.1 Efficiency of the collecting system can be calculated by the following equation (Note 3):

$$N = Q \times d \times 120\,(\text{min}) \times S_h \times (T_{out} - T_{in})/q \times A \times 2\,(h) \quad (1)$$

SI:

$$N = Q \times d \times S_h \times (T_{out} - T_{in})/q \times A \quad (2)$$

TABLE 5 Parameters of Solar Domestic Hot Water Systems

System Type	Flow Rate, $cm^3/m^2·s$ ($gal/min·ft^2$)	Temperature Rise, On, °C (°F)	Temperature Rise, Off, °C (°F)	Specific Heat, W·s/g·°C (Btu/lb·°F)	Density, g/cm^3 (lb/gal)	Solar Radiation, Minimum, W/m^2 ($Btu/h·ft^2$)
Flat Plate:						
draindown	7–27 (0.01–0.04)	5–11 (10–20)	0.5–3 (1–5)	4.2 (1.0)	1 (8.25–8.33)	630 (200)
drainback	7–27 (0.01–0.04)	5–11 (10–20)	0.5–3 (1–5)	4.2 (1.0)	1 (8.25–8.33)	630 (200)
closed loop	7–27 (0.01–0.04)	5–11 (10–20)	0.5–3 (1–5)	3.35 (0.8)	1 (8.25–8.33)	630 (200)
thermosyphon	...	... ...	... ...	4.2 (1.0)	1 (8.25–8.33)	630 (200)
Air	25 $L/m^2·s$ (5 $ft^3/min·ft^2$)	11–22 (20–40)	0.5–11 (1–20)	0.8 (0.2)	0.005 (0.29)	630 (200)
Tank Absorber	14 (0.02)	... ...	... ...	4.2 (1.0)	1 (8.25–8.33)	630 (200)
Concentrating Type:						
parabolic trough	14 (0.02)	5–11 (10–20)	0.5–3 (1–5)	3.35 (0.8)	1 (8.25–8.33)	630 (200)
evacuated tube	7 (0.01)	17–22 (30–40)	0.5–3 (1–5)	3.35 (0.8)	1 (8.25–8.33)	630 (200)

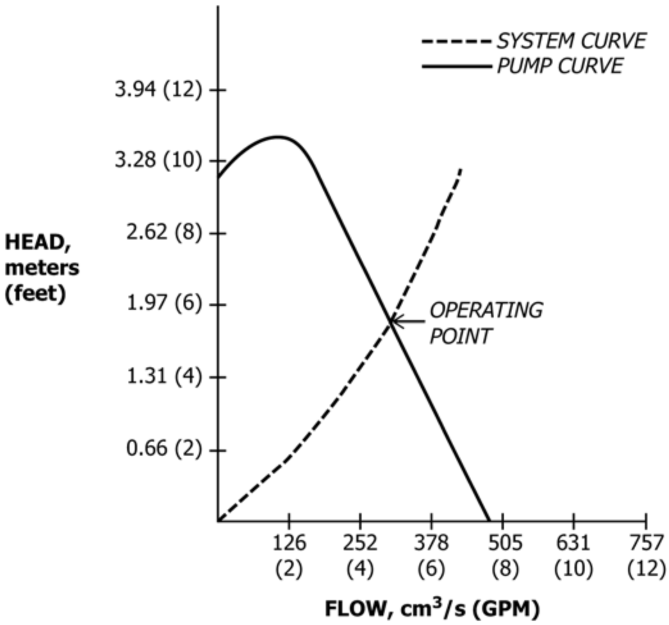

FIG. 2 Pump And System Curves (Closed Loop)

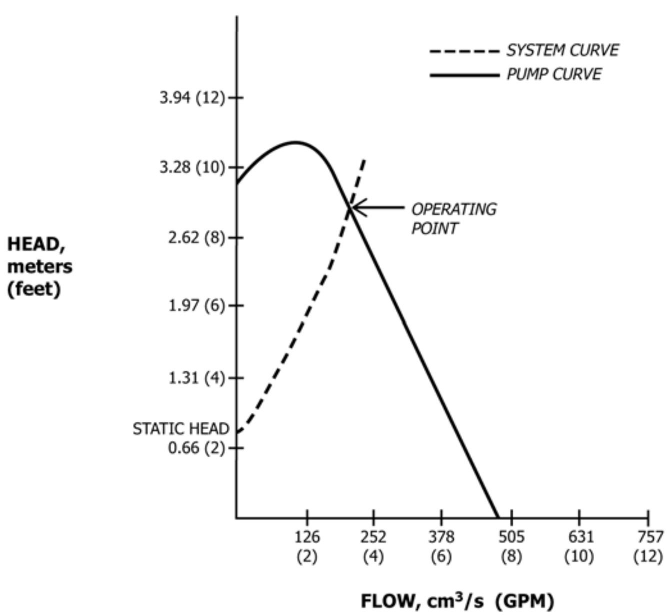

FIG. 3 Pump And System Curves (Open Loop)

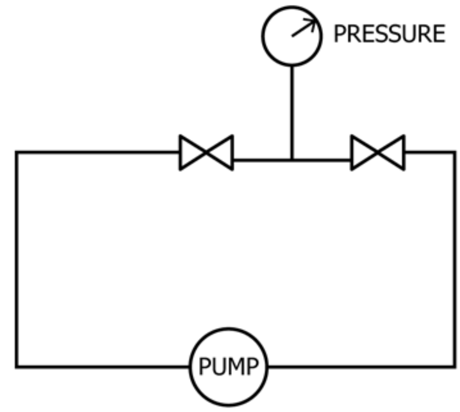

FIG. 4 Pressure Gage

where:

N = collector efficiency,
Q = collector fluid flow rate, cm^3/s (gal/min),
d = density of collector fluid, g/cm^3 (lb/gal), (water = 8.33 at 68°F, 8.25 at 120°F (1 g/cm^3)),
S_h = specific heat of collector fluid, Btu/lb × °F (water = 4.2 W·s/g°C (1.0 BTU/lb°F)),
q = total solar radiation, W/m^2 [5] (Btu/h × ft^2),
A = area of collector, m^2 (ft^2),
T_{out} = average collector fluid temperature[7] at collector outlet, °C (°F), and
T_{in} = average collector fluid temperature[7] at collector inlet, °C (°F).

NOTE 3—For tank absorber measure increase in tank temperature over 2 h (gal × d × S_h × (T_{out} − T_{in}).

8.3.2 Efficiencies should be greater than 30 %. If flow rate or temperature rise is too low, efficiency should be low—look for system defects. A plot of efficiency versus $[(T_{in} - T_{amb})/q]$ can be compared to ASHRAE 93-1986 curves Ref **(4).**

FREEZE PROTECTION

9. Test Level A—Visual Inspection

9.1 *Procedure:*

9.1.1 For indirect or air system, make sure that system cannot thermosyphon through the heat exchanger when the outside temperature is below 0°C (32°F) (for example, presence of check valve or damper).

9.1.2 In drainback or draindown systems check location of sensors and valves pertaining to freeze protection. Make sure all outside collector array piping is sloped for proper drainage. See Ref (**5**) for drain valve failure data.

9.1.3 For evacuated tube collectors consult manufacturer's instructions regarding freeze protection devices.

9.1.4 For tank absorber and thermosyphon systems secure for freezing season.

9.2 *Interpretation and Report of Results:*

9.2.1 If elements are not there for freeze protection add them or make appropriate corrections.

[7] Average of 15-min readings for the 2-h period.

10. Test Level B

10.1 *Procedure:*

10.1.1 If antifreeze is used in closed system, check, with hydrometer, that mixture contains the correct percentage of antifreeze.

10.1.2 If an open system, turnoff power and make sure system drains down or back. Also verify that the system will drain when temperature is below 5°C (40°F), test freeze protection by directing stream of cold gas from a CO_2 or compressed air cartridge or sensor.

10.2 *Instrumentation:*

10.2.1 Hydrometer and Thermometer.

10.3 *Interpretation and Report of Results:*

10.3.1 Add correct antifreeze if needed, adjust sensor control so that valve opens at or near 5°C (40°F) or replace if nonadjustable snap switch. Make sure sensor is attached at correct location and is secure.

CONTROLLER

11. Test Level A (Visual)

11.1 *Procedure:*

11.1.1 Locate attachment points for all sensors. Collector sensors should be screwed or bolted directly to the collector absorber plate or immediately outside the housing on or in the collector inlet and outlet pipes. Tank sensors must be attached to wall or tank or on collector supply pipe immediately adjacent to tank (differential control sensor should be near bottom of tank). Sensors should be insulated from external environment to correctly read intended temperatures. Verify collector sensor is properly insulated. Trace sensors back to controllers, where possible, to make sure wire is insulated, in good shape, and is tagged plus routed to correct location on controller. Inspection should be made of all splices especially where short sensor wires attach to long wires going to the controller. Corroded splices will give wrong readings. Turn on controller, make sure there is power to the control board and that electronics are functioning properly.

11.2 *Interpretation and Report of Results:*

11.2.1 Correct any deficiencies in the sensor locations or condition.

12. Test Level B

12.1 *Procedure*

12.1.1 Controller should be matched with appropriate sensor, either 3K, 10K, or 30K. Perform a resistance check on sensors. A reading of zero ohms indicates a short and a reading of infinite ohms indicates an open sensor or open snap switch in series (consult manufacturer's instructions before using ohmmeter). Typical correct thermistor sensor resistances are:

Temperature	3K Sensor, Ω	10K Sensor, Ω	30K Sensor, Ω
0°C (32°F)	10 000	32 600	97 890
25°C (77°F)	3 000	10 000	30 000
93°C (200°F)	250	830	2 480

12.2 *Instrumentation:*

12.2.1 Ohmmeter.

12.3 *Interpretation and Report of Results:*

12.3.1 Correct wiring by locating reasons for shorts or open wires. Make sure resistances comply with the table in 12.1.1 or with manufacturer's data (Note 4). See Ref (**5**) for data on sensor temperature response.

12.3.2 If pump fails to start, jump collector sensor terminals in differential controller. If pump still does not start, verify that tank is not at high limit and adjust if necessary. If pump still does not start, troubleshoot collector sensor.

NOTE 4—Nominal 1000-Ω or 2000-Ω resistance temperature detectors (RTD) or other sensors will have similar calibration points.

13. Test Level C

13.1 *Procedure:* (See Ref (**6**))

13.1.1 With differential controller in Auto or equivalent position check that pump starts if temperature at collector is 5 to 22°C (10 to 40°F) hotter than storage (Note 5). Also confirm that pump shuts off when collector outlet temperature for liquid systems is 0.5 to 3°C (1 to 5°F) more than storage temperature of 0.5 to 11°C (1 to 20°F) for air systems. This can be done by checking temperature readings during typical collection day or by using a test box furnished by manufacturer.

NOTE 5—Proportional controller or other controller features should be checked in accordance with the manufacturer's instructions.

13.1.2 If pump fails to start check continuity of pump power line input. If okay, next check ac input to controller (120 V ac) with controller ON. If the ac input voltage is correct, but the ac output voltage (to pump) is not, replace the controller. If the ac input and output voltages are correct, and the pump does not run, then the pump or wiring to it may be faulty.

13.2 *Instrumentation:*

13.2.1 Voltmeter and temperature readouts (either in controller or in line).

13.3 *Interpretation and Report of Results:*

13.3.1 Either repair or replace faulty components. Adjust, if feasible, controller so that pump turns on and off at correct temperature intervals 8 to 22°C (15 to 40°F) ON, 0.5 to 3°C (1 to 5°F) OFF (Note 6). See Ref (**5**) for deviations beyond specified limits of controllers.

NOTE 6—ON-OFF temperature settings should be within manufacturers' specification.

14. Keywords

14.1 collector; controller; freeze protection; on-site inspection; solar domestic hot water system; verification of operation

APPENDIX

(Nonmandatory Information)

X1. RATIONALE

X1.1 On-site performance measurements and acceptance criteria are required after system installation to ensure that the system is operating as advertised or as specified. Short-term determination of system performance can be used to certify operation. Ongoing evaluation or checks on system operation may be needed to make certain that the system is operating properly and remains adjusted for best performance.

X1.2 Demonstration programs have shown that poor system performance can sometimes be attributed to errors in installation or non-functioning components or subsystems. Because SHW systems have backup from conventional heaters, there is no obvious and immediate sign of problems or failure to function—hot water will be delivered to the tap in any case.

X1.3 More sophisticated tests and measurements of long-term thermal performance and efficiency may be needed. Given the current state of the art, such tests would be costly and time consuming to perform and would entail disruption of service and invasion or modification of the system. The inspection procedures and tests in this guide have been selected because of their potential for economy and simplicity.

X1.4 Although designed as an acceptance test, the procedure may be repeated at a future date, or at regular intervals, to verify acceptable system operation and to compare overall short-term system heat output to the baseline figures established at the time of installation.

REFERENCES

(1) Hollander, P. E., "Installation Guidelines for Solar DHW Systems in One- and Two-Family Dwellings," Franklin Research Center, U.S. Government Printing Office, April 1979.

(2) Procedural Standards for Testing Adjusting Balancing of Environmental Systems, National Environmental Balancing Bureau, Vienna, VA.

(3) Johnson, D. L., and Janich, D. M., "Procedures for Acceptance Testing of Solar Energy Systems," *CERL Technical Report E-192*, U.S. Army Corps of Engineers, Champaign, IL. April 1984.

(4) Kendall, P. W., and Logee, T. L., "Component Report Performance of Solar Collector Arrays and Collector Controllers in the National Solar Data Network," July 1984.

(5) Farrington, R. B., "Component Reliability and Control System Testing," *DOE/CONF-850388* , Washington, DC, March 1985.

(6) Durlak, E. R., "Preventive Maintenance: Solar Energy Thermal Systems," *Techdata Sheet 84-14, NCEL*, August 1984.