ICC 901/SRCC 100-20xx

Minimum Standards for Solar Thermal Collectors
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CHAPTER 1
APPLICATION AND ADMINISTRATION

SECTION 101
GENERAL

101.1 Purpose. This standard sets forth minimum durability, construction, performance criteria and procedures for characterizing the thermal performance and indicating the durability of solar collectors used in applications such as swimming pool heating, space heating, cooling and water heating.

SECTION 102
SCOPE

102.1 Scope. This standard applies to solar thermal collectors utilizing a fluid for the heat transfer. The standard sets forth minimum requirements for durability, construction and performance testing and provides the methodology and means for evaluating the durability and performance of tested solar thermal collectors.

103 REFERENCED DOCUMENTS

103.1 Reference documents. The codes and standards referenced in this standard shall be considered part of the requirements of this standard to the prescribed extent of each such reference. Chapter 5 contains a complete list of all referenced standards.
CHAPTER 2 DEFINITIONS

201 GENERAL

201.1 General. For the purpose of this standard, the terms listed in Section 202 have the indicated meaning.

201.2 Undefined terms. The meaning of terms not specifically defined in this document or in referenced standards shall have ordinarily accepted meanings such as the context implies. Where a definition does not appear herein, informative reference is made to ISO 9488.

201.3 Interchangeability. Words, terms and phrases used in the singular include the plural and the plural the singular.

202 DEFINED TERMS

ABSORBER. That part of the solar collector that receives the incident solar radiation and transforms it into thermal energy. It usually is a solar surface through which energy is transmitted to the transfer fluid; however, the transfer fluid itself could be the absorber in certain configurations.

ABSORBER AREA. The maximum area in which concentrated or un-concentrated solar radiation is admitted and converted to heat or power. Absorber Area does not include portions of the absorber/receiver where light is permanently screened and thermal barriers are in place.

ACTIVE CONTROLS. Control and actuator systems where external power and a computational device is used for operation and safety control purposes.

AMBIENT AIR. The air in the vicinity of the solar collector.

APERTURE AREA. The maximum area projected on a plane perpendicular to the optical normal through which the un-concentrated solar radiant energy is captured. In a concentrating collector, these areas are excluded: 1) any area of the reflector or refractor shaded by the optical elements (such as a secondary reflector or receiver); 2) structural elements such as supports; and 3) gaps between reflector segments within collector module.

AVAILABLE ENERGY. The time-integrated solar irradiance.

COLLECTED ENERGY. The product of the fluid mass, specific heat and integrated temperature gain across the collector.

COLLECTOR ENCLOSURE. The structural frame which supports the components of the collector and protects internal components from the environment.
COMBINED ASSEMBLY. A solar collector with one or more subcomponents that are not physically attached within a common structure or assembly at the point of manufacture, but are assembled in the field. Once assembled, collector modules shall not vary in geometry and performance from design specifications. A combined assembly would generally be comprised of subcomponents, each with individual nameplates and serial numbers, and may be shipped from separate facilities and manufacturers to a common location for final assembly. A building integrated collector system that requires specific shared external components for normal operation may be an example of a combined assembly.

COMPLETE ASSEMBLY. A solar collector designed and constructed as a permanent, single unit. Complete assemblies cannot be physically separated for normal operation and would generally carry a single nameplate and serial number. A single parabolic trough with mounted receiver and tracking frame is an example of a complete assembly.

CONCENTRATING PHOTOVOLTAIC (CPV): A solar collector which uses optical elements (such as lenses or mirrors) to concentrate sunlight onto high-efficiency solar cells to generate electrical energy.

CONCENTRATING THERMAL COLLECTOR. A solar collector that uses optical elements to concentrate solar energy onto an absorber. Concentrating collectors include flat plate and tubular collectors with mirrors.

CONCENTRATION. The direction of a quantity of solar insolation greater than normal incident insolation onto a solar collector absorber surface.

CONCENTRATOR. The concentrator is that part of the concentrating collector which directs the incident solar radiation onto the absorber.

CORROSION. The deterioration of a substance or its properties caused by a chemical or electrochemical reaction with its environment.

COVER PLATE. The material or materials covering the absorber. These materials generally are used to reduce the heat loss from the absorber to the surroundings and to protect the absorber. In some collector designs, materials in the shape of a tube may serve as a cover plate by enclosing the absorber. (See Transparent Covers)

CRAZING. Formation of minute surface cracks.

DELAMINATION. Separation into constituent layers, as in one layer of material separating from another.

DESIGN LIFE. Period for which a collector is expected to function at its designated capacity without major repairs.

DEGRADATION. Leading to significant permanent loss of collector performance and/or leading to elevated risk of danger to life, limb or product. “Repeated exposure” is
defined as a minimum total of 1000 hours/year at stagnation conditions during the design life

Modes of degradation shall include, but are not limited to:

- Outgassing from coatings or insulation that results in harmful deposits or significant structural failure or significant reduction in insulation value.

- Structural weakening with permanent failure, melting, charring, ignition, etc. of wooden or polymer components exposed to temperatures greater than documented limits

- Release of undesirable compounds from the wall of the fluid passageway into the heat transfer fluid.

**DISTRIBUTED ASSEMBLY.** A solar collector using subcomponents which are not physically attached to one another or a common structure. When fully assembled, the geometry of the assembly may vary from module to module due to customization of design or installation. Distributed assemblies have the potential to be scaled by subcomponent count and system geometry without changes to actual subcomponent specifications. An example of a distributed assembly would be a central receiver design where layout or count of heliostats can vary while the central receiver, and individual heliostat module designs and specifications remain fixed.

**DRY COLLECTORS.** Collectors where heat transfer fluid is not shared with other external components as part of a heat transfer loop.

**FAIL-SAFE.** An operating condition of a collector, where collector protection functions will continue under all collector and system failure modes.

**FLAT-PLATE COLLECTOR.** A solar collector (either liquid or air) in which the surface absorbing the incident radiation is essentially flat and employs no concentration. However, in this document the term refers to all collectors designed to perform satisfactorily with all parts of the collector in fixed positions.

**FLUID.** A substance that can flow and does not maintain a fixed shape. Gases and liquids are considered fluids.

**GROSS AREA.** The maximum projected area of the complete module, including integral mounting means.

**HAIL.** Precipitation in the form of small balls or lumps, usually consisting of concentric layers of clear ice and compact snow.

**HEAT TRANSFER FLUID.** Air, water, or other fluid that is used to transfer thermal energy between collectors and other components in a system.
INCIDENT ANGLE MODIFIER (IAM). The measurement of changes in collector efficiency as a function of the angle at which light enters the aperture.

INSTANTANEOUS EFFICIENCY. The amount of energy removed by the transfer fluid over a given measuring period divided by the total incident solar radiation onto the gross collector area during the measuring period.

INTEGRITY OF CONSTRUCTION. Those physical and mechanical properties of the solar collector which collectively are responsible for the overall thermal performance and physical structure of the solar collector.

IRRADIANCE. The rate of solar radiation received by a unit surface area in unit time. Irradiance is expressed in Btu per hour square ft. (Btu/hr-ft.²) (Watts per square metre (W/m²)).

IRRADIANCE, BEAM. The rate of solar radiation from a narrow angle comparable to the size of the solar disc received by a unit surface area in unit time.

IRRADIANCE, DIFFUSE. Scattered radiation falling on a surface from any point above the horizontal plane.

IRRADIANCE, GLOBAL. Hemispherical irradiance on a horizontal surface.

IRRADIANCE, HEMISPHERICAL. The sum of direct and diffuse irradiance.

MODEL. A unit of solar equipment that is identifiable by a specified size, set of materials, and performance. A change in any of these basic characteristics constitutes a new model.

NO-FLOW CONDITION. Condition where thermal energy is not transferred from the collector by means of heat transfer fluid flow.

NON-CONCENTRATING SOLAR THERMAL COLLECTOR. A solar collector with no optical elements that redirect incident solar radiation onto an integral flat absorber.

NORMAL SOLAR ANGLE, GEOMETRIC. An imaginary line perpendicular to the surface of an optical medium. The word normal is used here in the mathematical sense, meaning perpendicular.

OPTICAL NORMAL SOLAR ANGLE. The angle at which the sun is perpendicular to each axis of the solar collector optical plane, as determined by the manufacturer. The aperture optical plane can be characterized as an invisible datum plane that may or may not be orthogonal to or have any symmetrical relationship to the aperture, reflecting elements, heat collecting apparatus, or the solar collector system frame. An optical based definition of the normal solar angle is required when the collector is geometrically asymmetrical or has a tailored and non-symmetrical solar response. The manufacturer will define the normal solar angle and must provide a point of reference for proper mounting of the product.
OUTGASSING. The generation of vapors by solar collector components or construction materials - usually occurring during periods of solar collector exposure to elevated temperatures and/or reduced pressure.

PASSIVE. An operating condition of a solar concentrating collector where no human or mechanical intervention is required for operation as intended.

PASSIVE CONTROLS. Control and actuation systems where no external energy source is required and no computational device is used.

PITTING. The process by which localized material loss is caused in materials or components by erosion, corrosion, or chemical decomposition.

POWER. The amount of energy produced over time, expressed as watts or Btu per hour.

PYRANOMETER. A radiometer used to measure the total solar irradiance (direct, diffuse, and reflected) incident on a surface.

RECEIVER. The part of the solar collector to which the solar irradiance is finally directed or redirected, including the absorber and any associated glazing through which the redirected energy must pass.

REFLECTOR OR REFLECTIVE SURFACE. A surface intended for the primary function of reflecting radiant energy.

SITE DEPENDENT COLLECTOR. A collector intended to be assembled only at the site of its application because the fully assembled size of the collector or other construction characteristics make delivery in operational form impractical.

SOLAR THERMAL COLLECTOR. A device designed to absorb solar radiation and to transfer the thermal energy so produced to a fluid passing through it.

TRACKING SOLAR COLLECTOR. A solar collector that moves so as to follow the apparent motion of the sun. Tracking may be accomplished by rotation about a single axis in the transverse direction for tracking the sun through the day or by longitudinal adjustment. Two axis tracking may be employed to precisely track the sun in both the longitudinal as well as transverse axes.

TRANSPARENT COVER. Material covering the absorber.

SOLAR ENERGY. Energy originating from the sun’s radiation primarily encountered in the wavelength region from 0.3 to 3.0 micrometers.

STANDARD. A document which specifies the performance, durability, or safety requirements of a product.

THERMAL EFFICIENCY. Is the ratio of thermal energy removed from a collector to the available solar energy falling upon collector area.
**TIME CONSTANT.** The time required for the fluid leaving a solar collector to attain 63.2% of its steady state value following a step change in solar radiation or inlet fluid temperature.

**TRANSFER FLUID.** A medium such as air, water, or other fluid which passes through or comes in contact with a system component (e.g. the solar collector) and carries thermal energy to another component.

**WET COLLECTOR.** A concentrating collector where thermal subcomponents share a common heat transfer fluid with and are part of a fluid circuit with external components.
CHAPTER 3 GENERAL REQUIREMENTS

301
GENERAL

301.1 Collector standards. This chapter establishes minimum requirements for durability in collector design and construction.

302
COVER

302.1 General. Collector covers shall comply with Sections 302.1.1 through 302.1.3.

302.1.1 Tempered glass. Where the outer cover is flat, and constructed of glass, the glass shall be tempered in accordance with ASTM C1048. Testing in accordance with this section shall not be required when tempered glass is used.

302.1.2 Non-glass and non-tempered glass. The outer cover of the test specimen shall be tested in accordance with ISO 9806-2, paragraph 12. Where the outer cover is not flat, the impact shall be perpendicular to the curvature. All optical elements of the collector shall withstand impacts without adverse effect on operation or performance.

302.1.2.1 Impact resistance rating. For non-glass and non-tempered glass collector covers, the results of tests conducted in 302.1.2 shall be used to rate the impact resistance of the cover using the following scale. Tempered glass covers shall be given a scale rating of 11.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Minimum height at which the cover sustains damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No test has been conducted</td>
</tr>
<tr>
<td>1</td>
<td>0.4 meter (1.3 ft)</td>
</tr>
<tr>
<td>2</td>
<td>0.6 meter (2.0 ft)</td>
</tr>
<tr>
<td>3</td>
<td>0.8 meter (2.6 ft)</td>
</tr>
<tr>
<td>4</td>
<td>1.0 meter (3.3 ft)</td>
</tr>
<tr>
<td>5</td>
<td>1.2 meter (3.9 ft)</td>
</tr>
<tr>
<td>6</td>
<td>1.4 meter (4.6 ft)</td>
</tr>
<tr>
<td>7</td>
<td>1.6 meter (5.3 ft)</td>
</tr>
<tr>
<td>8</td>
<td>1.8 meter (5.9 ft)</td>
</tr>
</tbody>
</table>
303
CONденSATION

303.1 General. The collector shall be designed to prevent condensate build-up. The use of desiccants to control condensation shall be permitted. Test reports shall note any unusual condensate build up during any point in the testing.

304
PRESSURE TEST REQUIREMENTS

304.1 General. Pressure test results shall comply with Sections 304.1.1 through 304.1.2.

304.1.1 Liquid. A collector, after testing, shall be considered passable if: (a) a loss of pressure greater than that specified in Section 401.5.1.2 - 4 does not occur; (b) there is no evidence of fluid leakage; and (c) there is no evidence of fluid path deterioration, including but not limited to swelling and stretching.

304.1.2 Air. A collector, after testing, shall be considered passable if there is no evidence of permanent fluid path deterioration, including but not limited to swelling and stretching.

305
THERMAL SHOCK RESULTS

305.1 General. A collector shall be considered to have failed the test when the test specimen experiences permanent distortion, damage or degradation of performance.

305.2 Thermal Shock/Water Spray. The collector structure and performance shall not be degraded by moisture penetration. There shall be no cracking, crazing, warping or buckling of the cover plate.

305.3 Thermal Shock/Cold Fill. The collector’s fluid pathway shall not leak. The absorber shall not be permanently distorted enough to impact performance.

306
DISASSEMBLY AND FINAL INSPECTION
306.1 General. After completing the test sequence outlined in Section 5.0, the collector shall be disassembled, its subassemblies visually inspected, and their condition noted to determine final collector condition and actual or potential points of failure which may lead to impairment of function or abnormally short collector life. The format specified in ISO 9806-2, Appendix A.14, “Final inspection results,” shall be used to report conditions observed. Components and inspection criteria shall be in accordance with Table 306.1(1).

Test specimens and their components shall exhibit no conditions capable of producing premature failure including, but not limited to the items listed in Table 306.1(2).

<table>
<thead>
<tr>
<th>TABLE 306.1(1) COMPONENT INSPECTION CRITERIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collector Component</td>
</tr>
<tr>
<td>Collector box/fasteners</td>
</tr>
<tr>
<td>Mountings/structure</td>
</tr>
<tr>
<td>Seals/gaskets</td>
</tr>
<tr>
<td>Cover/reflector</td>
</tr>
<tr>
<td>Absorber coating</td>
</tr>
<tr>
<td>Absorber tubes and headers</td>
</tr>
<tr>
<td>Absorber mountings</td>
</tr>
<tr>
<td>Insulation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE 306.1(2) PREMATURE FAILURE CONDITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe deformation of the absorber</td>
</tr>
<tr>
<td>Severe deformation of the fluid flow passages.</td>
</tr>
<tr>
<td>Loss of bonding between fluid flow passages and absorber plate.</td>
</tr>
<tr>
<td>Leakage from fluid flow passages or connections.</td>
</tr>
<tr>
<td>Loss of mounting integrity.</td>
</tr>
<tr>
<td>Severe corrosion or other deterioration caused by chemical action.</td>
</tr>
<tr>
<td>Crazing, cracking, blistering or flaking of the absorber coating or concentrating optical element surfaces.</td>
</tr>
<tr>
<td>Excessive retention of water anywhere in the collector.</td>
</tr>
<tr>
<td>Swelling, severe outgassing or other detrimental changes in the collector insulation which could adversely affect collector performance.</td>
</tr>
<tr>
<td>Cracking, loss of elasticity, or loss of adhesion of gaskets and sealants.</td>
</tr>
<tr>
<td>Leakage or damage to hoses used inside the collector enclosure, or leakage from mechanical connections.</td>
</tr>
<tr>
<td>Cracking, crazing, permanent warping or buckling of the cover plate.</td>
</tr>
<tr>
<td>Cracking or warping of the collector enclosure materials.</td>
</tr>
</tbody>
</table>

Notes:
1. Deformation or corrosion shall be considered severe if it impairs the function of the collector or there is evidence that it will progress.

307
PROTECTION OF MATERIALS

307.1 Non-concentrating solar collectors. Materials used in the construction of non-concentrating solar collectors shall withstand no less than 1000 hours per year at stagnation temperature without significant degradation over the design life. Stagnation temperature shall be determined in accordance with ISO 9806-2, Annex B.1 or B.2.

307.2 Concentrating solar collectors. Materials used in the construction of concentrating solar collectors shall withstand, without significant degradation over the design life, the maximum temperature that the solar collector is tested to:
- collector stagnation temperature if no controls are employed. Stagnation temperature shall be determined in accordance with ISO 9806-2, Annex B.1 or B.2.
- manufacturer’s stated maximum operating temperature if controls are employed to protect the collector.

CHAPTER 4
TEST METHODS

401
REQUIREMENTS

401.1 General. Testing requirements for solar collectors shall be in accordance with Sections 401.2 through 401.14

401.2 Testing sequence. Collector testing shall be performed in the following sequence, unless indicated otherwise.

401.2.1 Collectors without storage.
1. Test Specimen Selection
2. Baseline Inspection
3. Pre-exposure Static Pressure Test
4. Pressure Drop Test (may be performed any time after the pre-exposure static pressure test and before the impact resistance test)
5. Thirty-Day Exposure Test
6. Thermal Shock/Water Spray Test (may be performed during or after the exposure test)

7. Thermal Shock/Cold Fill Test (may be performed during or after the exposure test)

8. Post-exposure Static Pressure Test

9. Collector Time Constant Determination Test

10. Thermal Performance Test (may be performed during or after the incident angle modifier test)

11. Incident Angle Modifier Test (may be performed during or after the post-exposure thermal performance test)

12. Controls Test, if active or passive controls are utilized to protect the collector (may be performed any time after at least 10 qualified exposure days have elapsed and before the impact resistance test)

13. Impact Resistance Test

14. Disassembly and Final Inspection

The identical serial-numbered collector must go through above tests 1 through 8, test 12 if controls are utilized to protect the collector, and tests 13 and 14. The same or a different identical serial-numbered collector must go through above tests 9 through 11, with the exception that if controls are utilized to protect the collector, test 9 is not required. If the same collector is used for all tests, tests 13 and 14 shall be performed after test 12.

401.2.2 Collectors with storage

1. Test Specimen Selection

2. Baseline Inspection

3. Pre-exposure Static Pressure Test

4. Pressure Drop Test (may be performed any time after the pre-exposure static pressure test and before the impact resistance test)

5. Thirty-Day Exposure Test

6. Thermal Shock/Water Spray Test (may be performed during or after the exposure test)

7. Thermal Shock/Cold Fill Test (may be performed during or after the exposure test)
8. Post-exposure Static Pressure Test

9. Thermal Performance Test (may be performed during or after the incident angle modifier test)

10. Impact Resistance Test

11. Disassembly and Final Inspection

The identical serial-numbered collector must go through above tests 1 through 8, 10 and 11. The same or a different identical serial-numbered collector must go through above test 9. If the same collector is used for all tests, tests 10 and 11 shall be performed after test 9.

401.3 Test specimen selection. Every collector to be tested shall be selected at random in accordance with Sections 401.3.1 through 401.3.2.

401.3.1 Selection method. Random selection of the test collector shall be accomplished by one of the following methods:
- Personal visit by the laboratory, certification body, or AHJ
- Selection from photographs of the collectors in stock.

All selected collectors, or collector components, shall be affixed with non-removable serial numbered labels.

401.3.2 Selection process. Collectors shall be randomly selected from a group of at least five collectors.

When final assembly of the collector components occurs only at the installation site, each of the components shall be randomly selected from a group of at least five components. It is required that the collector’s final assembly geometry cannot change from its design specification.

Exceptions:
1. Large collectors (greater than 4.6 m² (50 ft²)) shall be randomly selected from a group of at least two collectors when:
   a. transport in a fully-constructed condition is impractical, or
   b. collectors are not inventoried in a fully-constructed condition
2. If the collector design to be tested is always built for a specific installation, the collector is to be tested in-situ without random selection.
3. For distributed assembly solar concentrating collectors where the subcomponents are not physically connected to each other, the manufacturer shall specify the geometric parameters and configuration of all subcomponents and the total system. Such parameters shall include orientation, distance, height,
and angle of all solar collector subcomponents in relation to one another and the
installation site, including the quantity of each. The manufacturer's specifications
shall include minimum and maximum values for each geometric parameter
defining the configuration's final assembly with minimum and maximum operating
specifications. The configuration(s) to be tested shall fall within these specified
ranges, representing operating conditions closest to the minimum and maximum
allowed. The most rigorous test conditions applicable shall be used.

401.4 Baseline inspection. The collector(s) shall be tested as received from the
manufacturer. Test specimens shall be inspected prior to testing and any visible
damage or assembly flaws shall be recorded. Documentation shall include photographs
of the collector or its constituent parts, as received, showing all visible surfaces. Any
abnormalities shall be noted and photographed in detail.

401.5 Static pressure test. Static pressure testing shall comply with Sections 401.5.1
and 401.5.2.

401.5.1 Basis of test pressure. The basis of test pressure shall comply with
Sections 401.1.4.1.1 through 401.1.4.1.5.

401.5.1.1 Street pressure collectors. The test pressure for collectors
designed for direct exposure to street (city water) pressure shall be 1100
kPa Gauge (160 psig) based on:

1. Two times the allowable street gauge pressure 550 kPa Gauge (80
psig) in a dwelling.

2. The test pressure exceeding the required T&P valve relief setting
on approved hot water tanks, which is 1030 Gauge (150 psig).

401.5.1.2 Non-street pressure collectors. Collectors designed for use in
closed systems shall be pressure-tested at 1.5 times the manufacturer's
rated operating gauge pressure.

401.5.1.3 Collector documentation. Determination of test pressure shall
be based on documentation supplied with the collector and collector
markings.

401.5.2 Method of testing. Testing methods for liquid collectors shall be in
accordance with Section 401.1.4.2.1. Testing methods for air collectors shall be
in accordance with Section 401.1.4.2.2. Either hydrostatic or pneumatic pressure
sources are required to be used on liquid filled collectors. Pneumatic pressure
sources shall be used for air collectors.

401.5.2.1 Liquid Collectors. The testing methods for liquid collectors
shall be in accordance with items 1 through 4 of this section.
1. A pressure gauge shall be attached to read pressure at the collector, the collector shall be completely filled with fluid between 5°C (41°F) and 30°C (86°F), and the exit port shall be closed off. The ambient temperature shall be between 5°C (41°F) and 30°C (86°F).

2. Hydraulic pressure shall be applied via the inlet port until the gauge indicates the test pressure.

3. After stable test pressure has been achieved, the exit port shall be closed and the pressure shall be monitored for 10 minutes.

4. If the pressure drops by more than 17kPa (2.5 psi) or 5% of the test pressure, whichever is greater, the collector shall be deemed to have failed the test.

401.5.2.2 Air Collectors. The testing methods for air collectors shall be in accordance with items 1 and 2 of this section.

1. Pressure shall be measured at the exit port of the test specimen with an accuracy of no less than 2.5 Pa (0.01 inches water column). The air column shall be measured at any location between the air supply source and the collector with an accuracy of no less than 14.0 liters (0.5 cubic feet).

2. The pressure applied to the inlet port shall be increased to 125 Pa (0.5 inch water column) and monitored for a period of one hour. The volume of air added or removed in order to maintain the required pressure shall be documented.

401.6 Exposure test. Exposure testing shall be in accordance with Section 401.6.1 to 401.6.3 for a minimum of 30 days of exposure to adverse conditions.

401.6.1 Method of testing collectors without controls. Exposure testing of collectors that do not utilize controls for protection shall be in accordance with items 1 through 3 of this section.

1. The collector must be tested dry. However, units which use a sealed container or loop charged with a refrigerant, other phase change material or fluid, shall be tested with a normal charge of the material (according to manufacturer specifications).

2. Exposure conditions shall consist of 30 days of cumulative exposure to a minimum daily incident solar radiation flux of 17 MJ/m² day (1,500 Btu/ft² day) as measured in the plane of the collector aperture.
Part of the exposure test may be conducted indoors under a solar simulator, if the following conditions are met:

a. The minimum irradiance must meet ISO 9806-2, Table 4, Class B: 950 W/m² (301 Btu/(hr ft²)) with a daily total of 18 MJ/m² (1585 Btu/ft²)
b. The ambient air temperature must be above 15 °C (59°F)
c. Irradiation must be continuous until at least 18 MJ/m² (1585 Btu/ft²) of radiation has been measured in the plane of the collector. Then the lamp(s) must be turned off until the absorber returns to ambient air temperature. This sequence will count as one day of exposure.
d. A maximum of ten days of the exposure test may be performed indoors.

3. Data recorded and reported during exposure testing shall include integrated daily solar radiation and ambient air temperature. A regularly scheduled weekly visual inspection shall also be made, and a record of changes in the physical appearance of the collector shall be kept.

401.6.2 Method of testing collectors with controls. All collectors tested within this standard shall be expected to satisfy requirements intended to demonstrate durability under typical operating conditions.

Mechanical devices or controls to manage operation and protect the collector from conditions where material limits can be exceeded shall be required to be present during the test. For the purposes of this standard, these devices are classified as a) active or b) passive controls. Active controls are generally characterized by the use of mechanisms that require an external power source. Passive control action is generally accomplished by thermal mechanical means, such as a bimetallic material reacting to heat;

The use of controls requires additional steps in the testing sequence, thus primary and alternate testing paths are described in this standard. The testing path shall be based on: a) active controls used for protection and positioning; b) passive controls where collector protection and/or positioning is accomplished by thermal mechanical means such as a bimetallic material reacting to heat. A combination of active and passive controls is possible, therefore the testing path shall be chosen based on the individual protection or positioning subsystem of the collector.

401.6.2.1 Testing Program. The controls are tested for those collector designs that employ them. All collectors shall be subjected to durability testing, including a full 30 days of exposure testing.
When controls are required for tracking and protection of the collector from exceeding material limits, and require the flow of a heat transfer fluid, thermal performance testing shall commence as specified in Section 401.12. This exposure test configuration is characterized as "wet" testing. In these cases, collector durability can only be established when controls allow full on-sun and un-stowed exposure of material surfaces, and maximum temperatures to be reached, but not exceeded.

For collectors where controls are used, controls must be tested and verified. The function of tracking and other operating controls shall be verified in the course of the thermal performance test. Failure of tracking and/or operating controls shall be deemed a failure. Controls for material protection shall be verified in the course of durability testing and a control test phase following thermal performance testing.

All solar collectors shall demonstrate resistance to failure modes associated with normal solar exposure in the course of normal operation.. A testing program and individual operational points shall be established in accordance with Annex A - Test Program and Control Verification Guidelines.

401.6.2.2 Thirty Day Exposure Test. The purpose of this test is to verify integrity of collector construction after at least 30 days of outdoor exposure to environmental conditions. Any collector which exhibits compromised integrity either during the course of the exposure test or at its conclusion, such that it will no longer function as designed, the solar collector will be deemed to have failed the test. If the collector manufacturer elects to utilize active systems for collector protection purposes including, but not limited to, controls, motors, drives, actuators, or other equipment, those systems shall be active and operational during the exposure test. A test cycle that demonstrates the different functions of the active system shall be in operation during the exposure period. The collector, and all associated component parts and subsystems designated by the manufacturer as necessary for the operation of the collector as designed, shall be validated to be functional in accordance with the manufacturers description of intended operating characteristics.

Exposure conditions shall consist of 30 days of cumulative exposure to a minimum daily incident solar radiation flux for a Class B collector as defined in ISO 9806 -2: 1995, Section 7.3, Table 4, as measured in the plane of the collector aperture.

401.6.2.3 Method of Conducting Exposure Testing. The collector shall be tested over its full range of heat transfer loop conditions. If the manufacturer elects to test the collector "wet" (with heat transfer fluid flowing through the collector) and controls are used to manage both no-flow and high temperature conditions, then the collector shall be tested so that the temperature of the fluid at the collector exit reaches within 10°C of the maximum operating temperature, as defined by the manufacturer, for at least four hours near noon of each exposure day. On each exposure day the collector shall return to its normal night-time condition.

If the manufacturer elects to test the system “dry” and no controls are used for both high temperature and no-flow conditions, then stagnation temperatures must be reached in
the course of exposure testing. Collector designs which incorporate a factory sealed container used in the collection of heat are treated as “dry” unless controls are used for over temperature protection, then control operation must be verified.

If the collector assembly has active mechanism(s) which are intended to be functional during normal operation, those mechanism(s) shall be operational during testing.

Data recorded and reported during exposure testing shall include integrated daily solar radiation and ambient air temperature. A regularly scheduled weekly visual inspection shall be made, and a record of changes in the physical appearance of the collector shall be maintained.

With the exceptions detailed above, the Exposure Test shall be conducted in accordance with the provisions of EN 12975-2:2006, Section 5.4 Exposure Test.

401.7 Thermal shock/water spray test. The external thermal shock test shall be performed as specified in ISO 9806-2, Section 8, Class B. Where testing is conducted outdoors, one external shock shall be performed on each of two different days of the exposure test. Where testing is conducted indoors under a solar simulator, the second test may be performed on the same day as the first test provided that the collector has cooled to ambient air temperature (as measured by inserting a temperature sensor in the outlet fluid port) before this test is begun. Any test specimen whose integrity is permanently compromised by this test such that it obviously will not be able to perform later shall be considered to have failed the test.

Concentrating solar collector designs which incorporate a factory-sealed container charged with a refrigerant, other fluid, or phase-change material necessitate that these substances are not removed for this test. If the collector assembly has active mechanism(s) which are intended to be functional during normal operation, those mechanism(s) shall be operational during testing.

401.8 Thermal shock/cold fill test. Following the last water spray test, the internal thermal shock test shall be performed as specified in ISO 9806-2, Section 9, Class B. If this test is conducted outdoors, it shall be performed on a different day than the external shock test. If this test is conducted indoors under a solar simulator, it may be performed on the same day as one or both of the water spray tests, provided that the collector has cooled to ambient air temperature (as measured by a temperature sensor inserted in the outlet fluid port) before this test is begun.

Any part of a concentrating solar collector assembly that is not factory sealed shall be subjected to this test. If the collector assembly has active or passive mechanism(s) which are intended to be functional during normal operation, those mechanism(s) shall be operational during testing.

This test is not applicable to collectors in which heat transfer fluid is continuously flowing for protection purposes. In such cases, control(s) used to manage a no-flow condition shall be validated to be functional in such a way that any failure can be detected.
Control functions which have been verified shall be described and reported with the test results.

**401.9 Static pressure test.** A static pressure test shall be conducted in accordance with Section 401.5 after exposure and prior to thermal performance testing.

**401.10 Pressure drop test.** The pressure drop across the collector using a heat transfer fluid prescribed by the manufacturer shall be measured at sufficiently small flow rate intervals to accurately describe the pressure drop characteristics from minimum through maximum design flow rates, and shall include the flow rate used for the thermal performance test. This testing shall be conducted in accordance with ISO 9806-1 or 9806-3 with the exception that the accuracy of the pressure drop instrument must be no greater than 1.0% of the reading.

**401.11 Collector time constant.** A time constant test shall be conducted to determine the time required for the outlet fluid temperature to attain 63.2% of its steady state value following a step change in the input. The test specimen shall be tested in accordance with ISO 9806-1, Section 10 and ISO 9806-3, Section 10.

**401.12 Thermal performance test.** Thermal performance testing for liquid heating collectors shall be in accordance with Section 401.12.1. Thermal performance testing for air heating collectors shall be in accordance with Section 401.12.2. Thermal performance testing for collectors using controls for tracking or protection shall be in accordance with Section 401.12.3. Thermal performance testing for collectors containing internal storage shall be in accordance with Section 401.12.4. The thermal performance test determines "instantaneous" efficiency of the solar collector over a wide range of operating temperatures.

**401.12.1 Liquid heating.**

**401.12.1.1 Glazed collectors.** Specimens shall be tested in accordance with ISO 9806-1 with the following exceptions:

1. The preconditioning steady-state period and the test period shall each be a minimum of 10 minutes.

2. The highest inlet test temperature shall be the lowest of:

   a. 90°C (194 °F)
b. The temperature at which the temperature rise across the collector is between 1.5 and 2.0 K (2.7 and 3.6 R) at the given ambient test conditions.

401.12.1.2. Unglazed collectors. Specimens shall be tested in accordance with ISO 9806-3 with the following exceptions:

1. The lowest inlet test temperature shall be between 1 K and 3 K (1.8 and 5.4 R) above the collector environment dew point temperature at the time of the test.

2. The highest inlet test temperature shall be the temperature at which the temperature rise across the collector is between 1.0 and 1.5 K (1.8 and 2.7 R) at the given ambient test conditions.

401.12.2 Air-heating collectors. Specimens shall be tested in accordance with ASHRAE 93.

Air-heating collectors shall be tested at the higher of the flow rate specified by the collector manufacturer or the flow rate necessary for the temperature rise across the collector to be at least 10 K (28 R) when operating with the inlet air temperature equal to the ambient air temperature under a solar irradiance of 900 W/m² (285.5 Btu/hr ft²).

401.12.3 Collectors utilizing controls. The thermal performance test shall be conducted in accordance with EN 12975-2:2006, Section 6.3: Glazed and Unglazed Solar Collectors Under Quasi-Dynamic Conditions. The exceptions to this procedure are:

- the average wind speed can be 0-4.5 m/s (0-10.1 mph) during thermal performance data collection for concentrating collectors as per section 10.1.6 of ASTM E905-87 Standard Test Method for Determining Thermal Performance of Tracking Concentrating Solar Collectors.

- the thermal performance test shall be conducted after at least 10 qualified (see 7.2) exposure days have elapsed.

401.12.3.1 Concentrating Photovoltaic – Thermal (CPVT) Collectors. Thermal performance testing of CPVT shall be comprised of both open electrical circuit and combined electrical and thermal output modes with the use of a maximum power point (MPP) controller. In testing and reporting of performance, both electrical and thermal energy shall be accounted for. CPVT collectors shall be tested open electrical circuit for at least one complete testing day under clear sky conditions focused on determining the optical intercept and IAM. Findings shall be published in the report.
Electrical output (V) voltage and (I) current shall be measured in accordance with IEC 61925 at a point between the source and the MPP device. If the manufacturer provides the MPP tracking device, the details of this device shall be included in the report. Otherwise, a laboratory’s MPP may be used. If lab MPP is used, parameters of its operation shall be included in the test report.

Thermal performance test configurations and schematics are defined in EN 12975-2:2006, Section 6.1.3 Test Installation.


401.12.4 Collectors containing storage. Collectors containing storage require additional testing because the mass of the storage precludes measurement of instantaneous efficiency. These collectors include both integral collector storage (ICS) designs and thermosiphon designs where the collection function cannot be separated from the storage function for testing. These collectors shall be subjected to the applicable tests described in 401.12.4.1 through 401.12.4.5.3.

401.12.4.1 General testing procedures. All test objects shall be mounted in a manner that is similar to the intended usage. This requirement includes the use of such devices as reflectors and roof support structures. The intent is that all hydraulic, thermal and optical characteristics are reproduced during the test.

The applicability of extrapolating these test results to fluids other than water is limited. When testing with a fluid other than water, it is required that fluid composition tests be performed to ensure that the specified fluid composition exists. At a minimum, a hygrometer test or its equivalent should be performed and checked with the fluid specification before proceeding with the test.

In any collector with a heat exchanger containing more than 2.5% (by volume) of the storage vessel volume, the heat exchanger shall be preheated to the same temperature as the rest of the collector for all tests. In most cases, desirable preheating of the closed storage unit will occur during the heating of the adjacent fluid. For atmospheric systems, the rate of fill may be limited by the system’s components. Note that these loops are not to be directly purged at the end of the test. However, the energy within them should be purged in the normal operating fashion. This may require extended draw periods.

No performance test shall be performed in excess of manufacturers recommended operating conditions. This may necessitate the adjustment of certain test operating conditions to conform to the intent of the test.

401.12.4.1.1. Required instrumentation accuracy and resolution.
Table 401.12.4.1.1 indicates the required assurances for the instrumentation used in the following tests. The radiation measurements shall be performed with devices that meet the standards of the World Meteorological Organization for a first class pyranometer or pyrheliometer. The data resolution shall be no lower than the stated accuracy.

<table>
<thead>
<tr>
<th>Value to be Measured</th>
<th>Accuracy SI Units (±)</th>
<th>Accuracy IP Units (±)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>0.1 °C (precision 0.1 °C)</td>
<td>0.2 °F (precision 0.2 °F)</td>
</tr>
<tr>
<td>Temperature Difference</td>
<td>0.1 K (precision 0.1 K)</td>
<td>0.2 °R (precision 0.2 °R)</td>
</tr>
<tr>
<td>Mass</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Fossil Fuel Usage</td>
<td>Max (1%, 15Wh)</td>
<td>Max (1%, 511 Btu)</td>
</tr>
<tr>
<td>Electric Energy Usage</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Air Flow</td>
<td>1% measured mass value</td>
<td>1% measured mass value</td>
</tr>
<tr>
<td>Liquid Flow</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 401.12.4.1.1 Instrumentation Accuracies

The test lab shall ensure that data is checked for any offsets immediately prior to and at the conclusion of the test. Offsets should be applied to the processed data and noted in the test report.

401.12.4.1.2 Minimum Data Time Step. Unless otherwise indicated, all data shall be sampled with a maximum of a fifteen-second-time step. This data shall be averaged and reported at a maximum rate of 5 minutes for long-term tests (duration is longer than 1 day) or 0.5 minutes for short-term tests. Due to the interaction with TRNSYS, which uses a fixed time step, it is required that all data for all collected channels shall be reported in fixed time steps. Note that any test using an energy purge should be measured with the highest practical data resolution.

401.12.4.1.3 Instrument Calibration. All instrumentation used in the testing setup shall be calibrated to an accepted standard on a regular basis.

401.12.4.1.4 Required Experimental Data. The data specified in 401.4.1.4.1 through 401.4.1.4.3 is required.

401.12.4.1.4.1 Required Numerical Data. The minimum real time data to be collected for the tests shall consist of the following in SI/TRNSYS units. All data channels shall be reported on a regular time interval with non-null data, even if not used.

The test lab shall review for and address any missing or bad data. This data reduction shall occur prior to submission for modeling.

Gaps or corrections for critical data shall not last any longer than 10 minutes during non-purge periods. During purge periods, no critical data shall be missing or bad. The missing or adjusted data shall be filled in using proxy measurements or interpolation to existing data and highlighted in the data set and noted in the test report.
A log indicating the timing of the draw, purge, and irradiation start and stop times shall be included. Other data including site elevation, longitude, latitude, and test sample orientation shall also be supplied. Any data that does not meet these minimum requirements shall be rejected.

Required data includes:
1. Data collection time (both local and solar) and date, and day of year (dd-mm-yyyy)
2. Inlet temperature(s) (°C)
3. Outlet temperature(s) (°C)
4. Ambient temperature (e.g. “Outside”, if applicable) (°C)
5. Environmental temperature (e.g. “Inside”, if applicable) (°C)
6. Flow Rate(s) (kg/hr)
7. Fluid heat capacities(s) (kJ/kg- °C)
8. Wind velocity (m/s)
9. Auxiliary energy usage (if applicable) kJ
10. Radiation measurements (see below) (if applicable) (kJ/m²)
   a. Total surface
   b. Total horizontal
   c. Horizontal diffuse
   d. Horizontal infrared (ICS or unglazed collectors only)

401.12.4.1.4.2 Required Physical Data. Measure all easily accessible significant characteristics of the component or system, including:
   a. Diameters and/or lengths and/or widths (internal and external).
   b. Lengths (internal and external) and spacing of tubes and/or fins.
   c. Heights (internal and external), denote any minimum and maximum water levels.
   d. Thickness (insulation, tank shell, tank vessel, fins, etc.).
   e. Volumes (at ambient air temperature) of the tank and any integral heat exchanger(s).
   f. A diagram indicating geometry including vessel, shell, and any protrusions such as heat exchangers and plumbing connections.
   g. Materials used for vessel, insulation, shell, tank liner, heat exchangers, etc.
   h. Piping lengths and orientations.
   i. Slope of components.
Measurements shall be reported in consistent sets of units.

401.12.4.1.4.3 Additional Required Documentation. The following documentation shall be provided:
   a. Equipment model number(s)
   b. Description of the test method(s) and any deviations from the standard method.
   c. Photographs of any applicable equipment.
401.12.4.1.5 Data Processing Methods. The goal of these tests is to provide data for TRNSYS modeling of systems and or system components. The method of modeling depends upon the test and available TRNSYS models. The certification body will provide direction for new and innovative system tests that are not explicitly covered in this test method.

The calculation of temperature dependent densities and heat capacities shall be done using real-time data by the test lab. Data reduction shall include the filtering out of any bad data. The delivered energy value is to be used when matching net delivered energy with TRNSYS. Normally it is not necessary to adjust this value as the TRNSYS model accounts for energy changes (due to different starting and ending temperatures) and losses from the collector during the purge period.

All data shall be consistent with the test conditions. For example, if the pyranometer and pyrheliometer are not covered by the collector cover the visual radiation shall be set to zero and the sky infrared radiation shall be adjusted to an equivalent sky radiation to account for the covering of the collector during the purge period. Any adjustments shall be noted in the test report.

The testing and analytical work consist of several steps:
1. The test lab shall determine physical parameters from the tests (e.g. length)
2. The test lab shall collect extended test data from warm up tests
3. The test lab shall prepare the data in the format requested by the certification body.
4. The certification body shall create the TRNSYS model.

401.12.4.1.6 TRNSYS Processing for Component Model Calibration. Upon receipt of the processed data, the certification body shall create a series of TRNSYS models. One model is created for each test. This model is called the “audit” model. Each of the audit models is then fit to the test data as indicated below:

a. Collector heat loss is generally determined as follows:
   1. When both capacitance and heat loss tests are performed, the results from the heat loss test and capacitance tests are iterated upon until a final value of collector loss rate is determined. The loss value is input to the model directly. No other explicit fit is done at this point.
   2. When only the heat loss test is performed, the results are used to fit the TRNSYS model. The loss value is input to the model directly. No other explicit fit is done at this point.

b. Parameters for heat exchangers integral to a collector are input to the model directly. No other explicit fit is done at this point. The fit is done by minimizing the chi2 value for all data sets.

c. The data from each of the individual data points in the warm-up tests shall be used to calibrate the TRNSYS model using the FR_{TA} and FR_{UL}.
isothermal initial conditions. A fitting routine shall be used to fit the observed net, solar or auxiliary energy deliveries (to the observed data points, one per test). The fit is done by minimizing the chi\(^2\) value for all data sets.

For ICS collectors, the FR\(_{UL}\) adjustment is actually a UA\(_{loss}\) adjustment since there is no FR\(_{UL}\) data point. (Note that the ICS night time loss test shall be fit as part of the data set). The net result of this process are two points (FR\(_{TA}\) and FR\(_{UL}\)) that are used in the rating model.

d. When the collector is initially stratified due to the presence of an auxiliary heater, a separate set of tests and fits shall be done. This is typically done when a heater is located within the storage vessel of a thermosiphon collector.

401.12.4.2 **Standard Experimental Procedures.** The test procedures referenced in Section 401.12.4.3 are described in Sections 401.12.4.2.1 through 401.12.4.7.

401.12.4.2.1 **Collector charge.** Charge method:

a. Charge shall occur at any rate up to manufacturer's recommended maximum flow rate.

b. Heat and fully mix the collector to the starting temperature appropriate for the test being conducted by filling with conditioned fluid until

\[ |T_{in} - T_{del}| = 0.2^\circ K(0.4^\circ R) \text{ or } \frac{\partial |T_{in} - T_{del}|}{\partial t} = 0.05^\circ K(0.09^\circ R) \text{ for the minimum of a 10-minute period or the dwell (fill) time. The dwell time is the time required for the fluid leaving a collector to attain 63.2% of its steady state value following a step change in inlet fluid temperature.} \]

c. Draw should occur at 0.125-0.189 l/s (2-3 GPM) until

\[ |T_{in} - T_{del}| = 0.2^\circ K(0.4^\circ R) \text{ or } \frac{\partial |T_{in} - T_{del}|}{\partial t} = 0.05^\circ K(0.09^\circ R) \text{ for a 10-minute period.} \]

d. Conduct real time measurements of the mass that is withdrawn, the fluid inlet temperature, the fluid outlet temperature and the ambient air temperature.

Analysis Method:
The analysis of all energy purges shall utilize the following equations:
\[ Q_{\text{del}} = \int Rho(t) \times Cp(t) \times V_{\text{rate}} \times [T_{\text{del}}(t) - T_{\text{in}}(t)] \, dt \]

b. \[ T_{\text{used}} = \frac{T_{\text{tank ave orig}} + T_{\text{in}}}{2} \], Extrapolated average collector temperature value.

c. \[ T_{\text{test}} = \frac{T_{\text{tank ave orig}} + T_{\text{in}}}{2} \], Tested average collector temperature value.

d. \[ Q_{\text{initial}} = \frac{Q_{\text{del}} \times Rho(T_{\text{test}}) \times Cp(T_{\text{test}})}{Rho(T_{\text{used}}) \times Cp(T_{\text{used}})} \times \left( \frac{T_{\text{tank ave orig}} - T_{\text{in final}}}{T_{\text{final}} - T_{\text{in final}}} \right) \]

Where \( Q_{\text{del}} \) is the instantaneous purge energy and ‘test’ refers to the initial purge test conditions and ‘used’ refers to the conditions this value is extrapolated to, when required for temperature ranges other than those tested. \( Q_{\text{initial}} = Q_{\text{del}} \) unless extrapolation is required.

401.12.4.2.3 Installed Capacitance Test. The purpose of this test is to measure the collector capacitance value to be used in the loss test. This test is only required if it is determined that the collector could stratify significantly on charge due to parts of the collector not getting fully charged.

This test is to be performed indoors in an environment with nearly constant temperature. The collector is to be installed in a manner consistent with the intended system design. Piping connections are to be made, but isolated with valves. This test is typically performed before the loss tests so that a baseline collector capacitance can be determined. This test shall also be used in conjunction with the solar testing to determine initial charge energy for a high temperature warm-up test. In these cases, the test does not necessarily have to be performed immediately before the collector test if the collector and surroundings are maintained at similar temperatures before commencing this test and the subsequent warm-up tests.

a. Charge collector to a starting temperature of about 60°C (140°F) (see 401.12.4.2.1).

b. Measure ambient temperature during the entire test period.

c. Purge the energy in the collector (see 401.12.4.2.2) with the inlet temperature approximately equal to the ambient air temperature.

The resulting capacitance energy calculation from this test is used as the basis for the initial collector energy value in tests 401.12.4.2.4 and 401.12.4.2.5 when the construction characteristics of the collector make the analytical determination of this value difficult. The values for the starting temperature in the high-temperature and capacitance tests, and the temperature of the water in the collector at the beginning of a low-temperature test (approximately equal to the ambient air temperature), shall be set as part of the test or the extrapolation in Section 401.12.4.2.2 so that they match the corresponding test conditions for the heat loss test.

401.12.4.2.4 Heat loss test methods. The heat loss rate of the collector shall be measured in accordance with 401.12.4.2.4.1 or 401.12.4.2.4.2.

401.12.4.2.4.1 Heat Loss Test [Standard Decay Method].
Test Method:
This method shall be used when:
- the collector can be placed in a nearly constant temperature room
- the collector capacitance can be readily determined
- the collector can be fully mixed.

The collector is to be installed in a manner consistent with the intended system design. This test shall be performed indoors, in an environment with nearly constant temperature. Any source of heating, including resistance heaters and/or solar radiation, shall be shut off or blocked. All pumps, etc. shall be shut off for the duration of the test. If the room temperature variation is greater than 10% or if significant stratification is anticipated, the use of internal temperature probe(s) is required, in which case the alternative test method should be used.

a. Charge the collector (see 401.12.4.2.1) to a starting temperature of about 60°C (140°F).
b. Piping connections shall be made, but isolated with valves.
c. Wait until:

$$\frac{T_{tank\ ave\ orig} - T_{amb\ ave}}{3} \leq (T_{tank\ ave\ final} - T_{amb\ ave}) \leq \frac{2}{3} (T_{tank\ ave\ orig} - T_{amb\ ave}).$$

This shall be estimated before the test is run using the known collector volume and estimated environmental temperatures. Measure the environment temperature during the entire test period.
d. Open the valves closed in step b.
e. Purge the remaining energy in the collector (see 401.12.4.2.2) with the fluid inlet temperature equal to the ambient air temperature.

Analysis Method:
The following calculations shall be used, which assume ideal exponential temperature decay.

a. Determine collector thermal capacitance from either the capacitance test or a theoretical calculation.
   1. Experimental Method (preferred, see 401.12.4.2.3)
      $$M_{tank} * C_p = \frac{Q_{initial}}{T_{tank\ ave\ orig} - T_{tank\ ave\ final}}$$
   2. Theoretical Method
      This calculation should include full mass and specific heat of all significant collector components
      $$M_{tank} * C_p = M_{tank} * C_p (T_{tank\ ave\ orig} - T_{tank\ ave\ final})$$
b. Determine the steady state ideal heat loss (UA).
   1. $$T_{tank\ ave\ final} = T_{tank\ ave\ purge} + \frac{Q_{del}}{M_{tank} * C_p}$$
   2. $$UA = \frac{M_{tank} * C_p}{Time_{decay}} * \ln \left( \frac{(T_{tank\ ave\ orig} - T_{amb\ ave})}{(T_{tank\ ave\ final} - T_{amb\ ave})} \right)$$

Data from this test can be used to determine the UA installed loss total. UA isolated loss total value is to be used in the TRNSYS model if both the capacitance and heat loss tests are
used. Note the availability of the experimentally determined $Q_{\text{initial}}$ value in section 401.12.4.2.3. Determination of the heat loss and capacitance values will require iteration of these values from these two tests (401.12.4.2.3 and 401.12.4.2.4.1) if both the capacitance and heat loss tests are conducted.

If only the heat loss test is run, the actual data from the test will be used in the TRNSYS model. In these cases, an estimate of capacitance shall be used.

For collectors such as ICS where this value is implicit in the overall re-normalization of the model, this test is not required. In these cases, a calculated value is used instead of this test due to the variability of this value with collector to ambient temperature difference.

401.12.4.2.4.2  Heat Loss Test [Real Time Measurement Method].

Test Method:
This method should be used when the collector is instrumented with internal temperature probes (e.g. a “tree”). The collector is to be installed in a manner consistent with the intended installation. This test shall be performed indoors. All sources of heating, including resistance heaters and solar radiation, shall be shut off or blocked. All pumps, etc. shall be shut off for the duration of the test.

a. Charge the collector (see 401.12.4.2.1) to a starting temperature of about 60°C (140°F).

b. Piping connections are to be made, but isolated with valves.

c. Run the test until the following are satisfied, measuring the collector temperatures and environmental temperature during the entire test:

a. The collector temperature drops at least 3 °C.

b. The differential between the average collector temperature and the average environmental temperature changes by at least 3 °C.

d. Open the valves closed in step b.

e. Purge the remaining energy in the collector (see 401.12.4.2.2) with the fluid inlet temperature equal to the ambient air temperature.

Analysis Method:
A real time numerical loss calculation shall be used to calculate the losses. The real time method requires the use of internal temperature measurements and is the preferred calculation method when this instrumentation can be installed. The average collector temperature is calculated as the straight average of the equally placed temperature sensors on the tree.

a. $Q_{\text{loss}} = Q_{\text{initial}} - Q_{\text{del}}$ (the delivered energy from the purge)

b. Numerically solve for the heat loss rate, $Q_{\text{loss}} = \sum UA* (T_{\text{ave, tank}} - T_{\text{amb}})*\Delta t$

Data from this test can be used to determine the $UA_{\text{installed loss total}}, UA_{\text{isolated loss total}}$ value is to be used in the TRNSYS model.

For collectors such as ICS where this value is implicit in the overall re-normalization of the model, this test is not required. A calculated value is used instead of this test due
to the variability of this value with collector to ambient temperature difference. Note the availability of the experimentally determined $Q_{\text{initial}}$ value in test 401.12.4.2.3.

**401.12.4.2.5 Solar Collector Warm-Up and Decay Tests.** These are the primary set of tests used to calibrate the TRNSYS models to the test results.

These tests have been designed for outdoor conditions. When a solar simulator is used, considerations shall be made for infrared radiation, diffuse radiation, ambient airflow, sky temperature, and the view of the collector when taking and/or analyzing the data.

An implicit consideration in these protocols is that the collector is sized on the order of 60-80.3 l/m² (1.5-2 gal/ft²) storage per collector area, which is typical of residential SDHW systems used in the United States. These tests are intended for collectors with at least 5 gallons (18.7 l) of capacity. If a particular collector design falls outside of this range, the test exposure times and temperature rises (see 401.12.4.2.5.1 and 401.12.4.2.5.2) shall be adjusted with respect to this ratio.

These tests are to be performed on the actual pre-heat collector installed in a conventional manner (with added instrumentation and bypass loops for preconditioning). If the collector contains a single tank with integral heating, then the collector shall be tested with and without the heater in operation. In the test with the heater, set the heater thermostat at 50°C (122°F) and energize the heater for the first hour of each test.

Because of the variability of these tests, it may be necessary to extract summary information from a previous test in order to set the operating conditions of a succeeding test. This is necessary so that the minimum temperature and/or radiation requirements are met. If the criteria are not met, it will be necessary to perform additional test(s) in order to satisfy the diversity of data. In general, the clear, low temperature tests are designed to give the “high” performance when the test is run at “cool” temperatures, and the cloudy, high temperature tests and nighttime decay tests are designed to give the “low” performance when the test is run at “high” temperatures. On the low temperature tests, the initial temp shall be near the ambient air temperature. The high temperature test uses elevated starting temps. In addition to meeting the specified solar radiation, each individual warm-up test also shall have a minimal 5 K (9 R) temperature rise, to minimize the effect of errors in the test data. Decay tests should have a similar drop in temperature.

In tests utilizing an end of period purge, a cover shall be placed on the collector component at the beginning of the purge process. The cover shall consist of 0.04 m (1.6 inches) insulation board, with foil-covered surfaces. The cover shall extend at least 0.08 m (3.1 inches) beyond the gross horizontal collector aperture area and cover any vertically exposed optical components. The exposed side of the cover shall be backed with any appropriate material required for structural rigidity and exposure to the weather (e.g. plywood and plastic).
Before commencing the warm up or decay tests, it is required to pre-heat the entire collector to a uniform temperature. In collectors with integral collector and storage components (ICS), this is accomplished by fully mixing the collector heat transfer fluid. In systems utilizing a heat exchanger between the collector and storage components, it is required to take additional steps to ensure that the entire collector is pre-heated to the same temperature. The following procedures shall be used:

a. When the desired collector temperature is close to the ambient temperature:
   1. Non-separable thermosiphon: Uncover collector during mixing period (about 10 minutes prior to exposure start)
   2. Others: Cover collector
b. When the desired collector temperature is lower than the ambient temperature, cover the collector.

c. When the desired collector temperature is higher than the ambient temperature:
   1. Non-separable Thermosiphon: Uncover collector during mixing period (about 10 minutes prior to exposure start)
   2. Others: Partially uncover the collector during mixing to allow some heating, but do not allow stagnation.

All test articles shall be positioned and fixed with the collecting surface facing the equator. The required tilt for the collector in warm-up mode is that the collector shall be normal to the sun at solar noon +/- 4° on the day of the test, unless this contradicts the manufacturers recommended tilt. For collectors such as non-separable thermosiphon, use the manufacturer’s recommend minimum tilt to ensure adequate flow. In these cases, use the recommended tilt that will come closest to meeting the above requirement.

These procedures assume that the temperature in the collector at the beginning of a low-temperature test is close to ambient temperature.

Wind at a speed between 1 and 3 m/s shall be required for the testing of collectors with integral storage tanks and/or unglazed collectors that have not been tested with a measured wind blowing across them.

When the tests are conducted in a solar simulator, there are two different profiles for each of the “cloudy” days. The clear day has only one profile. The clear day is a constant 800 W/m² for 4 hours. The first cloudy day is a constant 400 W/m² for 6 hours. The second cloudy day is also 4 hours long consisting of rotating 30-minute periods of 200 W/m² and 600 W/m². Note there are no specific profiles for outdoor testing.

The warm-up tests are expected to yield a minimum of 4 data points (2 clear, low temperature differential and 2 cloudy, high temperature differential, where the differential is measured from the tank average temperature to the ambient average...
temperature). A data point (test) is considered to meet the criteria if the radiation condition is met and the minimal 5 K (9 R) tank temperature rise is achieved. The goal of the tests is to gather approximately 13,000 kJ/m$^2$ (1145 Btu/ft$^2$) of radiation for all tests (cloudy test length shall be adjusted to not exceed this value) to equalize relative experimental errors and to equally weight the various conditions. The collector inlet temperature should be selected so that the temperature at the beginning of a high-temperature test does not exceed the collector recommended maximum operating temperature.

All of the measurements listed in 401.12.4.1.4.1 shall be made during all the tests. The clearness index, $K_T$, is used to classify clear vs cloudy test conditions for exterior warm-up tests:

$$K_T = \frac{\text{Horizontal Irradiance}}{\text{Extraterrestrial Horizontal Irradiance}}$$

where the extra-terrestrial horizontal irradiance is given by:

$$G_0 = (G_{SC} \times [1+ 0.033 \cos(D)] \cos \theta)$$

where:

- $D = \frac{2\pi n}{365}$ radians
- $n =$ day of the year, ranging from 1 on January 1 to 365 on December 31.

401.12.4.2.5.1 Warm Up Test Clear, Low Temperature Differential, Isothermal Start. This test is to be performed on a minimum of two clear ($0.65<K_T$) days. When testing in a solar simulator, only one test is required.

a. Charge the collector (see 401.12.4.2.1) until it is uniformly mixed at a temperature approximately equal to the ambient air temperature. This starting temperature must be chosen so that the high-temperature test starting temperature requirement (see 401.12.4.2.5.2) can be met.
b. Expose the collector until it has received approximately 13,000 kJ/m$^2$ (1145 Btu/ft$^2$) of radiation. (Typically for 3-4 hours.)
c. At the conclusion of the irradiation period, cover the collector and purge (see 401.12.4.2.2) the gathered energy from the collector with an inlet temperature equal to the starting temperature.
d. Check radiation requirements (see 401.12.4.2.5) to see if further data is required.

401.12.4.2.5.2 Warm Up Test: Cloudy, High Temperature Differential, Isothermal Start. This test is to be performed on a minimum of two cloudy ($K_T<0.65$) days.

a. Charge the collector (see 401.12.4.2.1) until it is uniformly mixed at a temperature approximately 30 K higher than the starting temperature used in the low-temperature warm-up test.
b. Expose the collector until it has received approximately 13,000 kJ/m$^2$ (1145 Btu/ft$^2$) of radiation. (Typically for 5-6 hours.)
c. At the conclusion of the irradiation period, cover the collector and purge (see 401.12.4.2.2) the gathered energy from the collector with an inlet temperature equal to the starting temperature.

d. Check the radiation requirements (see 401.12.4.2.5) to see if further data is required.

401.12.4.2.6 Nighttime Decay Heat Loss Test (only for collectors with hot storage surface visible from the sky). Perform a heat loss test on an installed collector outdoors two times. The collector should be uncovered. The test shall be started within one hour of dusk and completed within one hour of dawn. The two tests shall be conducted so that the difference between the average outdoor sky temperature and the average ambient temperature varies 8 K between the two tests. Two methods can be used to determine sky temperature:

1. Direct measurement of net infrared (preferred)
   Note: In this equation, sky temperature and ambient air temperature are in degrees Kelvin, Q_{net IR} is in W/m², ε is typically =0.9, σ = 5.67E-08 W/m²-K^4
   \[ T_{sky} = \sqrt{\frac{Q_{net IR}}{\varepsilon \sigma}} + T_{ambient}^{0.25} \]

2. Indirect Calculation (Berdahl and Martin)
   Note: In this equation, sky temperature and ambient air temperature are in degrees Kelvin, T_{dewp} is dewpoint in degrees Celsius, and time_{midn} is hours from midnight.
   \[ T_{sky} = T_{ambient} \times \left[ 0.711 + 0.0056 \times T_{dewp} + 0.000073 \times T_{dewp}^2 + 0.013 \times \cos(15 \times \text{time}_{midn}) \right]^{0.25} \]

a. Charge the collector (see 401.12.4.2.1) until it is uniformly mixed at a temperature approximately 30 K higher than the starting temperature used in the low-temperature warm-up test.

b. Expose the collector overnight.

c. At the conclusion of the exposure period, cover the collector and purge (see 401.12.4.2.2) the gathered energy from the collector with an inlet temperature equal to the starting temperature.

d. Check the sky temp requirements to see if further data is required.

401.12.4.2.7 Warm Up and Decay Test Analysis. The analysis is implicit in the fitting process for the test data. This is accomplished by means of a least squares fit (using the simplex method) to a set of data based upon minimizing the residual difference between the measured energy delivered during the test and the energy delivered calculated by TRNSYS. In this case, delivered energy is defined as the sum of the draw, estimated collector losses during the draw period, and the change in collector internal energy that occurs during the test. For collectors with no hot storage vessel surfaces visible from the sky, two low-temperature warm-up tests and two high-temperature warm-up tests shall be weighted equally. For collectors with any hot storage vessel surface visible from the sky, two low-temperature warm-up tests, two nighttime decay tests, and two high-temperature warm-up tests shall be weighed
equally. More tests are allowed for both collector types, but the weighting shall be adjusted to maintain an equal weighting of each type of test.

The results of this analysis are the FR\textsubscript{TA} and FR\textsubscript{UL} multipliers that are used for modeling these collectors for a given set of design parameters.

401.12.4.3 Tests for collectors containing storage. Collectors containing storage shall be tested in accordance with sections 401.12.4.3.1 through 401.12.4.3.3.

401.12.4.3.1 Qualification tests. Collect physical data (see 401.12.4.1.4.2). Conduct qualification (pressure, stagnation, shock, etc.) tests (see 401.2.2). Both the supply side and the load side of heat exchangers shall be tested.

401.12.4.3.2 Heat Loss Tests. Conduct the following tests:
   1. Capacitance test (see 401.12.4.2.3).
   2. Conduct one of the following heat loss tests:
      a. Collectors with no hot storage surface visible from the sky – conduct the heat loss test specified in 401.12.4.2.4.
      b. Collectors with hot storage surface visible from the sky – conduct the nighttime decay loss test specified in 401.12.4.2.6.

401.12.4.3.3 Warm-up Tests. Conduct the solar collector warm-up tests (see 401.12.4.2.5). If a collector contains a tank with an integral heater, an additional set of tests shall be performed. The tests shall be identical to the set in 401.12.4.2.5.1, with the exception that stratified operation due to the heater operation shall be measured by activating the heater for the first hour of the warm up test.

401.13 Collector incident angle modifier. The incident angle modifier curve shall be determined for each test specimen in accordance with ISO 9806-1 or ISO 9806-3.

Biaxial incident angle modifiers are required on collectors that are non-symmetrical in their response to irradiance as solar altitude and azimuth change. Data shall be taken in each of the two perpendicular planes that characterize the collector geometry.

401.13.1 Concentrating collectors. Concentrating solar collector testing shall include all operational conditions in which the collector is designed to operate. Incident Angle Modifiers (IAM) shall be found for the maximum acceptance angle and all intermediate angles as needed to properly characterize the optical behavior of the collector. Unless manufacturer stipulates otherwise, the maximum acceptance angle be tested to shall be 70°. All testing shall comply with practices referenced by this standard in EN12975-2.

Biaxial IAM testing and reporting are required on all non-tracking concentrating collectors as covered by this standard and any single axis tracking collector where reflectors and/or receivers move independently of each other.
The manufacturer shall submit a drawing showing the optical normal, transverse plane and longitudinal plane.

401.14 ACTIVE AND PASSIVE CONTROLS TESTING. The manufacturer shall identify all components and systems which are designed to protect the operational integrity of the collector during normal operating conditions. A test cycle demonstrating all functions of all active collector protection mechanism(s), including, but not limited to, overheating protection, wind protection, or other collector protection mechanisms which are necessary for the continued operation of the collector as designed, shall be observed at least once during the exposure period. All of the collector’s components shall operate in accordance with the manufacturer’s specifications.

Where system operation is dependent on associated collector tracking and/or safety control function(s), such control(s) shall be tested for normal operation and shall demonstrate operational capability in the event of loss of grid electrical supply. If collector tracking and/or safety systems do not rely on active controls but employ other passive means of managing over-limit conditions, such system operations shall be demonstrated during the thermal performance test. Visual observation of the collector tracking system and associated safety controls shall be made, and any non-conformity of operation with intended system function shall be noted. Hydraulic loop temperature measurements shall be used to verify intended operation of the controls, and to confirm that operation within design limits has been maintained.

Active controls are required to use an electrical temperature measuring element and testing of the control over-temperature protection will be satisfactorily proven with local heating of the temperature sensing element and observation of the active control responding appropriately. If fluid thermal sensors are used for over temperature sensing, they shall be operable when the receiver is dry unless a flow sensor is used as an interlock.

If the collector is defocused for over-temperature control by passive mechanical means, the collector shall be operated normally, then heat exchange fluid flow stopped. It is required that the over-temperature mechanism is independent of any flow controls. If active control is mixed with passive elements, an interlock functionality shall be demonstrated.

During tracking or safety control(s) testing, any migration of collector temperature, pressure or other factors intended to be limited by collector or control(s) design, into operating conditions outside of design limits is considered failure.

Any failure of controls, which shall be reported as such based on manufacturer’s operational parameters, that causes a halt in system testing and that prevents the publishing of a thermal performance report shall result in the collector failing the test.

The manufacturer shall establish control set points and parameters and submit these to the lab for verification of proper control operation.
401.15 **Disassembly and final inspection.** After the completion of testing, test specimens shall be disassembled and inspected in accordance with Section 306. Any visible damage, deformation, discoloration or flaw shall be recorded.

**CHAPTER 5 **

**REFERENCED STANDARDS**

This chapter lists the standards that are referenced in various sections of this document. The standards are listed herein by the promulgating agency of the standard, the standard identification, the effective date and title and the section or sections of this document that reference the standard. The application of the referenced standards shall be as specified in Section 104.1.


APPENDIX A – Test Guidelines
(This appendix is informative and is not intended to be part of the standard.)

System Types
System types for certification and types for purposes of control description and testing are comprised of two discrete groups.

1. Collector Assembly Type
2. Control

Figure A1 – Assembly Types

- **Complete Assembly**
  - Random Selection
  - All Components are fixed and geometries do not change

- **Combined Assembly**
  - Alternate Selection
  - All Components are fixed and geometries do not change but must be field assembled.

- **Distributed Assembly**
  - Alternate for Central Reviewers
  - Receivers and reflectors are fixed. Reflector configuration and quantity are certified as a min-max range.

Figure A2 - Control Types

<table>
<thead>
<tr>
<th>Active Control</th>
<th>Passive Control</th>
<th>No Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control.Active</td>
<td>Control.Passive</td>
<td></td>
</tr>
<tr>
<td>.Fluid</td>
<td>.Fluid</td>
<td></td>
</tr>
<tr>
<td>.Positioning</td>
<td>.Positioning</td>
<td></td>
</tr>
<tr>
<td>Function</td>
<td>Function</td>
<td></td>
</tr>
<tr>
<td>.FlowRate</td>
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<tr>
<td>.Positioning</td>
<td>.Positioning</td>
<td></td>
</tr>
<tr>
<td>Action</td>
<td>Action</td>
<td></td>
</tr>
<tr>
<td>.ThermalShock</td>
<td>.ThermalShock</td>
<td></td>
</tr>
<tr>
<td>.HighTemp</td>
<td>.HighTemp</td>
<td></td>
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<tr>
<td>.Defocus</td>
<td>.Defocus</td>
<td></td>
</tr>
<tr>
<td>.PowerFailure</td>
<td>.PowerFailure</td>
<td></td>
</tr>
</tbody>
</table>
**Tracks**

The tracks indicate the ability to run test modules simultaneously. Dry exposure test remove this possibly from those collectors that do not track and do not use wet heat removal. Track 2 and 3 are indicative of tracks that can be followed with active and passive controls. Track 4 is indicative of a distributed assembly collector where a minimum configuration must be tested as well as a maximum.

![Figure A3 - Track Examples (1)](image)

<table>
<thead>
<tr>
<th>Tracking Type</th>
<th>None</th>
<th>None</th>
<th>None</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overtemperature Protection</td>
<td>Active TOD</td>
<td>Active TOY</td>
<td>Active, Thermal Limit</td>
<td>Active, Flow Control</td>
</tr>
<tr>
<td>Internal Thermal Shock Protection</td>
<td>Fluid</td>
<td>Positioning</td>
<td>Fluid</td>
<td>Positioning</td>
</tr>
<tr>
<td>Mechanical Stress Protection</td>
<td>Required</td>
<td>Required</td>
<td>Required</td>
<td>Required</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>7.1 Static Pressure Test</th>
<th>7.2 Exposure Test</th>
<th>7.3 External Thermal Shock Test</th>
<th>7.4 Internal Thermal Shock Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required</td>
<td>ALT2 Wet (Operation)</td>
<td>ALT2 Wet (Operational)</td>
<td>ALT2 Wet (Operational)</td>
</tr>
<tr>
<td>Required</td>
<td>Required</td>
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</table>

<table>
<thead>
<tr>
<th>7.5 Control Verification</th>
<th>7.5.1 Protection, Overtemperature</th>
<th>7.5.2 Protection, Thermal Shock</th>
<th>7.5.3 Protection, Structural</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required</td>
<td>Action .Stow</td>
<td>Optional</td>
<td>Optional</td>
</tr>
<tr>
<td>Required</td>
<td>Action .Stow</td>
<td>Optional</td>
<td>Optional</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>7.6 Static Pressure Test</th>
<th>7.7 Operational Pressure Drop Test</th>
<th>7.8 Impact Resistance Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required</td>
<td>Required</td>
<td>Required</td>
</tr>
<tr>
<td>Required</td>
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<td>Optional</td>
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<td>Optional</td>
</tr>
<tr>
<td>Optional</td>
<td>Optional</td>
<td>Optional</td>
</tr>
</tbody>
</table>

**Note:** 7.8 is to be carried out at +-45 degrees of vertically down.
The main branches are:

If wet thermal control is used for thermal limit protection for exposure testing, then active control alternate track can be selected and the controls must be verified.

If active control is used for internal thermal shock control, module 7.4 can be skipped and then active control operation with relevant operation control points and actions must be verified.

Figure A 4 – Track Example (2)

<table>
<thead>
<tr>
<th>Concentrating</th>
<th>Application</th>
<th>Selection &amp; Inspection</th>
<th>Durability Testing</th>
<th>Thermal Performance Testing</th>
<th>Active Control Testing</th>
<th>Final Inspection</th>
<th>Final Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentrating Track 1</td>
<td>Application</td>
<td>Selection &amp; Inspection</td>
<td>Durability Testing</td>
<td>Thermal Performance Testing</td>
<td>Active Control Testing</td>
<td>Final Inspection</td>
<td>Final Report</td>
</tr>
<tr>
<td>Concentrating Track 2</td>
<td>Application</td>
<td>Selection &amp; Inspection</td>
<td>Durability Testing</td>
<td>Thermal Performance Testing</td>
<td>Active Control Testing</td>
<td>Final Inspection</td>
<td>Final Report</td>
</tr>
<tr>
<td>Concentrating Track 3</td>
<td>Application</td>
<td>Selection &amp; Inspection</td>
<td>Durability Testing</td>
<td>Thermal Performance Testing</td>
<td>Active Control Testing</td>
<td>Final Inspection</td>
<td>Final Report</td>
</tr>
</tbody>
</table>