



BSI Standards Publication

Solar energy - Solar thermal collectors - Test methods (ISO 9806:2017)

National foreword

This British Standard is the UK implementation of EN ISO 9806:2017. It is identical to ISO 9806:2017. It supersedes BS EN ISO 9806:2013, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee RHE/25, Solar Heating.

A list of organizations represented on this committee can be obtained on request to its secretary.

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European foreword

This document (EN ISO 9806:2017) has been prepared by Technical Committee ISO/TC 180 "Solar energy" in collaboration with Technical Committee CEN/TC 312 "Thermal solar systems and components" the secretariat of which is held by ELOT.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by May 2018, and conflicting national standards shall be withdrawn at the latest by May 2018.

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Endorsement notice

The text of ISO 9806:2017 has been approved by CEN as EN ISO 9806:2017 without any modification.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by the European Committee for Standardization (CEN) Technical Committee CEN/TC 312, *Thermal solar systems and components*, in collaboration with ISO Technical Committee TC 180, *Solar energy*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition ISO 9806:2013, which has been technically revised.

Introduction

This document defines procedures for testing fluid heating solar collectors for thermal performance, reliability, durability and safety under well-defined and repeatable conditions. It contains performance test methods for conducting tests outdoors under natural solar irradiance and natural and simulated wind and for conducting tests indoors under simulated solar irradiance and wind. Outdoor tests can be performed either steady-state or as all-day measurements, under changing weather conditions.

Collectors tested according to this document represent a wide range of applications, e.g. glazed flat plate collectors and evacuated tube collectors for domestic water and space heating, collectors for heating swimming pools or for other low temperature systems or tracking concentrating collectors for thermal power generation and process heat applications. This document is applicable to collectors using liquids, as well as air as heat transfer fluid. Similarly, collectors using external power sources for normal operation and/or safety purposes (overheating protection, environmental hazards, etc.), as well as hybrid devices generating thermal power and electrical power are also considered.

Solar energy — Solar thermal collectors — Test methods

1 Scope

This document specifies test methods for assessing the durability, reliability, safety and thermal performance of fluid heating solar collectors. The test methods are applicable for laboratory testing and for *in situ* testing.

This document is applicable to all types of fluid heating solar collectors, air heating solar collectors, hybrid solar collectors co-generating heat and electric power, as well as to solar collectors using external power sources for normal operation and/or safety purposes. It does not cover electrical safety aspects or other specific properties directly related to electric power generation.

This document is not applicable to those devices in which a thermal storage unit is an integral part to such an extent that the collection process cannot be separated from the storage process for making the collector thermal performance measurements.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9060, *Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation*

ISO 9488, *Solar energy — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 9488 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

3.1

longitudinal plane

plane defined by the normal to the plane of the collector and the concentrator axis, or the largest symmetry line for flat biaxial geometries

3.2

maximum operating temperature

maximum temperature allowed during collector or system normal operation specified by the manufacturer

3.3

outgassing

process in which any material releases gases when it is exposed to elevated temperatures and/or reduced pressure

**3.4
reflector**

surface intended for reflecting radiant energy

**3.5
transversal plane**

plane defined by the normal to the plane of the collector and the line orthogonal to the concentrator axis, or the shortest symmetry line for flat biaxial geometries

**3.6
trigger temperature**

temperature value at which the safety controls are activated for fail-safe operating condition

4 Symbols

A_G	Gross area of collector as defined in the ISO 9488	m^2
a_1	Heat loss coefficient	$W/(m^2 \cdot K)$
a_2	Temperature dependence of the heat loss coefficient	$W/(m^2 \cdot K^2)$
a_3	Wind speed dependence of the heat loss coefficient	$J/(m^3 \cdot K)$
a_4	Sky temperature dependence of the heat loss coefficient	—
a_5	Effective thermal capacity	$J/(m^2 \cdot K)$
a_6	Wind speed dependence of the zero loss efficiency	s/m
a_7	Wind speed dependence of IR radiation exchange	$W/(m^2 \cdot K^4)$
a_8	Radiation losses	$W/(m^2 \cdot K^4)$
b_u	Collector efficiency coefficient (wind dependence)	s/m
C	Effective thermal capacity of collector	J/K
C_R	Geometric concentration ratio	—
c_f	Specific heat capacity of heat transfer fluid	$J/(kgK)$
$c_{f,i}$	Specific heat capacity of heat transfer fluid at the collector inlet	$J/(kgK)$
$c_{f,e}$	Specific heat capacity of heat transfer fluid at the collector outlet	$J/(kgK)$
$c_{f,a}$	Specific heat capacity of the ambient air	$J/(kgK)$
E_L	Longwave irradiance ($\lambda > 3 \mu m$)	W/m^2
G_{hem}	Hemispherical solar irradiance	W/m^2
G_S	Hemispherical solar irradiance for the calculation for the standard stagnation temperature	W/m^2
G_m	Average measured hemispherical solar irradiance	W/m^2
G''	Net irradiance	W/m^2
G_b	Direct solar irradiance (beam irradiance)	W/m^2

G_d	Diffuse solar irradiance	W/m ²
H	Irradiation on collector plane for exposure test	MJ/m ²
$K_{\text{hem}}(\theta_L, \theta_T)$	Incidence angle modifier for hemispherical solar radiation	—
$K_b(\theta_L, \theta_T)$	Incidence angle modifier for direct solar irradiance	—
$K_{\theta L}$	Incidence angle modifier in the longitudinal plane	—
$K_{\theta T}$	Incidence angle modifier in the transversal plane	—
K_d	Incidence angle modifier for diffuse solar radiation	—
$\dot{m}$	Mass flow rate of heat transfer fluid	kg/s
$\dot{m}_{\text{min}}$	Minimum mass flow by the performance test	kg/h
$\dot{m}_{\text{max}}$	Maximum mass flow by the performance test	kg/h
$\dot{m}_e$	Downstream air mass flow rate	kg/s
$\dot{m}_i$	Upstream air mass flow rate	kg/s
$\dot{m}_l$	Leakage air mass flow rate	kg/s
$p_{f,e}$	Static pressure of the heat transfer fluid (air) at the outlet of the solar collector	Pa
$p_{f,i}$	Static pressure of the heat transfer fluid (air) at the inlet of the solar collector	Pa
p_{abs}	Absolute pressure of the ambient air	Pa
$\dot{Q}$	Useful power extracted from collector	W
$\dot{Q}_{\text{Peak}}$	Peak power. Power output of the collector for normal incidence, $G_b = 850 \text{ W/m}^2$, $G_d = 150 \text{ W/m}^2$ and $\vartheta_m - \vartheta_a = 0 \text{ K}$	W
R_D	Gas constant for water vapour	461,4 J/(kgK)
R_L	Gas constant for air	287,1 J/(kgK)
T	Absolute temperature	K
t	Time	s
u	Surrounding air speed	m/s
u'	Reduced surrounding air speed $u' = u - 3 \text{ m/s}$	m/s
U	Measured overall heat loss coefficient of collector with reference to $(\vartheta_m - \vartheta_a)/G_{\text{hem}}$	W/(m ² K)
V_f	Fluid capacity of the collector	m ³
$\dot{V}$	Volumetric flow	m ³ /s

$\dot{V}_e$	Volumetric flow at the outlet of the solar collector	m ³ /s
$\dot{V}_i$	Volumetric flow at the inlet of the solar collector	m ³ /s
$\dot{V}_l$	Volumetric leakage flow rate	m ³ /s
$X_{W,a}$	Water content of the ambient air	kg H ₂ O/kg dry air
$X_{W,e}$	Water content of the air at the exit of the solar collector	kg H ₂ O/kg dry air
$X_{W,i}$	Water content of the air at the inlet of the solar collector	kg H ₂ O/kg dry air
Δp	Pressure difference between fluid inlet and outlet	Pa
Δt	Time interval	s
ΔT	Temperature difference between fluid outlet and inlet ($\vartheta_e - \vartheta_{in}$)	K
γ	Solar azimuth angle	°
η_b	Collector efficiency based on beam irradiance G_b	—
η_{hem}	Collector efficiency based on hemispherical irradiance G_{hem}	—
$\eta_{0,b}$	Peak collector efficiency (η_b at $\vartheta_m - \vartheta_a = 0$ K) based on beam irradiance G_b	—
$\eta_{0,hem}$	Peak collector efficiency ($\eta_{0,hem}$ at $\vartheta_m - \vartheta_a = 0$ K) based on hemispherical irradiance G_{hem}	—
$\eta_{hem,\dot{m}_i}$	Collector efficiency, with reference to mass flow $\dot{m}_i$	—
θ	Angle of incidence	°
θ_L	Longitudinal angle of incidence: angle between the normal to the plane of the collector and incident sunbeam projected into the longitudinal plane	°
θ_T	Transversal angle of incidence: angle between the normal to the plane of the collector and incident sunbeam projected into the transversal plane	°
ϑ_a	Ambient air temperature	°C
ϑ_{am}	Measured ambient air temperature	°C
ϑ_{as}	Ambient air temperature for the standard stagnation temperature	°C
ϑ_e	Collector outlet temperature	°C
ϑ_i	Collector inlet temperature	°C
ϑ_m	Mean temperature of heat transfer fluid	°C
ϑ_{max_op}	Maximum operating temperature	°C
ϑ_{stg}	Standard stagnation temperature	°C
ϑ_{sky}	Atmospheric or sky temperature	°C

$\vartheta_{\text{trigger}}$	Trigger temperature for safety activation	°C
$\vartheta_{\text{m,th}}$	Volume flow weighted mean temperature	°C
$\vartheta_{\text{mp,e}}$	Fluid temperate at the downstream air mass flow meter	°C
$\vartheta_{\text{mp,i}}$	Fluid temperate at the upstream air mass flow meter	°C
ϑ_{sm}	Average measured absorber temperature	°C
λ	Wavelength	µm
ρ	Density of heat transfer fluid	kg/m ³
ρ_{l}	Density of air	kg/m ³
σ	Stefan-Boltzmann constant	W/(m ² K ⁴)
τ_{c}	Collector time constant	s
τ	Transmittance	
$(\tau\alpha)$	Effective transmittance-absorptance product	—

5 General

5.1 Test overview — Sequence of the tests

A full test sequence for solar thermal collectors including durability test and thermal performance measurements is proposed in [Table 1](#). This test sequence may be modified or only single tests may be performed as required. For some tests, however, a certain preconditioning or a half-exposure test (see [Clause 10](#)) is mandatory. For all test sequences and single tests, the final inspection (see [Clause 17](#)) is recommended as concluding test for the proper identification and description of the test sample, as well as to identify problems or deficiencies.

Table 1 — Test list

Clause	Test
Clause 7	Air leakage rate test ^f
Clause 8	Rupture or collapse test ^f
Clause 9	Standard stagnation temperature
Clause 10	Exposure test ^b
Clause 11	External thermal shock test ^b
Clause 12	Internal thermal shock test ^{b,e}
Clause 13	Rain penetration test ^f
Clause 14	Freeze resistance test ^{c,f}
Clause 6	Internal pressure test for fluid channels ^{a,d,e}
Clause 15	Mechanical load test ^f
Clause 16	Impact resistance test ^g
Clause 17	Final inspection

Table 1 (continued)

Clause	Test
Clause 19 to 26	Thermal performance test ^h
Clause 27	Pressure drop measurement
^a For polymeric absorbers, the standard stagnation temperature is needed. ^b The external and internal thermal shock tests may be combined with the exposure test. ^c For collectors claimed to be freeze resistant and collectors containing heat pipes. ^d Applicable only for liquid heating collectors. Last test of a test sequence, but before final inspection. ^e Half-exposure is required before the test for fluid channels containing polymeric materials (including sealing). ^f Half-exposure is required before the test. In case the heat transfer medium is in direct contact with polymeric materials, this test shall be performed at standard stagnation temperature. ^g Half-exposure is required before the test if polymer cover. ^h Exposure is required before the performance testing of heat pipe collectors.	

5.2 Testing of collectors with specific attributes

5.2.1 General

The general test procedures described in this document cover most current standard products. Some collector constructions with additional specific attributes shall be tested as indicated in this clause. Collectors may have one or several attributes. Attributes not mentioned in the test report shall not be considered as applicable for the tested collector.

5.2.2 Collectors using external power sources and collectors with active or passive measures for normal operation and self-protection

5.2.2.1 General

These collectors shall be tested to demonstrate suitable performance under normal operating conditions and/or the ability to protect themselves from major failures due to conditions that can arise in standard operation. All tests shall be performed using the intended original manufacturer's equipment of the collector (tracking devices, pumps, sensors, etc.) and using external power sources as specified by the manufacturer. The manufacturer shall clearly define the equipment protection features and shall specify whether the equipment requires an external energy source to operate.

NOTE External equipment such as solar pumps or fans providing fluid flow for normal operation of the solar thermal fluid loop are not considered as part of the collector.

5.2.2.2 Collectors using external power sources for normal operation

The total power consumption for the normal operation mode of the collector shall be assessed and indicated in an appropriate manner in the test report.

5.2.2.3 Collectors using any active or passive measures for self-protection

The protection systems can be active (such as actuators, motors and other equipment) or passive (such as materials reacting to heat or other designs). Usually, such self-protection systems are activated at a certain threshold value (temperature, pressure, mechanical load, etc.). The manufacturer shall submit to the laboratories the control set points and parameters. All the durability tests shall be performed as described in this document, however at conditions closest to these thresholds without activating the

self-protection measures. If necessary, the collector is operated using appropriate fluids and flow rates. These test conditions take precedence over the test conditions given in the following chapters.

In a supplementary test, the functioning of each of the self-protection measures shall be checked at least two times by passing over the thresholds to the test conditions as defined in this document.

For all devices using external power sources for self-protection, it is assumed that power is available at the required level for normal operation and for 5 min after a self-protection threshold has been passed. It shall be checked whether the systems is able to protect the collector in time and whether it remains protected after that, even in case of a successive complete power failure of at least one hour.

If these methods are not applicable, an alternative test sequence shall be defined to verify suitable operation of all the active and passive mechanisms during normal operating conditions and in the case where self-protection measures have to be activated.

5.2.2.4 Reporting

Particular aspects of collectors using external power sources and active or passive measures for normal operation and self-protection shall be described and reported in the corresponding subclause of [Annex A](#). Specifications shall be given for flow rate, fluid temperature, and duration of flow if a fluid flow was applied in the test.

5.2.3 Collectors co-generating thermal and electrical power

5.2.3.1 General

These collectors shall be tested as any other solar thermal collector with respect to durability and thermal performance. All thermal performance tests shall be made under maximum electrical power generation conditions. For all durability tests, the electrical power generator shall not be connected to any load (open circuit) to prevent from cooling the collector and to simulate worst operating conditions.

5.2.3.2 Reporting

The electrical power generator shall be described in detail in the test report. The electrical operating mode shall be reported for all tests.

5.2.4 Wind and/or infrared sensitive collectors (WISC)

5.2.4.1 General

Different types of collectors are considered as sensitive to wind and/or thermal radiation. For these collectors, usually the absorber or the heat transfer fluid is in close contact with ambient. Typical examples are polymeric collectors without cover, some PVT collectors or some air-heating collectors.

5.2.5 Façade collectors

5.2.5.1 General

Collectors that, according to the manufacturer specification, can be operational at inclinations above 75° shall be considered as façade collectors.

5.2.6 Air and liquid heating collectors

5.2.6.1 General

Collectors intended for operation as liquid heating and air heating may be tested with both functions active with clear definition of collector working conditions in both functions or as either liquid heating collectors or air heating collectors.

These collectors shall be tested as any other solar thermal collector with respect to durability and thermal performance. For thermal performance tests, the function not being tested shall be operated in the conditions indicated below.

5.2.6.2 Conditions for thermal performance testing as liquid heating collectors

When testing the collector as a liquid heating collector, the part to be working as air collector shall be operated with the working flow rate indicated by the manufacturer and with inlet temperature close to ambient temperature.

5.2.6.3 Conditions for thermal performance testing as air heating collectors

When testing the collector as an air heating collector, the part to be working as liquid heating collector shall be operated with the working flow rate indicated by the manufacturer and with inlet temperature close to ambient temperature.

6 Internal pressure tests for fluid channels

6.1 Objective

This test is intended to assess the capability of a collector to withstand the maximum pressure in the fluid channels as specified by the manufacturer.

6.2 Fluid channels made of non-polymeric materials

6.2.1 Apparatus and procedure

The apparatus consists of a hydraulic or pneumatic pressure source, a safety valve, an air-bleed valve and a pressure gauge with a standard uncertainty better than 5 %. The air-bleed valve shall be used to empty the fluid channels of air before pressurization. The fluid channels shall be filled with fluid at room temperature and pressurized to the test pressure. After the pressure in the collector fluid channels has been raised to the test pressure, the fluid channels shall be isolated from the pressure source by means of an isolating valve. The fluid channels shall remain isolated from the pressure source during the test period, and the pressure within the fluid channels shall be observed.

6.2.2 Test conditions

The fluid channels shall be pressure-tested at ambient temperature in the range $20\text{ °C} \pm 15\text{ °C}$, shielded from light. The test pressure shall remain stable within $\pm 5\%$ of 1,5 times the maximum collector operating pressure specified by the manufacturer before isolating the collector from the pressure source. The test pressure shall be maintained for at least 15 min.

6.3 Fluid channels made of polymeric materials

6.3.1 Apparatus and procedure

The fluid channels shall be tested at standard stagnation temperature because the pressure resistance of polymeric fluid channels can be affected as its temperature is increased. The apparatus consists of

either a hydraulic or a pneumatic pressure source and a means of heating the fluid channels to the required test temperature. The fluid channels shall be maintained at the test temperature for at least 30 min prior to the test and for the full duration of the test.

The test pressure shall be maintained stable within ± 5 %.

One of the following methods shall be chosen.

- a) Submerging the fluid channels in a temperature controlled water bath and using compressed air or inked water as test medium.
- b) Connecting to a temperature and pressure controlled liquid circuit.
- c) Heating the collector in a solar irradiance simulator or under natural solar irradiance and using a fluid as test medium.

6.3.2 Test conditions

The test temperature shall be the maximum operation temperature specified by the manufacturer or the standard stagnation temperature, whichever is greater. For systems that experience atmospheric pressure and intended to drain while under stagnation conditions as tested per [5.2.2.3](#), the test temperature shall be the maximum operation temperature specified by the manufacturer. The test pressure shall be 1,5 times the maximum collector operating pressure specified by the manufacturer. The test pressure shall be maintained for at least 1 h.

6.4 Results and reporting

If visible, the fluid channels shall be inspected for leakage, swelling and distortion. For non-polymeric fluid channels, leakage is assumed for a pressure loss $\Delta p > 5$ % of the test pressure or 17 kPa, whichever is greater and/or if any leaking fluid droplets are observed. For polymeric fluid channels, leakage is assumed if any droplets or loss of air is observed. The results of this inspection shall be reported as in [A.4](#).

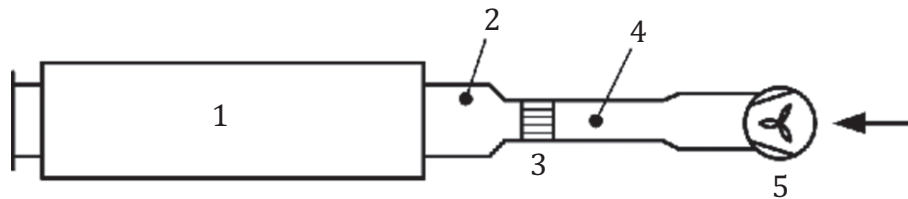
7 Air leakage rate test (air heating collectors only)

7.1 Objective

The test is intended to quantify the leakage volumetric flow rate of air heating collectors. In some cases of collector designs, the air leakage rate test is not applicable, e.g. collectors open to ambient.

7.2 Apparatus and procedure

The air leakage rate test is conducted using a volumetric flow meter, e.g. as shown in [Figure 1](#). Leakages resulting from other sources than the test object shall be quantified and deducted from the collector test results.

**Key**

- 1 solar air heater
- 2 pressure gauge
- 3 flow meter
- 4 temperature sensor
- 5 fan

Figure 1 — Schematic of apparatus used for measuring air leakage rate in solar air collectors

7.3 Test conditions

All pipe connections except for one shall be sealed. The remaining pipe connection shall be connected to a volumetric airflow measurement device and a variable speed fan. The pressure difference between the remaining pipe connection and the ambient shall be measured using a differential pressure measurement device.

The test consists of two parts: a positive and a negative air leakage rate test. The test shall be performed with positive and negative pressure. The standard uncertainty shall be better than $\pm 2\%$ for volumetric airflow measurement and better than ± 10 Pa for the differential pressure measurement.

In the case of polymeric fluid channels the test shall be performed at the maximum operating temperature specified by the manufacturer.

7.4 Results and reporting

The results shall be reported as required in [A.5](#).

8 Rupture or collapse test (air heating collectors only)

8.1 Objective

This test is intended to determine the ability of air heating collectors to withstand the pressure levels expected in the air duct systems with which they will be incorporated.

8.2 Apparatus and procedure

8.2.1 General

The test setup shall be similar to that used for the leakage test of air collectors and the measurement accuracy shall fulfil the same requirements (see [7.2](#)). Ensure that the variable speed fan is able to apply the appropriate positive or negative pressure.

The test shall be conducted at ambient temperature. In case the heat transfer medium is in direct contact with polymeric materials, this test shall be performed at standard stagnation temperature. The collector shall be heated using one of the following methods.

- a) Connecting a heater in the fluid circuit and circulating hot air through the collector before the collector outlet is sealed.
- b) Heating the whole collector in a solar irradiance simulator.
- c) Heating the whole collector outdoors under natural solar irradiance.

8.2.2 Closed-loop collectors

The procedure shall be as follows.

- a) Seal the pressure gauge into the collector outlet port and connect the inlet port through the flow meter and pressure regulator to the air supply.
- b) Ensure that the air supply is suitable for applying the appropriate positive or negative gauge pressure.
- c) Set the pressure regulator to the ambient pressure and note the pressure gauge zero reading.
- d) If the test is conducted at a temperature other than ambient temperature, then the collector shall be heated by one of the methods given in [8.2.1](#).
- e) Activate the air supply and open the regulator valve until a gauge pressure of 1,5 times the maximum (positive and/or negative) collector operating pressure specified by the manufacturer is reached and maintain it for 10 min.
- f) Inspect the collector and record any evidence of structural damage.

8.2.3 Open to ambient collectors

The procedure shall be as follows.

- a) With no airflow through the collector, note the pressure gauge zero reading.
- b) Activate the air supply and increase it until 1,5 times the maximum flow rate specified by the manufacturer is reached over a period of not less than 15 s. The collector will be tested in the normal use configuration, with air at atmospheric pressure being drawn into the collector.
- c) The airflow shall be maintained for not less than 10 min. At the end of 10 min, while maintaining airflow rate, inspect the collector and record any evidence of distortion or collapse.

8.3 Results and reporting

The results shall be reported as required in [A.6](#).

9 Standard stagnation temperature

9.1 Objective

This clause provides two methods ([9.3](#) and [9.4](#)) for determining the standard stagnation temperature of a collector, i.e. the temperature of the collector during periods of no useful heat removal from the collector with high solar radiation and ambient temperatures. The standard stagnation temperature, ϑ_{stg} , is determined for a solar irradiance $G_s = 1\,000\text{ W/m}^2$ and an ambient temperature $\vartheta_{\text{as}} = 30\text{ °C}$. The standard stagnation temperature is used in the following tests:

- internal pressure testing of collectors with polymeric absorbers (see [6.3](#));

- air leakage rate test of air heating collectors with polymeric fluid channels (see [Clause 7](#));
- rupture or collapse test of air heating collectors with polymeric materials (see [Clause 8](#));
- exposure test (see [Clause 10](#)).

9.2 Testing under stagnation conditions

The term testing under stagnation conditions is defined as follows: the collector shall be mounted outdoors or in a solar simulator. Liquid heating collectors shall not be filled with fluid. All fluid pipes except for one shall be sealed to prevent cooling by natural circulation of air. If a temperature sensor is required, it shall be fixed firmly at the absorber location where the highest temperature relevant to the heat transfer fluid is to be expected. The sensor shall be shielded from solar radiation. If the collector is provided with a sensor tube, the temperature sensor shall be installed there using heat conductive paste to ensure good thermal contact. Otherwise, the following applies: For flat plate collectors and direct flow evacuated tube collectors, this position is defined at two-thirds of the absorber height and half the absorber width. For evacuated tube collectors with heat pipes, this position is found directly on a condenser of a heat pipe. For some evacuated tube collectors, it may be reasonable to measure the standard stagnation temperature on a single tube with appropriate insulation on top to reduce heat losses to simulate a complete collector. Where these definitions are not applicable, an alternative suitable location has to be defined.

Collectors without backside insulation shall be mounted on a dark non-metallic surface ($\alpha > 80 \%$) to produce maximum temperatures consistent with worst-case conditions.

Self-protecting collectors shall be operated as specified in [5.2.2.3](#) at a temperature between $0,95 \cdot \vartheta_{\text{trigger}}$ and $\vartheta_{\text{trigger}}$.

9.3 Measurement and extrapolation of standard stagnation temperature

The collector shall be tested under stagnation conditions with a temperature sensor attached. The position of the sensor shall be described in the test report.

The collector is exposed for at least 1,5 h under stable stagnation conditions with average surrounding air speed of less than 1 m/s. Stable conditions are given if the irradiance level G_m is always within $1\,000 \text{ W/m}^2 \pm 100 \text{ W/m}^2$ if the measured ambient temperature ϑ_{am} is always within $30 \text{ }^\circ\text{C} \pm 10 \text{ }^\circ\text{C}$.

Based on the approximation that the ratio $(\vartheta_{\text{sm}} - \vartheta_{\text{am}})/G_m$ remains constant under steady-state collector stagnation conditions, the standard stagnation temperature for the selected parameters (G_s and ϑ_{as}) is then given by [Formula \(1\)](#):

$$\vartheta_{\text{stg}} = \vartheta_{\text{as}} + \frac{G_s}{G_m} (\vartheta_{\text{sm}} - \vartheta_{\text{am}}) \quad (1)$$

The standard stagnation temperature of the collector is defined as the average value of ϑ_{stg} over the measuring period of 1 h. The average is the mean of the individual temperature points, calculated from data measured at intervals of maximum 1 min.

9.4 Determining standard stagnation temperature using efficiency parameters

Based on the definition that under stagnation no useful heat removal is possible, the stagnation temperature is defined as absorber temperature ϑ_{abs} where the measured thermal performance

equals zero. The standard stagnation temperature ϑ_{stg} for the irradiance $G_S = 1\,000\text{ W/m}^2$ and ambient temperature $\vartheta_{\text{as}} = 30\text{ °C}$ is then calculated using [Formula \(2\)](#):

$$\vartheta_{\text{stg}} = 1,2 \cdot \left(\vartheta_{\text{as}} + \frac{-a_1 + \sqrt{a_1^2 + 4\eta_{0,\text{hem}} a_2 G_S}}{2a_2} \right) \quad (2)$$

The factor of 1,2 is introduced to compensate for the wind speed of 2 m/s – 4 m/s during the performance measurements which is higher than in stagnation conditions. For quasi-dynamic measurements, $(\eta_{0,\text{hem}} \cdot 1\,000\text{ W/m}^2)$ is replaced by $\{\eta_{0,b} \cdot [K_b(0,0) \cdot 850\text{ W/m}^2 + K_d \cdot 150\text{ W/m}^2]\}$.

This approach is based on extrapolating the collector efficiency formula to the stagnation condition, i.e. where the thermal output is zero. To ensure that the efficiency formula is still valid, some of the measured collector efficiency data shall have been measured with parameters ϑ_m , ϑ_{as} and G resulting in a power output $\dot{Q} \leq \dot{Q}_{\text{peak}}/2$ with the additional condition that $G > 800\text{ W/m}^2$. If this is not the case, the method is not applicable.

Stagnation temperatures for other climatic conditions G'_S and ϑ'_{am} shall be calculated using the standard stagnation temperature given in [Formula \(3\)](#):

$$\vartheta_{\text{stg}}(G'_S, \vartheta'_{\text{am}}) = \vartheta'_{\text{am}} + \frac{G'_S}{1000} (\vartheta_{\text{stg}} - 30) \quad (3)$$

9.5 Results and reporting

The standard stagnation temperature is reported in an up-rounded 10 °C resolution (see [A.7](#)).

10 Exposure and half-exposure test

10.1 Objective

The exposure test provides a simple reliability test sequence, indicating (or simulating) operating conditions that are likely to occur during real service and allows the collector to settle, such that subsequent qualification tests are more likely to give repeatable results. For the purpose of allowing the collector to settle before performing certain tests, a half-exposure sequence test is defined. The exposure test always includes the half-exposure test.

One of the climate classes as defined in [Table 2](#) has to be selected for testing. Climate class C is intended for special purposes and can be defined as required. Three different procedures are available to perform the tests. The results of the three procedures are deemed comparable. Every exposure and half-exposure test is started with an initial outdoor exposure under stagnation conditions (see [10.2](#)) followed by either one of the three test methods.

10.2 Initial outdoor exposure

The collector shall be mounted outdoors under any climatic conditions for testing under stagnation conditions (see [Clause 9](#)) for at least 30 days (or 15 days for half-exposure). The inclination angle shall be in the range of 30° to 60° if within the specification of the manufacturer. If not, then use the manufacturers' specification closest to this range. For façade collectors, 50 % of the initial outdoor exposure shall be made with the collector vertically installed. At least once a week, the collector shall be subject to a visual inspection and any signs of damage as specified in [Clause 17](#) shall be registered and reported with the test results.

10.3 Method 1

The ambient air temperature shall be recorded to a standard uncertainty of 1 K and the hemispherical irradiance on the plane of the collector recorded using a pyranometer of class I or better, in accordance with ISO 9060. Irradiation and mean ambient temperature values shall be recorded at least every 5 min.

The collector shall be further exposed until the minimum irradiation H shown in [Table 2](#) is reached. The initial outdoor exposure time can be included if ambient air temperature and hemispherical irradiance are measured accordingly.

The collector shall also be exposed for at least 32 h (16 h for half-exposure) at irradiance and ambient air temperature greater than the value shown in [Table 2](#). Conditions resulting in the same collector temperature according to [Clause 9](#) are acceptable. These hours shall be made up of periods of at least 30 min. The initial outdoor exposure can be included if the mentioned data are measured accordingly.

Indoor exposure using a solar simulator may be used to reach the 32 h or 16 h and/or the irradiation once the 30 or 15 outdoor days have been reached. It shall consist of cycles of maximum 8 h. If a cycle takes more than 8 h, just 8 h are counted. A minimum of 4 h shall be passed in between each cycle to cool down the collector to close to ambient temperature. The characteristics of the solar irradiance simulator to be used shall be as in [19.2.2](#). For non-WISC collectors, only the irradiance spectrum in the short wavelength range has to be considered.

At least once a week, the collector shall be subject to a visual inspection and any signs of damage as specified in [Clause 17](#) shall be registered and reported with the test results.

10.4 Method 2

After the initial outdoor exposure, the collector is connected to a pumped heat transfer loop using a suitable heat transfer liquid, with the collector forming part of the loop. A suitable heat transfer fluid is one that will remain in its liquid state at the stagnation temperature and the maximum operating pressure of the collector. The collector is operated at a fluid temperature $\vartheta_m = \vartheta'_{stg}(G'_s, \vartheta'_{am}) + 10\text{ °C}$ using the highest possible flow rate, where $\vartheta'_{stg}(G'_s, \vartheta'_{am})$ shall be calculated as stagnation temperature for the selected climate class following [Clause 9](#). Run the system at this flow rate and temperature for maximum 8 h and then turn the pump off for at least 4 h. Continue these cycles until the values for the selected climate class are reached.

Visually inspect the collector daily and note any changes in its appearance.

This method is not applicable for heat pipe collectors.

10.5 Method 3

After the initial outdoor exposure, the collector is installed for testing under stagnation conditions (see [9.2](#)) in a temperature-controlled solar simulator. The solar simulator output is adjusted so that the average radiation measured at six uniformly distributed points on the collector is greater than indicated for the selected climate class in [Table 2](#), with less than 20 % variation across the aperture. The ambient temperature shall be higher than indicated for the selected climate class. Run the system under these conditions with the simulator being operated maximum 8 h on and at least 4 h off. Continue this cycle of operation until the values for the selected climate class are reached.

Visually inspect the collector daily and note any changes in its appearance.

10.6 Test conditions

The set of reference conditions given in [Table 2](#) shall be used. Values given are minimum values for testing. The climate class is selected by the collector manufacturer.

Table 2 — Climate reference conditions for exposure test and thermal shock

Climate condition	Value for climate class				
	Class C Individual		Class B Sunny	Class A Very Sunny	Class A+ Extremely Sunny
Minimum hemispherical solar irradiance G_{hem} on collector plane during minimum 32 h (or 16 h in case of half-exposure) at minimum ambient temperature $\vartheta_{a,a}$ ^a	G_x $\vartheta_{a,x}$		900 W/m ² 15 °C	1 000 W/m ² 20 °C	1 100 W/m ² 40 °C
Irradiation H on collector plane for exposure test during minimum 30 days	H_x		540 MJ/m ²	600 MJ/m ²	700 MJ/m ²
Irradiation H on collector plane for half-exposure sequence during minimum 15 days	$H_x/2$		270 MJ/m ²	300 MJ/m ²	350 MJ/m ²
^a For thermal shock tests, the values can be understood as 1 h average values.					

10.7 Results and reporting

The results including the selected climate class, the measured irradiance and temperatures levels, and any observations shall be reported as required in [A.8](#).

11 External thermal shock

11.1 Objective

Collectors can, from time to time, be exposed to sudden rainstorms on hot sunny days, causing a severe external thermal shock. This test is intended to assess the capability of a collector to withstand such thermal shocks without a failure.

Collectors using toughened glass are deemed to comply with this requirement and testing is not required.

11.2 Apparatus and procedure

The collector shall be operated under stagnation conditions or shall be connected to a fluid loop as in Method 2 of the exposure test. In case of air-heating collectors, the inlet and outlet shall be protected from water penetration.

An array of water jets shall be arranged to provide a uniform spray of water over the front of the collector.

The collector shall be subject to two external thermal shocks.

11.3 Test conditions

The collector shall be exposed to the selected climatic conditions as described in [Table 2](#) or conditions resulting in the same collector temperature according to [Clause 9](#) for a period of 1 h before it is sprayed with water for at least 5 min.

Collectors with overheating self-protection mechanisms shall be operated close to the self-protection trigger temperature for a period of 1 h before being sprayed with water for at least 15 min.

The water spray shall have a temperature always between 10 °C and 25 °C and provide a spraying rate of more than 0,03 kg/s per square meter of collector gross area.

11.4 Results and reporting

The results shall be reported as required in [A.9](#).

12 Internal thermal shock test (Liquid heating collectors only)

12.1 Objective

Collectors can, from time to time, be exposed to a sudden intake of cold heat transfer fluid on hot sunny days, causing an internal thermal shock, for example, after a period of shutdown, when the installation is brought back into operation while the collector is at its stagnation temperature. This test is intended to assess the capability of a collector to withstand such thermal shocks without failure.

12.2 Apparatus and procedure

The collector shall be mounted either outdoors or in a solar irradiance simulator. Liquid heating collectors shall not be filled with fluid. All fluid channels shall be sealed except for one that is left open to permit free expansion of air in the absorber. One of the sealed fluid pipes shall be connected via a shutoff valve to a heat transfer fluid source.

The collector shall be subject to two internal thermal shocks.

This test is not applicable to those parts of the collector that are factory sealed.

12.3 Test conditions

The collector shall be exposed to the selected climatic conditions as described in [Table 2](#) or conditions resulting in the same collector temperature according to [Clause 9](#) for a period of 1 h before it is flushed with cold heat transfer fluid for at least 5 min. For all collectors, it has to be ensured that the collector is completely filled with fluid.

Collectors with overheating self-protection mechanisms shall be operated close to the self-protection trigger temperature for a period of 1 h before being flushed with cold fluid for at least 5 min.

The cold heat transfer fluid shall have a temperature of less than 25 °C. The fluid flow rate shall be the maximum flow rate of the thermal performance test or at least 0,02 kg/s per square meter of collector gross area (unless otherwise specified by the manufacturer).

12.4 Results and reporting

The results shall be reported as required in [A.10](#).

13 Rain penetration test

13.1 Objective

This test is intended to assess the capability of a collector to withstand free-falling rain or driving rain without damage and without ingress of water to such an extent that a significant reduction of performance or lifetime is to be expected.

13.2 Apparatus and procedure

The collector shall be installed on an open frame and at the shallowest installation angle specified by the manufacturer. Collectors designed to be installed exclusively into a roof structure shall be mounted in a simulated roof and have their underside protected. The positioning of the collector and the spray nozzles is defined in [Figure 2](#).

If this test setup is not applicable or deemed inadequate, a comparable configuration shall be set-up where all exposed points of the collector construction potentially susceptible to damage or ingress of rain (for example, the motor of a tracking parabolic trough collector) shall be sprayed using additional spraying nozzles.

During the whole test procedure, the collector shall be shaded from light ($G < 200 \text{ W/m}^2$) and shall be kept warm by circulating a hot fluid at $55 \text{ }^\circ\text{C}$ ($\pm 5 \text{ K}$) through the absorber. Air heating collectors shall be left at ambient temperature without forced airflow. All collectors shall stabilize under these conditions for at least 1 h. The collector is then sprayed for 4 h. After the spraying, the collector shall remain shaded until final inspection.

The penetration of water into the collector shall be determined by final inspection (see [Clause 17](#)) within 72 h after spraying, thus allowing for the impact resistance and mechanical load tests. The collector shall remain shaded from direct light but not being kept warm anymore until the final inspection. The collector shall be stored in such a way that the results are not influenced and unnecessary transportation shall be avoided.

13.3 Test conditions

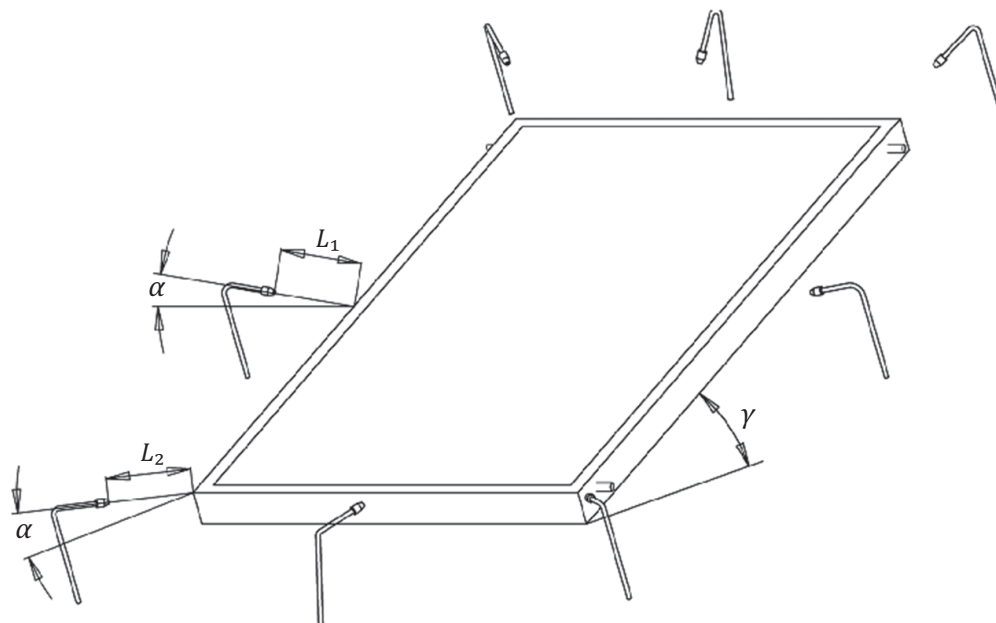
The spray nozzles required are specified as follows:

- full cone spraying;
- mass flow of 2 kg/min ($\pm 0,5 \text{ kg/min}$) per nozzle;
- spray angle of $60^\circ \pm 5^\circ$;
- drop size $>150 \text{ }\mu\text{m}$, according to technical information from spray nozzle manufacturer;
- the water pressure at every nozzle shall be maintained at 300 kPa ($\pm 50 \text{ kPa}$).

If applicable, the positioning of the spray heads shall be such that:

- at least every corner and every side of the casing is sprayed directly as shown in [Figure 2](#);
- at least every area shown in [Figure 3](#) (flat plate collectors with middle bars) is sprayed directly;
- at least every area shown in [Figure 4](#) (evacuated tube collectors) is sprayed directly;
- the spray nozzles are directed at an angle of 30° ($\pm 5^\circ$) onto the plane of the collector;
- the spray heads are at a distance of 250 mm ($\pm 50 \text{ mm}$) from the collector;
- the maximum distance between two spraying nozzles is 150 cm . Additional spraying heads shall be installed if this is not possible.

Middle bars and any other structural components where ingress of water is assumed possible shall be sprayed accordingly. Additional spraying heads shall be placed with a distance of 400 mm to 600 mm to the collector; the angle of 30° is not required.



Key

L_1 L_2 250 mm

A 30° angle of spray nozzle with respect to the collector surface

γ smallest tilt angle to the horizontal recommended by the manufacturer, if this angle is not specified, use 30°

Figure 2 — Positioning of collector and spray nozzles for rain penetration test

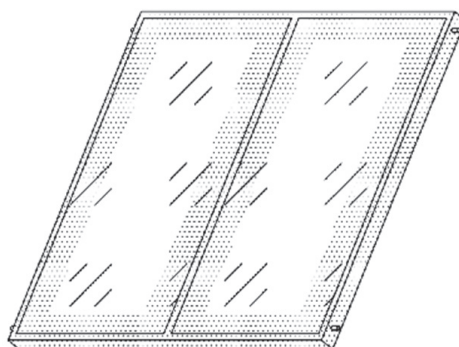


Figure 3 — Spraying areas of flat plate collectors (including middle bar)

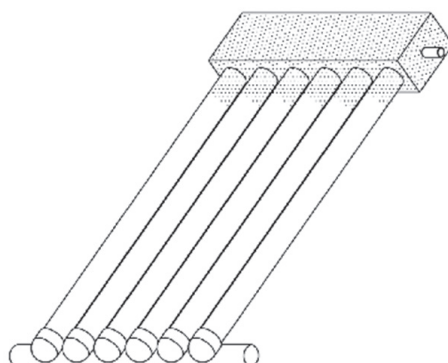


Figure 4 — Spraying areas of evacuated tube collectors

13.4 Results and reporting

The results shall be reported as required in [A.11](#).

14 Freeze resistance test

14.1 Objective

This test is intended to assess the capability of a collector to withstand freezing conditions without damage. This test is only applicable for collectors claimed to be freeze resistant and collectors containing heat pipes. For self-protecting collectors, [5.2.2.3](#) applies. Collectors using additional liquids with the risk of freezing, e.g. in heat pipes, shall be tested for their freeze resistance.

Depending on the collector, one or both of the following methods shall be used.

14.2 Freeze resistant collectors

14.2.1 General

The collector shall be mounted in a cold chamber. The collector shall be fitted correctly, shut completely and inclined at the smallest tilt angle to the horizontal recommended by the manufacturer.

14.2.1.1 Collectors with drain-down freeze protection

Prior to every test cycle, the collector shall be filled with water for 10 min and then drained for 5 min using the device installed by the manufacturer. A temperature sensor shall be attached at the lowest point of the collector piping to monitor the temperature of any remaining water.

14.2.1.2 Freeze-resistant collectors

The collector shall be filled with water at the operating pressure. At the end of each cycle, the collector shall be refilled with water at operating pressure. The temperature of the water shall be monitored throughout the test.

14.2.2 Test conditions

The test temperature shall be set such that the temperature sensor indicates a temperature of maximum $-20\text{ }^{\circ}\text{C}$ (or as specified by the manufacturer) for at least 1 h per cycle. The collector is then thawed to at least $+10\text{ }^{\circ}\text{C}$ sensor temperature and kept warm for at least 1 h per cycle. This test cycle shall be repeated three times.

14.3 Heatpipe collectors

14.3.1 General

This test shall be performed on all heat pipe collectors. A minimum of six heat pipes shall be selected to undergo a freeze resistance test. These heat pipes shall have undergone at least a half exposure as part of a full collector before testing. At least one heat pipe shall be retained as a control sample for comparison with the tested samples. It may be necessary to destroy part of the collector (evacuated tubes, collector housing, etc.) to extract the heat pipes. The test shall be performed in a suitable controllable climate chamber for the duration of a set number of freeze and thaw cycles. Alternatively, a low temperature fluid loop may be used for freezing. The test shall then be performed on a complete assembled collector.

14.3.2 Test conditions

A detailed initial inspection of all of the heat pipes shall document the following:

- the shape (round, oval, cylindrical, conical, etc.) and outside dimensions of all parts of the heat pipe;
- photographic record of all test samples.

At least one heat pipe shall have a temperature sensor attached to ensure an accurate and average temperature is measured. The temperature sensor shall be attached mechanically and thermally to the lower end of a heat pipe near the fluid level when all of the fluid inside the heat pipe is condensed and the heat pipe is held at the tilt to be used in this test. The temperature indicated by this sensor will be assumed to represent the temperature of the fluid inside the heat pipe.

Heat pipes that cannot be separated from the evacuated tube without damage may be tested with the evacuated tube in place. On one additional sample, the condenser shall be opened by drilling a hole so that a temperature sensor can be inserted and run to the location where the heatpipe heat transfer fluid rests.

The heatpipes shall be tested at the highest recommended tilt angle. The test temperature shall be set such that the temperature sensor indicates a temperature of maximum -20°C (or as specified by the manufacturer) for at least 1 h per cycle. The collector is then thawed to at least $+10^{\circ}\text{C}$ sensor temperature and kept warm for at least 1 h per cycle. This test cycle shall be repeated ten times.

A detailed final inspection including a photographic record shall be made for all samples.

14.3.3 Results and reporting

The results shall be reported as required in [A.12](#).

15 Mechanical load test with positive or negative pressure

15.1 Objective

The mechanical load tests are intended to assess the extent to which the collector and its attachment points are able to resist positive pressure load due to wind or snow and negative pressure or uplift forces caused by wind. The mounting hardware is not evaluated.

15.2 Apparatus and procedure

15.2.1 Mounting

The collector shall be installed using the manufacturers' original equipment for mounting. The collector is attached to the mounting hardware at the collector attachment points (see [Figure 5](#)). The mounting hardware is attached to the test rig. The test rig shall be rigid. Flashings or sealing kits that are an integral part of the collector shall be included in the test.