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Énergie solaire — Capteurs thermiques solaires — Méthodes d'essai

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Foreword

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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 ($\lambda > 3$ µm)	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
$K_{hem}(\theta_L,\theta_T)$	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
$\dot{m}_{min}$	Minimum mass flow by the performance test	kg/h
$\dot{m}_{max}$	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
$\dot{Q}_{Peak}$	Peak power. Power output of the collector for normal incidence, G_b = 850 W/m², G_d = 150 W/m² and ϑ_m - ϑ_a = 0 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 $u' = u - 3$ m/s	m/s
U	Measured overall heat loss coefficient of collector with reference to $(\vartheta_m - \vartheta_a)/G_{hem}$	$W/(m^2K)$
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_2O/kg dry air
$X_{W,e}$	Water content of the air at the exit of the solar collector	kg H_2O/kg dry air
$X_{W,i}$	Water content of the air at the inlet of the solar collector	kg H_2O/kg dry air
Δp	Pressure difference between fluid inlet and outlet	Pa
Δt	Time interval	s
ΔT	Temperature difference between fluid outlet and inlet (ϑ_e - ϑ_{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

$\vartheta_{trigger}$	Trigger temperature for safety activation	°C
$\vartheta_{m,th}$	Volume flow weighted mean temperature	°C
$\vartheta_{mp,e}$	Fluid temperate at the downstream air mass flow meter	°C
$\vartheta_{mp,i}$	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 °C ± 15 °C, shielded from light. The test pressure shall remain stable within ±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 Δp > 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.

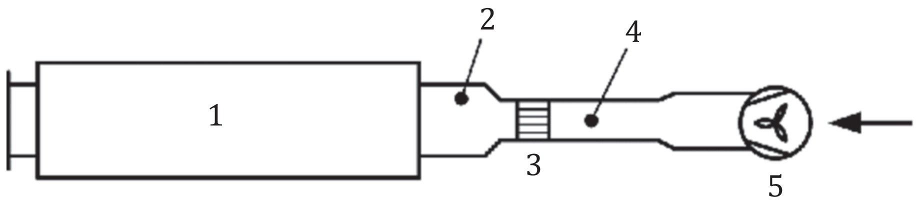
7 Air leakage rate test (air heating collectors only)

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 ±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 W/m^2 and an ambient temperature ϑ_{as} = 30 °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 (α > 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 $0{,}95 \cdot \vartheta_{trigger}$ and $\vartheta_{trigger}$.

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 W/m^2 ± 100 W/m^2 if the measured ambient temperature ϑ_{am} is always within 30 °C ± 10 °C.

Based on the approximation that the ratio $(\vartheta_{sm} - \vartheta_{am})/G_m$ 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):

$$\vartheta_{stg} = \vartheta_{as} + \frac{G_S}{G_m}\left(\vartheta_{sm} - \vartheta_{am}\right) \quad (1)$$

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 W/m^2 and ambient temperature ϑ_{as} = 30 °C is then calculated using Formula (2):

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

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, ($\eta_{0,hem}$·1 000 W/m^2) is replaced by {$\eta_{0,b}$·[K_b(0,0)·850 W/m^2+K_d·150 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 $\dot{Q} \leq \dot{Q}_{peak}/2$ with the additional condition that G > 800 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):

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

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 $\vartheta_{m} = \vartheta'_{stg}(G'_{S},\vartheta'_{am}) + 10\ °C$ 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 ϑ_a.[a]	G_x $\vartheta_{a,x}$		900 W/m² 15 °C	1 000 W/m² 20 °C	1 100 W/m² 40 °C
Irradiation H on collector plane for exposure test during minimum 30 days·	H_x		540 MJ/m²	600 MJ/m²	700 MJ/m²
Irradiation H on collector plane for half-exposure sequence during minimum 15 days.	$H_x/2$		270 MJ/m²	300 MJ/m²	350 MJ/m²

[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 ingression 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 W/m^2) and shall be kept warm by circulating a hot fluid at 55 °C (±5 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 (±0,5 kg/min) per nozzle;

— spray angle of 60° ± 5°;

— drop size >150 µm, according to technical information from spray nozzle manufacturer;

— the water pressure at every nozzle shall be maintained at 300 kPa (±50 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;

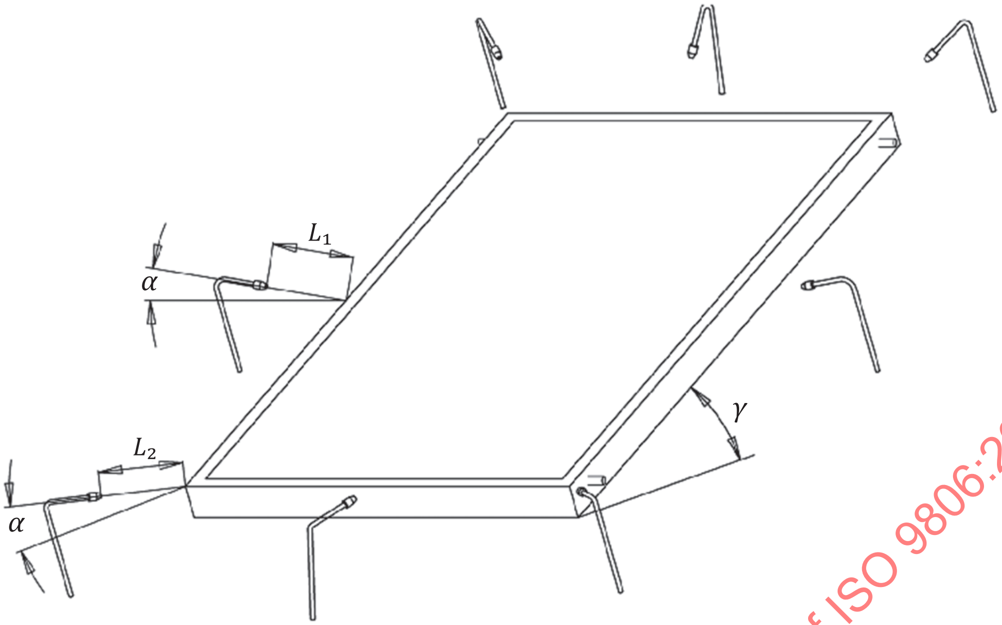
— at least every area shown in Figure 4 (evacuated tube collectors) is sprayed directly;

— the spray nozzles are directed at an angle of 30° (±5°) onto the plane of the collector;

— the spray heads are at a distance of 250 mm (±50 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

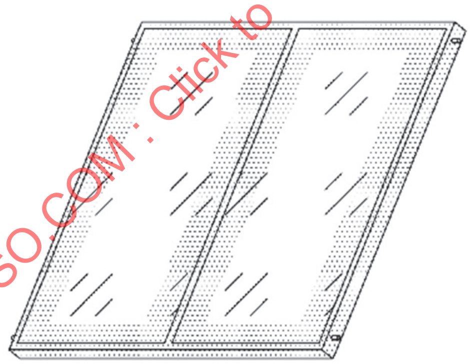


Figure 3 — Spraying areas of flat plate collectors (including middle bar)

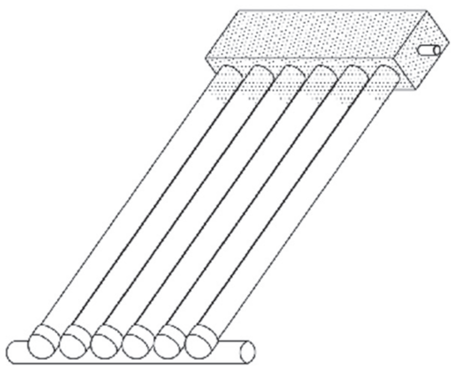


Figure 4 — Spraying areas of evacuated tube collectors

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 °C (or as specified by the manufacturer) for at least 1 h per cycle. The collector is then thawed to at least +10 °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°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

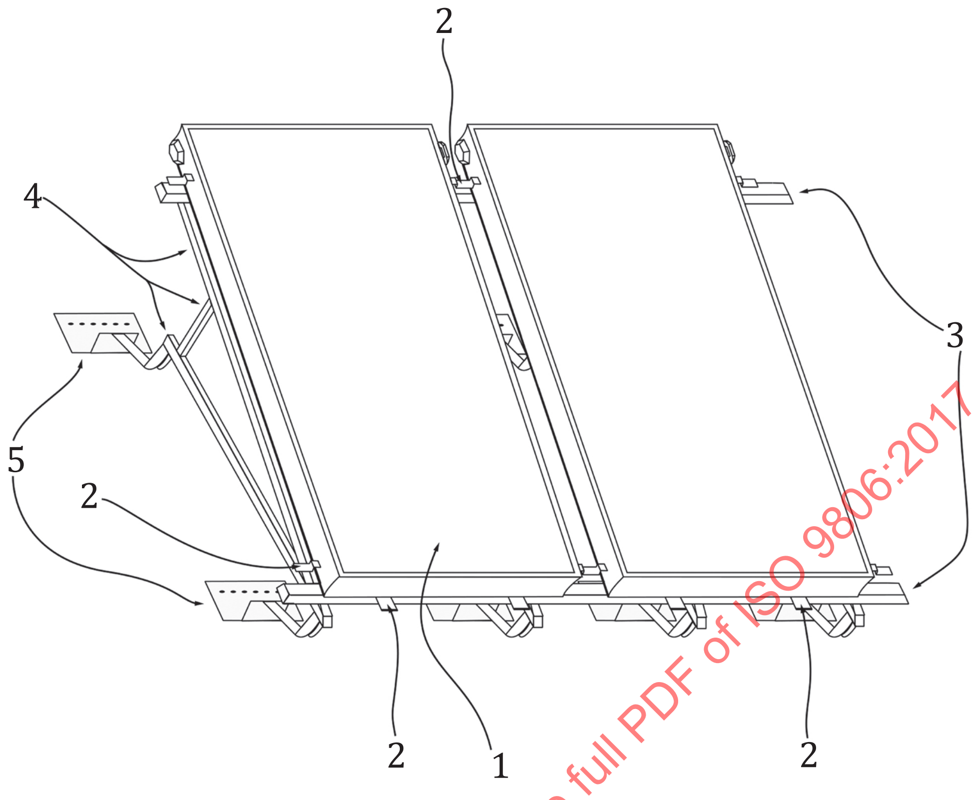
15.1 Objective

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.



Key

1 collector

2 attachment points (relevant for the test result)

3 mounting hardware to be used for testing (attached to the test rig, but not relevant for the test result)

4 stand (not tested)

5 roof hooks (not tested)

Figure 5 — Definition of mounting hardware and attachment points

15.2.2 Methods for the application of the loads

Different methodologies may be used to apply evenly distributed positive and negative load to the collector such as follows.

— Foil and gravel, sand or water: The collector is placed horizontally covered by a flexible foil. A surrounding frame high enough to contain the required amount of gravel, sand or water is placed over the collector. The gravel, sand or water shall be distributed evenly in the frame so that everywhere the same load is created until the desired height is reached.

— Suction cups: Mechanically actuated suction cups are distributed evenly on the collector surface. The suction cups shall not hinder the movement of the collector cover caused by the mechanical load.

— Air pressure: The collector is installed in a test rig where a positive or negative air pressure can be applied from the front or rear side, for example, by using air cushions or by other methods.

Depending on the collector type, other methods may be more appropriate as well, as long as they provide a homogeneous pressure distribution over the whole collector gross area. The test method shall be described in the test report.

15.2.3 Particular specifications for tracking collectors or other specific collector types

If the methods described are not applicable (for example, for tracking parabolic trough collectors), the laboratory shall design specific and suitable procedures to test the resistance against mechanical load in accordance with 5.2. When, according to the manufacturer's instructions, controls are present to protect the collectors against wind or snow load, these control functions shall be checked accordingly. The test setup and procedure shall be clearly described together with the test results.

15.3 Test conditions

The pressures shall be increased in steps of maximum 500 Pa. The reference area to be used is the gross area of the collector. Each load step shall be maintained for a minimum of 5 min. A permanent deformation shall be assigned to a load value, while it is completely relieved after every load increment and the distortion is measured compared to the beginning of the test sequence.

15.4 Results and reporting

The results shall be reported as required in A.13.

16 Impact resistance test

16.1 Objective

This test is intended to assess the extent to which a collector can withstand the effects of impacts caused by hailstones.

16.2 Test procedure

Two test methods are available either using ice balls or steel balls.

The test procedure consists in a succession of shot series on the collector. Each shot series consists in four shots of the same impact strength. For ice balls, the impact strength of a shot is determined by the ball diameter and velocity according to Table 3. For steel balls, the impact strength of the shot is determined by the height of drop according to 16.5.

Balls of increasing impact strength shall be used in the successive shot series. For the first series of shots, the smallest ice ball diameter specified by the manufacturer or the lowest height of drop specified by the manufacturer for the steel ball shall be used.

Impact locations shall be selected according to 16.3.

For evacuated tube collectors, the following rule applies: If one tube breaks, the test shall be repeated with an additional tube. If this tube also breaks, the test is considered as failed.

If the fluid containing absorber can be hit directly by hailstones, the collector shall be filled with a fluid at atmospheric pressure.

16.3 Impact location

a) Glazed flat plate collectors: The points of impact shall be located inside a radius of 75 mm from the visible glass corner. For each series of shots of one specific ice ball diameter or test height, a different corner shall be chosen.

b) Evacuated tube collectors: For each ice ball diameter or height of drop, four randomly chosen tubes of the collector shall be tested. Two tubes shall be tested at the upper end and two tubes at the lower end. The points of impact shall be located at a maximum of 75 mm from the upper visible end and from the lower visible end and impact the tube in the centre where the tube surface is normal to the impact. The shot direction shall be normal to the tube axis.

c) Collectors that cannot be clearly classified into the category a) or b): Four representative impact locations shall be defined by the testing laboratory. The coordinates of the points of impact shall be defined before the shots.

16.4 Method 1: Impact resistance test using ice balls

16.4.1 Apparatus

16.4.1.1 Storage container, for storing the ice balls at a temperature of less than −4 °C.

16.4.1.2 A rigid frame, for supporting the collector, with the impact surface perpendicular to the path of the projected ice ball; the support shall be stiff enough so that there is negligible distortion or deflection at the time of impact.

16.4.1.3 Balance, to determine the mass of an ice ball to a standard uncertainty of ±2 %.

16.4.1.4 Launcher, capable of propelling an ice ball as defined in 16.4.2.

16.4.1.5 Instrument for measuring the velocity of the ice ball to a standard uncertainty of ±1 m/s. The distance of the velocity sensor to the collector surface shall be at maximum 1 m.

16.4.2 Ice balls

The ice balls shall be made of water without any additive. They shall consist in clear ice entirely free of air bubbles and shall not have any crack visible to an unaided eye. The ball diameter shall be one of those listed in Table 3. The ice balls used for the shots shall have a temperature of less than −4 °C.

Table 3 — Ice ball masses and test velocities

Nominal diameter (mm)	**Mass** (g ± 5 %)	**Test velocity** (m/s ± 5 %)
15	1,63	17,8
25	7,53	23,0
35	20,7	27,2
45	43,9	30,7

16.4.3 Specific aspects of the test procedure using ice balls

a) Place the balls in the storage container and leave them there for at least 1 h before use.

b) Ensure that all surfaces of the launcher likely to be in contact with the ice balls are near room temperature.

c) Install the collector at room temperature on the rigid frame.

d) The time between the removal of the ice ball from the container and its impact on the collector shall not exceed 60 s.

e) Fire the shot series on the collector as required. Inspect the collector at the points of impact and take notice of any sign of damage and visible effect of the shots.

16.5 Method 2: Impact resistance test using steel balls

The collector shall be mounted either vertically or horizontally on a support. The support shall be stiff enough so that there is negligible distortion or deflection at the time of impact.

Steel balls shall be used to simulate a hail impact. If the collector is mounted horizontally, then the steel balls are dropped vertically or if it is mounted vertically, then the impacts are directed horizontally by means of a pendulum. In both cases, the height of drop is the vertical distance between the point of release and the horizontal plane containing the point of impact.

If the test is conducted according to this method, the steel ball shall have a mass of 150 g ± 10 g and the following heights of drop shall be considered: 0,4 m, 0,6 m, 0,8 m, 1,0 m, 1,2 m, 1,4 m, 1,6 m, 1,8 m and 2,0 m.

16.6 Results and reporting

The results shall be reported as required in A.14.

17 Final inspection

17.1 Objective

The final inspection is intended to record the structure and materials of the collector and to assess the condition of the collector after completion of testing if it is not going to be used for other tests anymore. Material efficiency aspects according to Annex F may be gathered during the final inspection.

17.2 Test procedure

The collector shall be dismantled and inspected completely under laboratory conditions, i.e. in a non-operating condition, shaded from light and at room temperature. Final inspection shall be considered as a destructive test method and shall therefore be the concluding test.

The collector shall be described as required in A.2. The information given shall be verified against the manufacturer's information.

Following the list in A.15, but not limited to, all defects and abnormalities shall be documented and rated where applicable according to the following key.

— **0 No problem:**

Performance, durability, safety and visual appearance are considered as not affected by the preceding tests and are deemed remaining stable over the expected lifetime.

No outgassing glazing discoloration visible.

— **1 Minor problem:**

Mainly visual appearance aspects, aesthetical defects. Durability and safety are considered as remaining stable over the expected lifetime. Slight outgassing glazing discoloration visible.

Permanent condensation and continuously progressing deficiencies shall be rated as major problems.

— **2 Major failure:**

Severe premature failure concerning performance, durability, safety or visual appearance is found or is to be expected. Significant outgassing glazing discoloration visible.

All findings rated as minor problem or as major failure shall be documented by photographs.

A "major failure" rating is mandatory (if applicable) in case of (but not limited to):

- breaking or permanent deformation of the cover or the cover fixing;
- liquid channel leakage;

— any deformation such that permanent contact between absorber and cover is established;

— breaking or severe deformation of collector fixing points or of the collector box;

— vacuum loss, loss of gas filling;

— dissolution of absorber coating;

— accumulation of humidity in form of permanent condensate on the inside of the transparent cover or permanent local retention of water excessing 25 ml anywhere in the collector.

17.3 Results and reporting

The results shall be reported as required in A.2 and A.15.

18 Test report

The format sheets given in Annex A shall be completed for each test, together with the introductory format sheet A.3 reporting a summary of main results, including the test methods.

19 Thermal performance testing

19.1 General

Thermal performance testing of solar collectors include at least the assessment of the heat power delivered by the collector under various operating conditions (see Clause 23), the measurement of the dependence of the thermal performance on the incidence angle of the irradiation onto the collector (see Clause 26) and the determination of the collector heat capacity (see Clause 25). These three sets of parameters are required for the calculation of the collector heat output.

This document also provides methods to determine additional important parameters such as the pressured drop and the time constant.

If the collector is supplied in fixed units of gross area smaller than 1 m^2, then a sufficient number of modules shall be linked together to give a test collector with a gross area of at least 1 m^2.

Two methods are available for thermal performance testing: the steady-state method and the quasi-dynamic test method. Both methods are deemed to provide equivalent test results and methods for mutual converting the parameters sets are available.

Thermal performance testing is possible on outdoor test facilities, as well as on indoor test rigs using a solar simulator.

19.2 Performance test using a solar irradiance simulator

19.2.1 General

The performance of collectors is affected by the amount of direct and diffuse solar radiation. Therefore, only solar simulators can be used for performance testing where a near-normal incidence beam of simulated solar radiation can be directed at the collector.

In practice, it is difficult to produce a uniform beam of simulated solar radiation and a mean irradiance level has therefore to be measured over the collector gross area.

19.2.2 Solar irradiance simulator for performance testing

Simulators for performance testing shall have the following characteristics.

The lamps shall be capable of producing a mean irradiance over the collector gross area of at least 700 W/m^2. All measurements shall start only after reaching stable working conditions.

At any time, the irradiance at any point on the collector gross area shall not differ from the mean irradiance over the gross area by more than ±15 %. The collimation of the simulator shall be such that the angles of incidence of at least 80 % of the simulated solar irradiance lie in the range in which the incident angle modifier of the collector varies by no more than ±2 % from its value at normal incidence. For typical flat plate collectors, this condition usually will be satisfied if at least 80 % of the simulated solar radiation received at any point on the collector under test shall have emanated from a region of the solar irradiance simulator contained within a subtended angle of 60° or less when viewed from any point. Additional requirements concerning collimation apply to measurements of the incident angle modifier (see 19.2.3).

The measured irradiance G shall be presented in the test report as a table for a grid spacing of maximum 150 mm over the whole collector gross area. The irradiance G_{hem} shall be measured in the plane of the absorber.

The spectral distribution of the simulated solar radiation shall be approximately equivalent to that of the solar spectrum at optical air mass 1,5. Measurement of the solar simulator's spectral qualities shall be made in the plane of the collector over the wavelength range of 0,3 µm to 3 µm and shall be determined in bandwidths of 0,1 µm or smaller. The thermal irradiance at the collector shall not exceed that of a blackbody cavity at ambient air temperature by more than 5 % of hemispherical irradiance.

The initial spectral determination shall be performed after the lamps have completed their burn-in period. The amount of infrared thermal energy at the collector plane shall be suitably measured (measurements in the wavelength range above about 2,5 µm if possible, but starting not beyond 4 µm).

A check shall be made to establish the effect of the difference in spectrum on the $(\tau\alpha)$ product for the collector. If the effective values of $(\tau\alpha)$ under the simulator and under the optical air mass 1,5 solar radiation spectrum differ by more than ±1 %, then a correction shall be applied to the test results.

$$(\tau\alpha)_{\text{eff}} = \frac{\int_{0{,}3\,\mu\text{m}}^{3\,\mu\text{m}} \tau(\lambda)\alpha(\lambda)G(\lambda)\text{d}\lambda}{\int_{0{,}3\,\mu\text{m}}^{3\,\mu\text{m}} G(\lambda)\text{d}\lambda} \quad (4)$$

A correction shall be applied to the zero heat loss efficiency measured in the simulator as shown in Formula (5):

$$\eta_{0,\text{hem}} = \eta_{0,\text{hem,measured}} \frac{(\tau\alpha)_{\text{eff};G=AM1{,}5}}{(\tau\alpha)_{\text{eff};G=\text{Simulator}}} \quad (5)$$

Alternatively, the peak efficiency η_0 can be determined in an outdoor measurement. If this value differs by more than ±1 % from the simulator measurement, then a correction shall be performed.

The major difference between indoor and outdoor testing of WISC collectors is the long wave thermal irradiance. The long wave radiation in a simulator shall not be higher than 50 W/m^2 (typically −100 W/m^2 for outdoor conditions).

The fluctuation of irradiance shall be less than ±1 % over the test period.

19.2.3 Solar irradiance simulator for the measurement of incidence angle modifiers

For the measurement of the incidence angle modifier, only solar irradiance simulators fulfilling at least all requirements of 19.2.2 shall be used. The collimation shall be such that at least 90 % of the simulated solar irradiance at any point on the collector under test has emanated from a region of the solar irradiance simulator contained within a subtended angle of 20° or less when viewed from the point.

The measured irradiance data and the measured collimation shall be measured with a grid spacing of maximum 150 mm over the whole collector gross area.

20 Collector mounting and location

20.1 General

The collector shall be mounted as specified by the manufacturer. Unless otherwise specified, an open mounting structure shall be used which allows air to circulate freely around the front, back and sides of the collector.

Collectors specified for roof/wall integration only, shall be installed according to the manufacturers' instruction and using the original parts (e.g. flashing kits) on a simulated roof/wall structure where the rear side of the collector is protected from wind, but without additional insulation.

Collectors specified to be installed on an insulated structure (some wall collector designs, some swimming pool collectors, WISC collectors, etc.) shall be mounted on an insulated backing with a quotient of the materials thermal conductivity to its thickness of 1 W/(m^{2}K) ± 0,3 W/(m^{2}K) and the upper surface painted matt white and ventilated at the back. The use of such insulation has to be described clearly in the test report together with a statement that the measured performance results are possible only when using an additional back insulation with the thermal conductivity as used for the test.

NOTE Example material suited for the insulated backing is 30 mm of polystyrene foam.

For site-built collectors not supplied in a pre-specified size, it shall be checked that a realistic flow pattern and flow velocity is used during the performance tests.

The collector shall be mounted such that the lower edge is not less than 0,5 m above the local ground surface. Currents of warm air, such as those that rise up the walls of a building, shall not be allowed to pass over the collector. Where collectors are tested on the roof of a building, they shall be located at least 2 m away from the roof edge.

20.2 Collector orientation outdoors

The azimuthal deviation of the collector from equatorial facing shall be taken into account when calculating the angle of incidence of solar radiation onto the collector area. Larger deviations from equatorial facing may be acceptable, but will lead to a non-symmetrical angular distribution of beam radiation.

20.3 Shading from direct solar irradiance

The location of the test stand shall be such that no shadow is cast on the collector and the irradiance measurement instruments during the test.

20.4 Diffuse and reflected solar irradiance

For the purposes of analysis of outdoor test results, solar irradiance not coming directly from the sun's disc is assumed coming isotropic from the hemispherical field of view of the collector. The collector shall be located where there is no significant solar radiation from surrounding buildings or surfaces reflected onto it, and where there are no significant obstructions in the field of view. Surfaces to be avoided in the collector's field of view include large expanses of glass, metal or water. It is also important to minimize reflections to the rear side of the collector, especially for evacuated tube collectors. The reflectance of most rough surfaces such as grass, weathered concrete or chippings is usually low enough so no problem is caused during collector testing.

In solar simulators, the simulated beam approximates direct solar irradiance only and it is necessary to minimize reflected irradiance. This can be achieved by painting all surfaces in the test chamber with dark low reflectance paint.

The solar reflectance of the background used during the performance test of collectors being non-opaque from the back shall not exceed 20 %.

20.5 Thermal irradiance

The thermal performance of some collectors is particularly sensitive to the levels of thermal irradiance. The temperature of surfaces adjacent to the collector shall be as close as possible to that of the ambient air in order to minimize the influence of thermal radiation. For example, the outdoor field of view of the collector shall not include chimneys, cooling towers or hot exhausts. For indoor and simulator testing, the collector shall be shielded from hot surfaces such as radiators, air-conditioning ducts and machinery, and from cold surfaces such as windows and external walls. Shielding is important both in front of and behind the collector.

20.6 Surrounding air speed

The thermal performance of many collectors is sensitive to surrounding air speeds. To maximize the reproducibility of the measurements, collectors shall be mounted such that air can freely pass over the aperture, back and sides of the collector.

Collectors designed for integration into a building envelope may have their backs protected from the wind; if so, this shall be reported with the test results.

The average surrounding air speed at a distance of 50 mm above and parallel to the collector front side shall cover the range specified in 23.3.3.2 subject to the tolerance specified in Table 6. If these conditions cannot be achieved under natural conditions, then an artificial wind generator shall be used.

21 Instrumentation

21.1 Solar radiation measurement

21.1.1 Pyranometer

21.1.1.1 General

Class I or better, as specified in ISO 9060, pyranometer(s) shall be used to measure the hemispherical solar radiation following the recommendation given in ISO/TR 9901. Class I or better pyranometer(s) equipped with a shading ring or alternatively a pyrheliometer, together with a pyranometer, shall be used to measure the diffuse short-wave radiation.

For highly concentrating collectors (CR > 3) mounted on the original manufacturer's solar tracking device, a pyrheliometer of Class I or better, as specified in ISO 9060, shall be used to measure the direct normal irradiance (DNI). The pyrheliometer shall be mounted on a separate solar tracking device. The pyrheliometer field of vision shall be no more than 6° of arc. The tracking errors associated to the mounting on the tracker shall not exceed ±0,5°.

Beam and diffuse irradiance shall be calculated by $G_b = \mathrm{DNI}\cdot\cos(\theta)$ and $G_d = G_{hem} - G_b$.

21.1.1.2 Mounting of the pyranometer

The pyranometer shall be installed such as to receive the same levels of direct, diffuse and reflected solar radiation as are received by the collector. The pyranometer shall be mounted such that its sensor is coplanar, within a tolerance of <1° with the collector plane. It shall not cast a shadow onto the collector area at any time during the test period. Care shall also be taken to prevent energy reflected from the solar collector onto the pyranometer. The body of the pyranometer and the emerging leads of the connector shall be shielded to minimize solar heating of the electrical connections.

21.1.1.3 Measurement of the angle of incidence of direct solar radiation

Incidence angles shall be determined by calculation or with sun position sensors with accuracy equal or higher than ±1°. In case of non-imaging stationary collectors as CPCs, they shall be mounted so that the beam radiation from the sun falls within the angular acceptance range of the design.

21.2 Thermal radiation measurement

21.2.1 General

If required, the long wave irradiance, E_L, shall be measured using a pyrgeometer mounted in the plane of the collector. The thermal irradiance shall be determined to a standard uncertainty of 10 W/m^2.

21.2.2 Measurement of thermal irradiance outdoors

The pyrgeometer shall be mounted to one side at mid-height of the collector.

21.2.3 Measurement of thermal irradiance indoors

Pyrgeometer shall be well ventilated to minimize the influence of solar or simulated solar irradiance. The influence of short wave solar heating effects shall be minimized.

21.3 Temperature measurements

21.3.1 General

Three temperature sensors are required for thermal performance measurements. These are the fluid temperature at the collector inlet, the fluid temperature at the collector outlet, and the ambient air temperature. The required accuracy and the environment for these measurements differ, and hence the sensor for temperature measurement and associated equipment may be different.

21.3.2 Heat transfer fluid temperatures (Liquid heating collectors)

21.3.2.1 Required accuracy

The difference between the collector outlet and inlet temperatures (ΔT) shall be determined to a standard uncertainty of <0,05 K and to an accuracy of better than 1 %.

21.3.2.2 Mounting of sensors

The sensor for temperature measurement of the heat transfer liquid shall be mounted at no more than 200 mm from the collector inlet and outlet, and insulation shall be placed around the pipe work both upstream and downstream of the sensor. If it is necessary to position the sensor more than 200 mm away from the collector, then a test shall be made to verify that the measurement of fluid temperature is not affected. To ensure mixing of the fluid at the position of temperature measurement, a bend in the pipe work, an orifice or a fluid-mixing device shall be placed upstream of the sensor. The sensor probe shall point upstream and in a pipe where the flow is rising (to prevent air from being trapped near the sensor).

21.3.3 Volume flow weighted mean temperature $\vartheta_{m,th}$ (Air heating collectors)

21.3.3.1 General

The volume flow weighted mean temperature describes the volume flow, heat capacity and density weighted temperature defining the mean temperature in an air duct.

If an airflow with $\vartheta > \vartheta_a$ is flowing through a ventilation channel, a certain temperature distribution is created and, consequently, a density and heat capacity distribution due to heat losses of the ventilation channel and the given flow velocity distribution in the ventilation channel. The weighted mean temperatures $\vartheta_{m,th,in}$ and $\vartheta_{m,th,out}$ are the representative temperatures for the caloric balance of an air heating collector.

$$\vartheta_{m,th} = \frac{\iint \vartheta(x,y) v(x,y) \rho(x,y) c(x,y) \mathrm{d}x\mathrm{d}y}{\iint v(x,y) \rho(x,y) c(x,y) \mathrm{d}x\mathrm{d}y} \quad (6)$$

Due to the small influence of density and heat capacity, this can be reduced to Formula (7):

$$\vartheta_{m,th} = \frac{1}{Av_m} \iint \vartheta(x,y) v(x,y) \mathrm{d}x\mathrm{d}y \quad (7)$$

The flow distribution shall be homogenized constructively over the channel cross-section. The temperature measurement shall be designed in a way that temperature gradients are balanced over the channel cross-section. For example, the flow distribution can be homogenized by introducing fine-mesh nets in the ventilation channel. Using an averaging, evenly distributed (Archimedean spiral) temperature sensor in the channel, the thermal average temperature can be determined.

21.3.3.2 Required accuracy

The temperature of the heat transfer fluid at the collector inlet shall be measured to a standard uncertainty of ±0,2 K. In order to check that the temperature is not drifting over time, higher resolution of the temperature signal of ±0,04 K is required.

21.3.3.3 Mounting of sensors

The sensor for temperature measurement shall be mounted at no more than 200 mm from the collector inlet/outlet and insulation shall be placed around the ducts both upstream and downstream of the sensor. If it is necessary to position the sensor more than 200 mm away from the collector, then a test shall be made to verify that the measurement of the fluid temperature is not affected; this can be done by a recalculation of the inlet and outlet temperature difference.

NOTE An example of a possible sensor configuration is given in Annex E.

21.3.3.4 Determination of heat transfer fluid temperature difference (ΔT)

The difference between the collector outlet and inlet temperature (ΔT) shall be determined to a standard uncertainty of <0,2 K. Delta-T sensors shall be calibrated in the relevant flow range and temperature range.

21.3.4 Measurement of ambient air temperature

21.3.4.1 Required accuracy

The ambient air temperature shall be measured to a standard uncertainty of <0,5 K.

21.3.4.2 Mounting of sensors

For outdoor measurements, the sensor shall be shaded from direct and reflected solar radiation by means of a white-painted, well-ventilated shelter, preferably with forced ventilation. The shelter itself shall be shaded and placed at the mid-height of the collector but at least 1 m above the local ground surface to ensure that it is removed from the influence of ground heating. The shelter shall be positioned not more than 10 m distance to the collector.

If air is forced over the collector by a wind generator, the air temperature shall be measured in the outlet of the wind generator and checks made to ensure that this temperature does not deviate from the ambient air temperature by more than ±2 K.

21.4 Flow rate measurement

21.4.1 Measurement of mass flow rate (liquid)

The standard uncertainty of the mass flow rate measurement shall be within ±1 % of the measured value. The flow meter shall be calibrated over the range of fluid flow rates and temperatures to be used during collector testing.

21.4.2 Measurement of collector fluid flow rate (Air heating collectors)

The standard uncertainty of the mass flow rate measurement shall be within ±2 % of the measured value. Through the determination of pressure and temperature, the volumetric flow rate can be converted to mass flow rate, as given in Formula (8)

$$\dot{m} = \dot{V} \cdot \rho_l \tag{8}$$

Where the density ρ_l is calculated as in Formula (9):

$$\rho_l = \frac{(1\,000 + X_W)}{(1\,000 \cdot R_L + X_W \cdot R_D)} \cdot \frac{(p_{abs} + p_f)}{(\vartheta_{mp} + 273{,}15)} \tag{9}$$

These parameters shall be measured to a standard uncertainty better than given in Table 4.

Table 4 — Maximum allowed measurement uncertainties

Parameter	Measurement value	Standard uncertainty
$\dot{V}$	Volumetric flow	±1 %
$\vartheta_{\dot{m}}$	Temperature of airflow at the volumetric flow rate measurement unit	±1 K
p_{abs}	Absolute pressure of the ambient air	±50 Pa
$\dot{m}$	Mass flow rate	±2 %

To determine the flow rate, measurement methods using the differential pressure method (orifice plates, venturi tubes or laminar-flow-elements) or mechanical methods (turbine gas meter) shall be used. Thermal measurement methods are not applicable due to large measurement errors caused by the water content in the air.

21.5 Measurement of air speed over the collector

21.5.1 General

The relationship between the meteorological wind speed and the air speed over the collector depends on the location of the test facility, so that meteorological wind speed is not a useful parameter for collector testing. By using the air speed measured over the collector, it is possible to define clearly the conditions in which the tests were performed. The air speed shall be monitored during the test at a convenient point that has been calibrated relative to the mean air speed over the collector.

21.5.2 Required accuracy

The speed of the surrounding air over the front surface of the collector shall be measured to a standard uncertainty of <0,5 m/s. It shall be taken into consideration that most anemometers have starting limits which lies between 0,5 m/s and 1 m/s. The surrounding air speed is usually not constant under outdoor conditions. The measurement of an average air speed is therefore required, either by an arithmetic average of sampled values or by a time integration over the test period.

21.5.2.1 Mounting of sensors for the measurement of air velocity over the collector

21.5.2.1.1 General

Surrounding wind or artificial wind generators may be used to provide the required wind speed parallel to the collector surface for testing. The uniformity of air speed in the field of collector area shall be checked as the air speed may vary from one end of the collector to the other. A series of air speed measurements shall be taken using a hand-held anemometer at a distance of 50 mm in front of the plane of the collector, at equally spaced positions over the whole collector area. An average value shall then be determined. The turbulence level shall always be in the range of 15 % to 40 %. During the test, the air speed shall then be monitored continuously at a convenient point that has been calibrated relative to the mean air speed over the collector, considering also surrounding air speed. The sensor shall not be shielded from the wind and it shall not cast a shadow on the collector during the test periods.

For collectors without back insulation and for collectors that are not mounted on a simulated roof surface, the air speed shall be adjusted and measured over the front and back surfaces. The average air speed on the front and back surface shall be used in the data correlation.

21.6 Elapsed time measurement

Elapsed time shall be measured to a standard uncertainty of <0,2 %.

21.7 Humidity measurement (Air collectors)

When air is used as the heat transfer fluid, its moisture content is needed for the correct determination of the specific heat capacity of air. The humidity ratio X_W shall be measured to an accuracy of ±0,001 (kg water/kg dry air) at 25 °C fluid temperature.

21.8 Collector dimensions

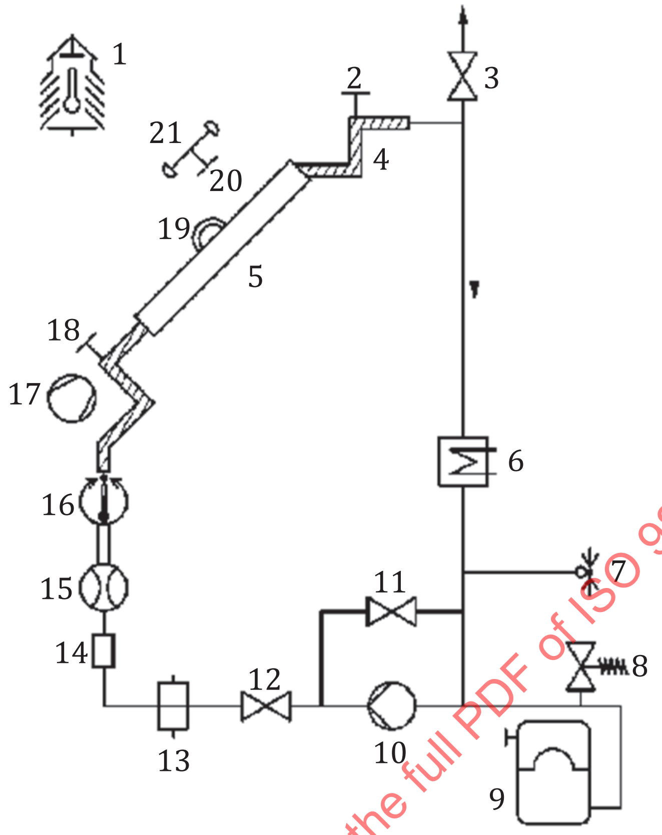
The collector dimension shall be measured to a standard uncertainty better than 0,3 %. Area measurements shall take place at a collector temperature of 20 °C ± 10 °C and under operating pressure if the absorber is made of polymeric material. If the resulting collector area is within 1 % of the manufacturer's specification, then the manufacturer's specification may be reported and used for efficiency calculation. If not, the measured collector area shall be used.

22 Test installation

22.1 Liquid heating collectors

22.1.1 General

An example of schematic test configurations for liquid heating collectors is shown in Figure 6.



Key

1 ambient temperature sensor
2 temperature sensor (ϑ_e)
3 air vent
4 insulated pipe
5 solar collector
6 heater/cooler for primary temperature control
7 pressure gauge
8 safety valve
9 expansion tank
10 pump
11 bypass valve
12 flow control valve
13 filter (200 µm)
14 sight glass
15 flow meter
16 secondary temperature regulator
17 artificial wind generator
18 temperature sensor (ϑ_{in})
19 pyrgeometer
20 pyranometer
21 anemometer

Figure 6 — Example of a closed test loop

22.1.2 Heat transfer fluid

The heat transfer fluid used for collector testing may be water or a fluid accepted by the collector manufacturer. The specific heat capacity and density of the fluid used shall be known to within ±1 % over the range of fluid temperatures used during the tests. Values for water are given in Annex C.

22.1.3 Pipe work and fittings

Pipe work shall be insulated such that the temperature gains or losses between the temperature sensing points and the collector inlet and outlet are reduced as much as possible under test conditions.

The collector pipe work shall be vented of trapped air and any contaminants shall be removed.

22.1.4 Pump and flow control devices

The fluid pump shall be located in the collector test loop such that the heat that is dissipated in the fluid does not affect either the control of the collector inlet temperature or the measurements of the fluid temperatures. The pump and flow controller shall be capable of maintaining the mass or volume flow rate through the collector stable to within 1 % despite temperature variations, at any inlet temperature chosen within the operating range.

22.2 Air heating collectors

22.2.1 General

Different types of air heating collectors are distinguished.

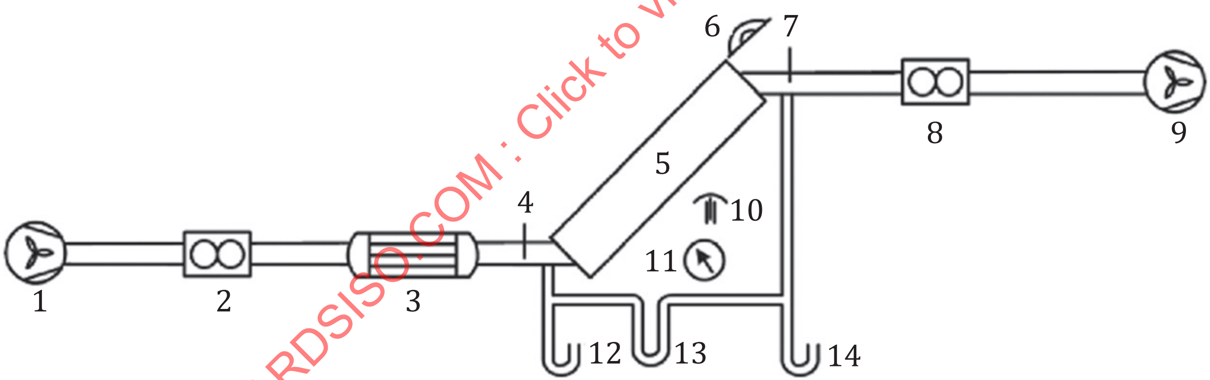
— Air heating collectors working in a closed air circuit (closed loop).

— Air heating collectors sucking ambient air. Transpired collectors where ambient air is sucked through the absorber material, or through the perforated glazed collector cover.

— Open to ambient air heating collectors where ambient air is sucked in at defined inlet openings.

22.2.2 Closed loop test circuit

Closed loop collectors shall be measured in a test loop as outlined in Figure 7. Two flow meters shall be used, one at the inlet and one at outlet. The collector shall be measured at ambient pressure, which is realized by using two fans. Between the two fans, an area where the air can be conditioned can be installed.



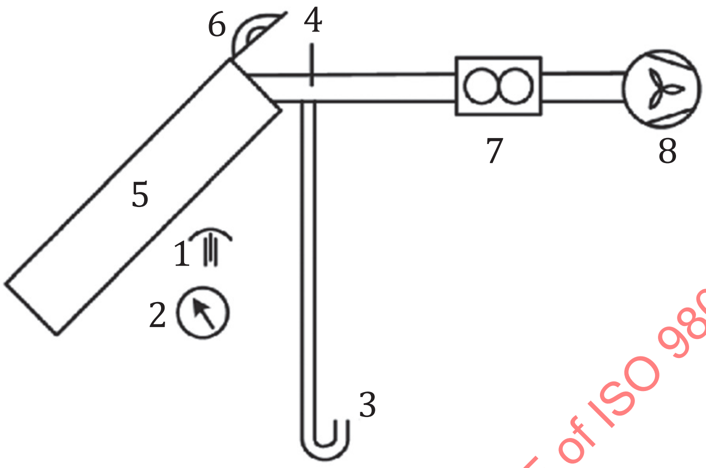
Key

1	fan	8	flow meter
2	flow meter	9	fan
3	electric air heater	10	ambient temperature sensor (ϑ_a)
4	temperature sensor (ϑ_{in})	11	pressure gauge for surrounding air (p_{abs})
5	solar air heater	12	pressure gauge ($p_{f,i}$)
6	pyranometer (G)	13	differential pressure ($\Delta p = p_{f,i} - p_{f,e}$)
7	temperature sensor (ϑ_e)	14	pressure gauge ($p_{f,e}$)

Figure 7 — Example of a closed test loop

22.2.3 Open to ambient test circuit

The mass flow for open to ambient air heating collectors can only be determined at the collector outlet. The collector inlet temperature corresponds to the ambient temperature. An example of a test configuration for testing open to ambient air heating collectors is shown in Figure 8.



Key

1 ambient temperature sensor (ϑ_a)

2 pressure gauge for surrounding air (p_{abs})

3 pressure gauge ($p_{f,e}$)

4 temperature sensor (ϑ_e)

5 solar air heater

6 pyranometer (G)

7 flow meter $\left[\dot{m}_e = f\left(\dot{V}_e, \vartheta_{mp,e}, rH_e, p_e\right)\right]$

8 fan

Figure 8 — Example of an open to ambient test setup

22.2.4 Heat transfer fluid

To determine the specific heat capacity of the air at each measurement point, the temperature and humidity are needed. This can be calculated with the fluid temperature as given in 21.3.3. The density shall be calculated as described in 21.4.2.

22.2.5 Test ducts

The air ducts upstream and downstream of the collector shall be of the same cross-sectional dimension as the collector inlet and outlet, respectively. The airflow pattern inside the collector is very important for a correct assessment of the performance. The airflow pattern inside the collector (especially the partition close to the inlet) mainly depends on the connection between ducting system and collector. In standardized tests, only a single collector module is tested, which might not comply with the mode of installation in practise.

To reach an even air flow pattern throughout the collector, regular distribution ducts provided by the manufacturer at the inlet and outlet shall be used for each collector tested. By means of boxes with perforated metal sheets at inlet and outlet, a well distributed air flow can be achieved, which means that an even air flow from the centre-line of the collector to the edges from entrance to outlet exists. The section between the inlet and outlet temperature sensor unit and the collector inlet and outlet shall be insulated to limit the heat losses to ±0,2 W/K. Filters shall be placed upstream of the flow measuring device and the fan in accordance with normal practice (a nominal filter size of 200 µm is usually adequate).

Care shall be taken to ensure that air leakage from the measurement system does not affect the accuracy of the measured collector thermal performance. Before the performance measurement, the inlet and outlet test ductwork shall be tested for leaks. The same method shall be used as described in Clause 7. No component shall have a higher leakage rate than 2 m^3/h at 250 Pa.

22.2.6 Fan and flow control devices

The fan shall be located in the collector test loop in such a position that the heat from it, which is dissipated in the fluid, does not affect either the inlet temperature or the measurements of the fluid temperature rise through the collector. The fan and flow controller shall be capable of maintaining the mass flow rate through the collector stable to within ±1,5 % despite temperature variations, at any inlet temperature chosen within the operating range.

22.2.7 Air preconditioning apparatus

The air preconditioning apparatus shall control the dry bulb temperature of the transfer medium entering the solar collector to within ±1,0 K of the desired test value at all times during the test period. Since the rate of energy collection in the collector is deduced by measuring instantaneous values of the fluid inlet and outlet temperatures, small variations in inlet temperature lead to errors in the rates of energy collection deduced. It is particularly important to avoid any drift in the collector inlet temperature.

22.2.8 Humidity ratio

When air is the transfer fluid and the test panel is operated at a negative pressure, the humidity ratio of the test fluid shall be equal to the humidity ratio of the air surrounding the test panel.

NOTE It is important to measure and control the humidity at the different measuring points. It is especially important to avoid that condensation occurs within the testing loop.

23 Thermal performance test procedures

23.1 General

The thermal performance of the solar collectors shall be tested according to one of the methods described in the following subclauses.

For collectors co-generating heat and electric power, the operation mode of the electric power generator (e.g. open or short circuit), has an influence on the thermal performance and shall be described in the report.

In case of concentrating collectors, the following applies:

— concentrating collectors without transparent cover and a concentration ration of C_R < 10 shall be treated as WISC collectors;

— concentrating collectors with transparent cover and with a concentration ratio of C_R < 3 shall be treated as any other glazed collector;

— for concentrating collectors with a transparent cover and a concentration ratio of C_R > 3, wind speed dependency can be neglected;

— for evacuated concentrating collectors, wind speed dependency can be neglected independent of the concentration ratio C_R;

— the thermal performance of highly concentrating tracking collectors is usually tested according the quasi-dynamic test method. The steady-state method may be used if a distinction between beam and diffuse irradiance is taken into account. The requirements and parameters as described in 24.1.3 for quasi-dynamic testing shall be followed.

23.2 Preconditioning of the collector

The collector shall be preconditioned under stagnation conditions (see 9.2) for at least 5 h at the level irradiation higher than 700 W/m² and ambient temperature higher than 10 °C. Half-exposure or exposure test is sufficient to satisfy this preconditioning. 5.2.2 applies if the collector is equipped with means to prevent from stagnation.

The collector cover, reflectors and tubes shall always be thoroughly cleaned for all thermal performance measurements. If moisture is formed on the collector components, the heat transfer fluid may be circulated at elevated temperatures for as long as is necessary to dry out collector again. If this form of preconditioning is carried out, then it shall be reported with the test results.

23.3 Test conditions

23.3.1 General

The heat transfer flow pattern shall be selected as recommended by the manufacturer and shall be described in the test report.

23.3.2 Flow rates

If the recommended fluid flow rate is close to the transition region between laminar and turbulent flow, this can cause instability of the internal heat transfer coefficient and variations in the measurements of the collector efficiency. To characterize such a collector, it may be necessary to use a higher flow rate, but this shall be clearly stated with the test results.

The flow rate shall be held stable according to Table 6 (steady-state) or to within ±2 % (quasi-dynamic) of the set value during each test period and shall not vary by more than ±5 % of the set value from one test period to another.

23.3.2.1 Flow rate for liquid heating collectors

The fluid flow rate shall be set at approximately 0,02 kg/s per square meter of collector gross area. If this is not within the manufacturers' specification, a reasonable flow rate within the specification shall be selected.

23.3.2.2 Flow rate for air heating collectors

The fluid flow rate shall be set as close as possible to the maximum, the minimum and the medium flow rate as specified by the manufacturer.

In case of a standalone collector (e.g. integrated PV for power supply for the fan and implicitly used as flow rate controller), the generated volumetric flow range dependence on the irradiance level shall be given.

23.3.3 Steady-state method

23.3.3.1 General

The angle of incidence of direct solar radiation at the plane of the collector shall be in the range in which the incident angle modifier for the collector varies by no more than ±2 % from its value at normal incidence. The collector shall be tested at diffuse irradiance levels of always less than 30 %.

At the time of the test, the hemispherical solar irradiance at the plane of the collector shall always be greater than 700 W/m^2.

23.3.3.2 Air speed parallel to the collector plane

For glazed collectors, the average value of air speed parallel to the plane of the collector, taking into account spatial variations over the collector and temporal variations during the test period, shall be 3 m/s ± 1 m/s.

For WISC collectors, measurements shall be made at three average air speed ranges parallel to the surface of the collector: <1 m/s, 1,5 ± 0,5 m/s and 3 ± 0,5 m/s.

23.3.3.3 Air heating collectors

Data points shall satisfy the requirements given below and be obtained for at least four fluid inlet temperatures evenly spaced over the specified operating temperature range of the collector. If possible, one inlet temperature shall be selected such that the mean inlet temperature is within ±3 K of the ambient air temperature, in order to obtain an accurate determination of $\eta_{0,\mathrm{hem}}$.

For open to ambient collectors, all data points are measured for inlet temperatures equal to the ambient temperature.

The air heating collector shall be measured at ambient pressure [i.e. $(p_\mathrm{i}+p_\mathrm{e})/2 = p_\mathrm{abs}$ and $\dot{m}_\mathrm{i} = \dot{m}_\mathrm{e}$] to minimize the volumetric leakage flow rate.

23.3.4 Quasi dynamic test

The average value of the surrounding air speed, taking into account spatial variations over the collector and temporal variations during the test period, shall be less than 4 m/s.

For glazed collectors, the air speed parallel to the plane of the collector, taking into account spatial variations over the collector and temporal variations during the test period, shall be 3 m/s ± 1 m/s. For WISC collectors, measurements shall be made over the whole range of wind speeds between 0 m/s and 4 m/s. Wind generators may be used if necessary to achieve sufficient wind speeds.

23.4 Test procedure

23.4.1 General

The collector shall be tested over the whole range of operating temperatures specified by the manufacturer. The inlet temperature shall always be kept above the dew point so that condensation of water on the absorber is avoided. If possible, one inlet temperature shall be selected such that the mean collector temperature is within ±3 K of the ambient air temperature.

During a test, the measurements shall be made as specified in 23.5.

23.4.2 Steady-state testing of liquid heating collector

Data sets shall be measured for at least four fluid inlet temperatures spaced evenly over the operating temperature range of the collector. At least four independent data points shall be obtained for each fluid inlet temperature. When testing in a solar simulator, at least two independent data points shall be obtained for each fluid inlet temperature

23.4.3 Steady-state testing of air heating collectors

The collector shall be tested over its operating temperature range and over the specified range of mass flow rates.

23.4.4 Steady-state testing of WISC collectors

Data sets shall be measured for at least three fluid inlet temperatures spaced evenly over the operating temperature range. At least four independent data points shall be obtained for each data set (inlet temperature and wind speed) to give 36 data points. When testing on a solar simulator, at least two independent data points shall be obtained for each fluid inlet temperature to give a total number of 18 data points.

23.4.5 Quasi dynamic testing

Data points satisfying the requirements given below shall be obtained for at least four fluid inlet temperatures spaced evenly over the operating temperature range of the collector.

Weather conditions shall be as described in 23.6.2, sequence day types 1 through 4. The second and third inlet temperature shall be selected so that the mean fluid temperature in the collector is evenly spaced between the lowest and the highest operating range of the collector.

The change in inlet temperature shall be done after each test sequence has been completed. Data recorded during this “step-change” period shall not be included in the test data. The inlet temperature shall be kept stable within ± 1 K during each test sequence.

23.5 Measurements

23.5.1 General

Depending on the chosen test method, the quantities in Table 5 shall be measured.

Table 5 — Measured quantities during testing

	Steady-state liquid heating	Steady-state solar air heating	WISC collectors and Quasi dynamic testing
Hemispherical solar irradiance at the plane of the collector	X	X	X
Diffuse solar irradiance at the plane of the collector (only outdoors)	X	X	X
Angle of incidence of direct solar radiation (only outdoors) (alternatively, this angle may be determined by calculation)	X	X	X
Air speed parallel to the plane of the collector	X	X	X
Temperature of the ambient air	X	X	X
Temperature of the heat transfer fluid at the collector inlet and outlet	X	X	X
Flow rate of the heat transfer fluid	X	—	X
Dew point temperature of the surrounding air	—	X	—
(Relative) humidity of the fluid at the collector inlet and outlet	—	X	—
The mass flow rate of the heat transfer fluid at the collector inlet (only closed loop)	—	X	—
The mass flow rate of the heat transfer fluid at the collector outlet	—	X	—

Table 5 *(continued)*

	Steady-state liquid heating	Steady-state solar air heating	WISC collectors and Quasi dynamic testing
Static pressure of the heat transfer fluid at the inlet and outlet of the solar collector	—	X	—
Absolute pressure of the ambient air	—	X	—
Long wave thermal irradiance in the collector plane	—	—	X (WISC only)

23.5.2 Additional measurements during tests in solar irradiance simulators

23.5.2.1 Measurement of simulated solar irradiance

The distribution of irradiance over the plane of the collector shall be measured using a grid of maximum spacing 150 mm. The spatial mean deduced by simple averaging shall be used for the data analysis.

23.5.2.2 Measurement of thermal irradiance in simulators

The thermal irradiance in a solar simulator is likely to be higher than that which typically occurs outdoors. It shall therefore be measured to ensure that it does not exceed the limit given in 19.2.2.

The mean thermal irradiance in the collector test plane shall be determined whenever changes are made in the simulator, which could affect the thermal irradiance. The mean thermal irradiance in the collector test plane and shall be reported with collector test results.

23.5.2.3 Ambient air temperature in simulators

The ambient air temperature ϑ_a in simulators shall be measured, taking the mean of several values, if necessary. Sensors shall be shielded to minimize radiation exchange. The air temperature in the outlet of the wind generator shall be used for the calculations of the collector performance.

23.5.3 Data acquisition requirements

Data shall be measured at intervals of 10 s or less. Average values shall be recorded at intervals of 30 s or less. For outdoor measurements each data record shall contain a unique time stamp to calculate the angle of incidence of the solar radiation onto the collector.

23.6 Test period

23.6.1 Steady-state testing

A collector is considered to have been operating in steady-state conditions over a given period if none of the experimental parameters deviates from its mean value by more than the limits given in Table 6. The measurement period is at least four times the time constant of the collector (if known), or not less than 15 min for liquid heating collectors (if time constant is not known).

For air-heating collectors, the measurement period shall be more than 20 min.

Table 6 — Permitted deviation of measured parameters during a measurement period

Parameter	Permitted deviation from the mean value	
	Liquid heating collector	Air heating collector
Hemispherical solar irradiance	±50 W/m^2	
Thermal irradiance (WISC only)	±20 W/m^2	
Ambient air temperature	±1,5 K	
Fluid mass flow rate	±1 %	±2 %
Fluid temperature at the collector inlet	±0,1 K	±1,5 K
Fluid temperature at the collector outlet	±0,4 K	±1,5 K
Surrounding air speed	±1,0 m/s deviation from set value	

23.6.2 Quasi dynamic testing

23.6.2.1 General

The test period consists of four to five sequences (days). The number of days is dependent on the weather conditions on the test site. The data record shall contain data equivalent to all the important normal operating conditions (enough variability and dynamic range), to give decoupled collector parameters. This is done by varying the inlet temperature to the collector within its design range. If sufficient data has been recorded after four to five days, this data shall be evaluated following the guidelines outlined in 24.1.3.

23.6.2.2 Description of test sequences

The minimum length of a test sequence shall be 3 h. The 3 h do not need to be consecutive and the test sequence can consist of several non-consecutive parts with a minimum length of 30 min.

Day type 1

The test sequence under η_0 - conditions shall be conducted under mostly clear sky conditions. It shall include values of the incident angle from larger than 60° down to values where the difference of the incident angle modifier of the beam irradiance differs not more than 2 % from the value at normal incidence (see 26.2.2.).

Day type 2

At least one test sequence shall be conducted under partly cloudy conditions, including broken cloud, as well as clear sky conditions. This can be a test sequence under elevated operating temperature or under η_0 - conditions.

Day type 3 (1 or 2 days)

Measurements under mean operating temperature conditions including clear sky conditions.

Day type 4

Measurements under high operating temperature conditions including clear sky conditions.

Day type 1 and day type 2 may be adapted for collectors with a concentration ratio $C_R > 20$. These modifications of the procedure have to be described and explained in the test report.

23.6.2.3 Evaluation of test data

To ensure that the initial state of the collector does not influence the result of the parameter identification, a period of at least four times the time constant of the collector (if known) or 15 min (if time constant is not known) with the correct fluid temperature at the inlet and with the correct wind speed across the collector (WISC only) shall not be included in the analysis. For clarity, the requirements are given in the form of idealized diagrams, showing important relationships between different test data, including the dynamic ranges that shall be in the data to achieve reliable and de-coupled collector parameters. These diagrams shall be plotted for the evaluation of the goodness of the test data used for parameter identification.

Figure 9 shows $\vartheta_m - \vartheta_a$ versus G_{hem} to check if sufficient data has been taken under η_0 - conditions and at higher inlet temperatures. This data will give all necessary information for the identification of $\eta_{0,b}$ and the collector heat losses.

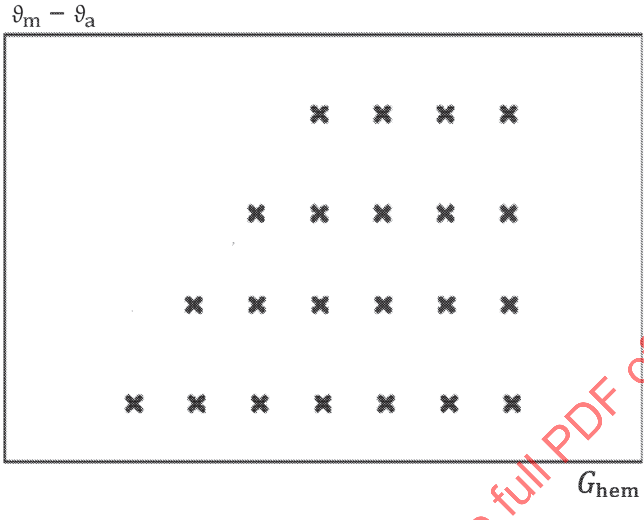


Figure 9 — $\vartheta_m - \vartheta_a$ versus G_{hem}

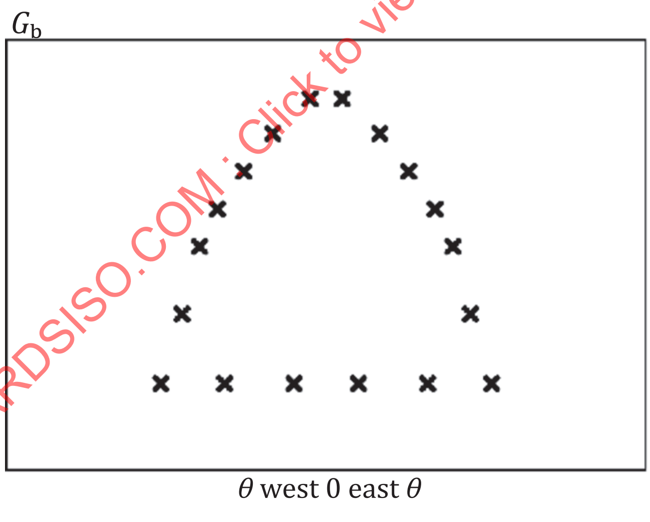


Figure 10 — G_b versus θ

Figure 10 and Figure 11 show if the data include enough data at high and low incident angle of the beam irradiance to identify $K_b(\theta_L,\theta_t)$, and if enough data at high diffuse radiation levels was taken to identify K_d. Measurement data with higher G_b-values (upper curve), will give $K_b(\theta_L,\theta_t)$. The lower values will give K_d.

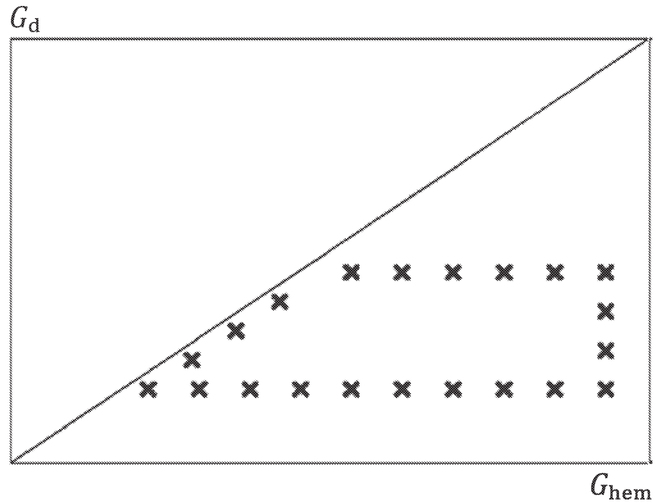


Figure 11 — G_d versus G_{hem}

For WISC collectors, Figure 12 showing the ideal distribution of wind speed versus G_{hem} and Figure 13 showing the ideal distribution of sky temperatures versus G_{hem} shall be included. The wind speeds as described in 23.3.4 shall be considered.

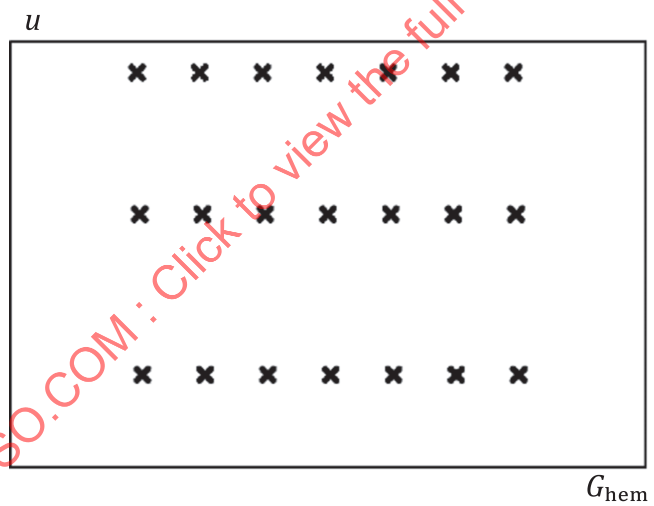


Figure 12 — Wind speed versus G_{hem}

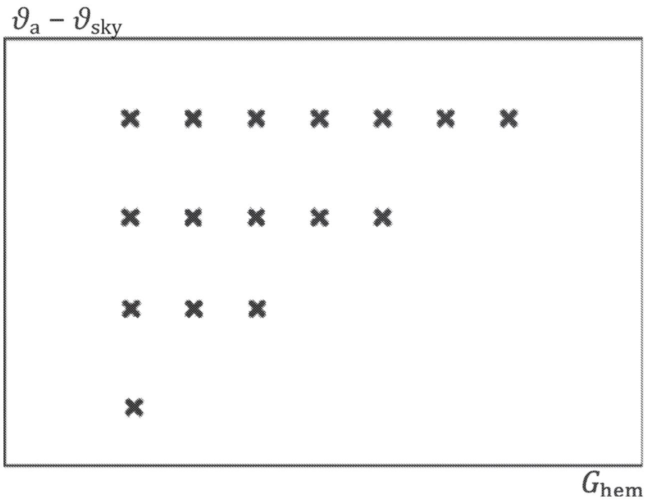


Figure 13 — $\vartheta_a - \vartheta_{sky}$ versus G_{hem}

For all collectors tested under natural wind, Figure 14 shall be included showing the ideal distribution of $\vartheta_m - \vartheta_a$ versus wind speed u.

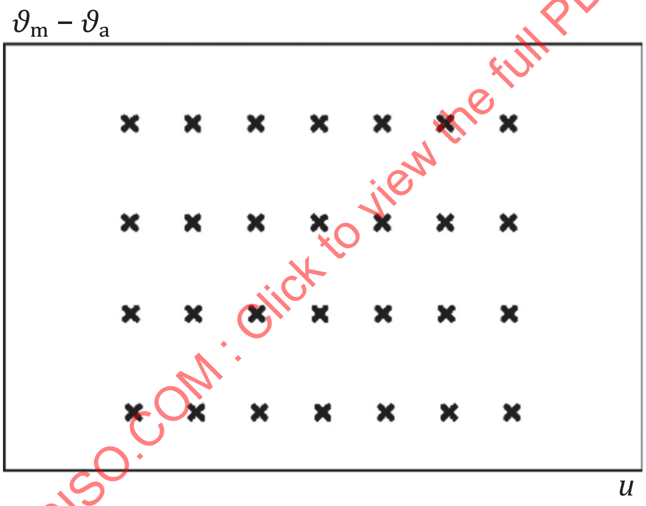


Figure 14 — $\vartheta_m - \vartheta_a$ versus u

24 Computation of the collector parameters

24.1 Liquid heating collectors

24.1.1 General

The useful power extracted $\dot{Q}$ is measured as given in Formula (10):

$$\dot{Q} = \dot{m} \cdot c_f \Delta T \quad (10)$$

A value of c_f corresponding to the mean fluid temperature shall be used. If $\dot{m}$ is obtained from volumetric flow rate measurement, then the density shall be determined for the temperature of the fluid in the flow meter.

The extracted power $\dot{Q}$ is modelled as described in 24.1.2 and 24.1.3. If these models are not applicable, tables of measurements of the collector performance shall be used.

The required surrounding wind speeds during the performance measurements (see 23.3.3 and 23.3.4) are taken into account by using the reduced wind speed $u' = u - 3$ m/s for modelling the extracted power.

24.1.2 Steady-state test method for liquid heating collectors

The extracted power $\dot{Q}$ is modelled as Formula (11):

$$\dot{Q} = A_G \left[\begin{array}{l} \eta_{0,\mathrm{hem}} G_{\mathrm{hem}} - a_1 (\vartheta_m - \vartheta_a) - a_2 (\vartheta_m - \vartheta_a)^2 - a_3 u' (\vartheta_m - \vartheta_a) + \\ a_4 \left(E_L - \sigma T_a^4 \right) - a_6 u' G_{\mathrm{hem}} - a_7 u' \left(E_L - \sigma T_a^4 \right) - a_8 (\vartheta_m - \vartheta_a)^4 \end{array} \right] \tag{11}$$

where

$$a_4 = \eta_{0,\mathrm{hem}} \frac{\varepsilon}{\alpha} \quad \text{and} \quad a_6 = \eta_{0,\mathrm{hem}} b_u \quad \text{and} \quad a_7 = \eta_{0,\mathrm{hem}} b_u \frac{\varepsilon}{\alpha} \tag{12}$$

If the value for (ε/α) is known from other measurements, it can be used for the modelling of the extracted power. A corresponding reference shall be given in the test report. Formula (12) allows linking the current parameters to the performance parameters defined in previous versions of this standard.

24.1.3 Quasi dynamic test method for liquid heating collectors

The extracted power $\dot{Q}$ is modelled as Formula (13):

$$\dot{Q} = A_G \left[\begin{array}{l} \eta_{0,b} K_b (\theta_L, \theta_T) G_b + \eta_{0,b} K_d G_d - a_1 (\vartheta_m - \vartheta_a) - a_2 (\vartheta_m - \vartheta_a)^2 - a_3 u' (\vartheta_m - \vartheta_a) + \\ a_4 \left(E_L - \sigma T_a^4 \right) - a_5 (d\vartheta_m / dt) - a_6 u' G - a_7 u' \left(E_L - \sigma T_a^4 \right) - a_8 (\vartheta_m - \vartheta_a)^4 \end{array} \right] \tag{13}$$

For collectors with a concentration ration $C_R < 20$, the use of $\eta_{0,b}$, $K_\theta(\theta_L, \theta_L)$, K_d, and the coefficients a_1, a_2, and a_5 are mandatory and they shall be identified. The parameter a_8 maybe set to 0.

For collectors with a concentration ratio $C_R > 20$, the parameters a_2, a_3, a_4, a_6, a_7 and K_d may be set to zero, a_5 is mandatory and shall be identified.

For covered collectors tested with artificial wind source at a speed between 2 m/s and 4 m/s, the coefficients a_3, a_4, a_6 and a_7 are set to 0.

For WISC collectors or collectors with a concentration ratio, the parameter a_8 may be set to 0.

24.1.4 Data analysis

The required performance parameters shall be deduced by statistical least square curve fitting of the measured data points. If one of these parameters is deduced with a negative value or if it has no statistical significance [i.e. the T ratio (parameter value/standard deviation of parameter value) < 3], this parameter shall be set to 0 in Formulae (11) or (13), and the parameter identification shall be repeated again. In the result sheets (Annex A), this parameter shall then be indicated with a value of 0. Under no circumstances it is admissible to set parameters to 0 without repeating the data analysis and without re-fitting the other parameters.

If the parameter a_5 is deduced with a negative value, it shall be replaced by the heat capacity as determined according to 25.3 divided by the gross area A_G.

24.2 Air heating collectors

24.2.1 General

The useful power extracted $\dot{Q}$ is measured as given in Formula (14)

$$\dot{Q}=\left(\dot{m}_\mathrm{e}\cdot c_\mathrm{f,e}\cdot\vartheta_\mathrm{e}\right)-\left(\dot{m}_\mathrm{i}\cdot c_\mathrm{f,i}\cdot\vartheta_\mathrm{i}\right)-\left[\left(\dot{m}_\mathrm{e}-\dot{m}_\mathrm{i}\right)\cdot c_\mathrm{f,a}\cdot\vartheta_\mathrm{a}\right] \tag{14}$$

A value of $c_\mathrm{f,e}$ corresponding to the inlet and outlet fluid temperature and the ambient temperature shall be used. If $\dot{m}$ is obtained from volumetric flow rate measurement, then the density shall be determined for the temperature of the fluid in the flow meter.

Where necessary, tables of measurements of the collector performance are admitted.

NOTE Formula 14 has an uncertainty if the measurement is done under positive gauge pressure because the exact temperature of the volumetric leakage flow rate is not known. Under positive pressure, the temperature of the volumetric leakage flow rate differs depending on whether it occurs at the beginning or at the end of the collector.

24.2.2 Steady-state test method for closed loop air heating collectors

Closed loop air heating collectors shall be modelled as liquid heating collectors (see 24.1).

24.2.3 Steady-state test method for open to ambient air heating collectors

The extracted power $\dot{Q}$ is modelled as Formula (15):

$$\dot{Q}=A_\mathrm{G}G\eta_{\mathrm{hem},\dot{m}_\mathrm{i}} \tag{15}$$

The collector efficiency $\eta_{\mathrm{hem},\dot{m}_\mathrm{i}}$ is dependent on the mass flow rate $\dot{m}_\mathrm{i}$ and shall be measured and indicated at minimum, mean and maximum flow rate as specified by the manufacturer.

24.2.4 Steady-state test method for open to ambient air heating WISC collectors

The solar energy intercepted on the collector is $A_\mathrm{G}G$ and the extracted power $\dot{Q}$ is modelled as Formula (16):

$$\dot{Q}=A_\mathrm{G}\left[G+\frac{\varepsilon}{\alpha}\left(E_L-\sigma T_a^4\right)\right]\left(\eta_{\mathrm{hem},\dot{m}_\mathrm{i}}-b_{\mathrm{u},\dot{m}_\mathrm{i}}u\right) \tag{16}$$

The collector efficiency parameters are dependent on the mass flow rates and shall be measured and indicated at minimum, mean and maximum flow rate as specified by the manufacturer.

24.3 Standard reporting conditions (SRC)

The collector output (table and graphical presentation) shall be reported in a comparable form independent of the test method and for the same climatic standard reporting conditions (SRC) defined in Table 7. For all calculations, the model used for the analysis of the measurements shall be used.

Table 7 — Standard Reporting Conditions (SRC)

Climatic conditions	Blue sky	Hazy sky	Grey sky
G_b	850 W/m^2	440 W/m^2	0 W/m^2
G_d	150 W/m^2	260 W/m^2	400 W/m^2
ϑ_a	20°C	20°C	20°C
E_L-$\sigma \cdot \vartheta_a^4$ [a]	−100 W/m^2	−50 W/m^2	0 W/m^2
u[a]	1,3 m/s	1,3 m/s	1,3 m/s
$d\vartheta_m/dt$[b]	0 K/s	0 K/s	0 K/s

[a] For WISC collectors only.

[b] For quasi dynamic tested collectors only.

NOTE (E_L-$\sigma \cdot \vartheta_a^4$) normally has a negative value as the effective sky radiation temperature is lower than the ambient air temperature. A net long wave irradiance of −100 W/m^2 corresponds to about a clear sky condition when ϑ_a = 20 °C and ϑ_{sky} = 0 °C.

For full compatibility, the parameters K_d and $\eta_{0,b}$ shall be determined, if not available, using the formulae given in Annex B.

Presentation of performance results shall be given up to the maximum temperature difference between mean fluid and ambient for which the collector was tested plus a maximum of 30 K. Results down to the measured minimum temperature difference minus 10 K may be indicated. It shall be stated that the measured collector parameters are applicable only for calculations in this range.

For all collectors, the Peak Power W_{peak} shall be calculated and reported as the power output per module operated under blue sky SRC at a temperature difference $\vartheta_m - \vartheta_a = 0$ and an incident angle of 0°.

24.4 Standard uncertainties

The standard uncertainties of the measured collector parameters may be derived as outlined Annex D.

24.5 Reference area conversion

If, in addition to the standard representation, thermal performance parameters have to be indicated with reference to other areas than the gross area, the conversion rules given in Annex G shall be used.

25 Determination of the effective thermal capacity and the time constant

25.1 General

The effective thermal capacity and the time constant are important parameters describing the collectors' transient performance. A collector can be considered as a combination of masses, probably at different temperatures. When a collector is operating, each collector component responds differently to a change in operating conditions, so it is useful to consider an effective thermal capacity for the whole collector.

It is evident that the effective thermal capacity and the overall time constant may depend on the operating conditions and are not always simple collector parameters with a unique value. For this reason, one of the following methods including the indicated reference conditions shall be chosen. The measurement of the heat capacity and the time constant shall be performed using a flow rate similar to that for collector efficiency testing.

25.2 Measurement of the effective thermal capacity with irradiance

The collector is installed and operated as defined in 23.4. The collector area is shielded from the solar radiation (natural or simulated) by means of a solar reflecting cover. The inlet fluid temperature is set to ambient temperature $\vartheta_{in} \approx \vartheta_a$ until steady-state conditions are reached ($\vartheta_{ex} \approx \vartheta_{in}$). The inlet temperature is being kept stable at ϑ_a. The cover is removed quickly and data are measured until the outlet temperature of the fluid varies by less than 0,5 K per minute, i.e. until steady-state conditions are achieved again.

The transient behaviour of the collector between the two steady-states 1 and 2 is described by Formula (17):

$$C\frac{d\vartheta_\mathrm{m}}{dt} = A\cdot\eta_{0,\mathrm{hem}}\cdot G - \dot{m}\cdot c_\mathrm{f}\cdot\Delta T - A_\mathrm{G}\cdot U\cdot(\vartheta_\mathrm{m} - \vartheta_\mathrm{a}) \tag{17}$$

Integrating over the period between the two steady-states gives the following formula for the collector thermal capacity:

$$C = \frac{A_\mathrm{G}\cdot\eta_{0,\mathrm{hem}}\int_{t_1}^{t_2} G\mathrm{d}t - \dot{m}\cdot c_\mathrm{f}\int_{t_1}^{t_2}\Delta T\mathrm{d}t - A_G\cdot U\left[\int_{t_1}^{t_2}(\vartheta_\mathrm{in} - \vartheta_\mathrm{a})\mathrm{d}t + \frac{1}{2}\int_{t_1}^{t_2}\Delta T\mathrm{d}t\right]}{(\vartheta_\mathrm{m2} - \vartheta_\mathrm{m1})} \tag{18}$$

25.3 Measurement of the effective thermal capacity using the quasi dynamic method

The effective thermal capacitance, modelled as a_5 and equal to C/A, is a mandatory part of the collector model and is identified simultaneously together with all other collector parameters.

The test data shall include periods with high variability in solar radiation so that the thermal capacitance effects are significant. The required condition that $d\vartheta_m/dt$ shall exceed ±0,005 K/s is usually met during partly cloudy days, type 2. If this is not the case, additional type 2 test days with partly cloudy conditions shall be added to the data set used for parameter identification.

25.4 Calculation method for the determination of the effective thermal capacity

The effective thermal capacity of the collector C is calculated as the sum of the total thermal capacities $m_i c_i$ of the constituent collector elements (glass, absorber, liquid contained, and insulation) weighted by a generic factor p_i:

$$C = \sum_i p_i \cdot m_i \cdot c_i \tag{19}$$

The weighting factor p_i (between 0 and 1) allows for the fact that certain elements are only partially involved in collector thermal inertia. The values of p_i are given in Table 8.

Table 8 — Values of weighting factors

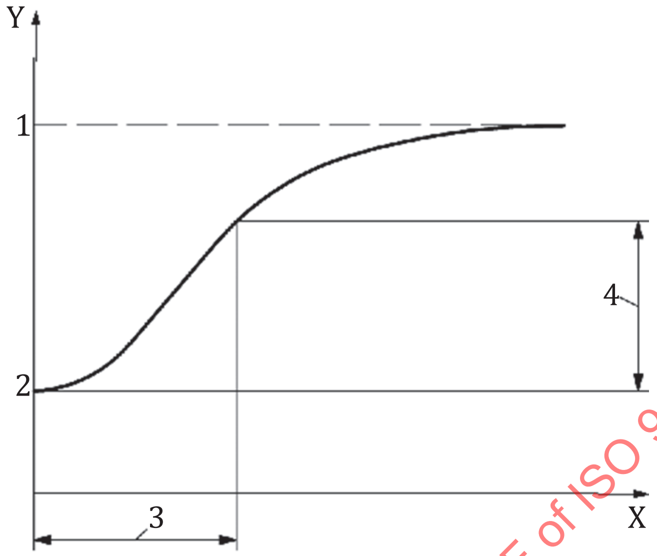
Elements	p_i
Absorber	1
Insulation	0,5
Heat transfer fluid	1
External glazing	$0,01 \cdot a_1$
Second glazing	$0,2 \cdot a_1$

All parts of the collector which are in direct contact with the heat transfer fluid (liquid or air) shall be weighted by $p_i = 1$.

25.5 Determination of collector time constant

The measurements made under 25.1 shall be used for the determination of the time constant.

The measured difference between the temperature of the fluid at the collector outlet and of the ambient air ($\vartheta_e - \vartheta_a$) are plotted against time, beginning with the initial steady-state condition until the second steady-state has been achieved (see Figure 15).



Key

1 $(\vartheta_e - \vartheta_a)_2$

2 $(\vartheta_e - \vartheta_a)_0$

3 τ_c

4 $0{,}632\ [(\vartheta_e - \vartheta_a)_2 - (\vartheta_e - \vartheta_a)_0]$

X time

Y $\vartheta_e - \vartheta_a$

Figure 15 — Collector time constant

The time constant τ_c of the collector is then defined as the elapsed time between the removal of the cover and the point where the collector outlet temperature crosses 0,632 of the total increase from $(\vartheta_e - \vartheta_a)_0$ to $(\vartheta_e - \vartheta_a)_2$.

Alternatively, the time constant can be determined during a cool down period rather, i.e. by reversing the measurements described in 25.1. The time constant of the collector is then the elapsed time between turning off the irradiance and the point where the collector outlet temperature rise drops by 63,2 % of its initial steady-state value.

26 Determination of the incident angle modifier (IAM)

26.1 General

The thermal efficiency parameters are determined for the collector at normal incidence conditions. A separate measurement shall be conducted to determine the incidence angle modifier to calculate the performance of the collector under any incidence angle.

26.2 Modelling

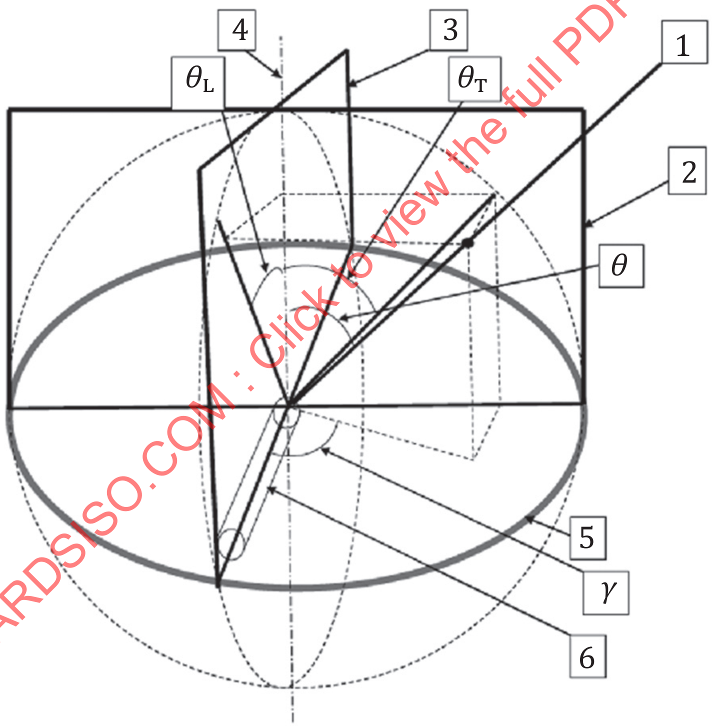
The incidence angle modifier is defined as the ratio of the peak efficiency at a given angle of incidence and the peak efficiency at normal incidence according to Formula (20) and (21), respectively.

$$K_{\mathrm{b}}(\theta_{\mathrm{L}},\theta_{\mathrm{T}})=\frac{\eta_{0,\mathrm{b}}(\theta_{\mathrm{L}},\theta_{\mathrm{T}})}{\eta_{0,\mathrm{b}}} \tag{20}$$

$$K_{\mathrm{hem}}(\theta_{\mathrm{L}},\theta_{\mathrm{T}})=\frac{\eta_{0,\mathrm{hem}}(\theta_{\mathrm{L}},\theta_{\mathrm{T}})}{\eta_{0,\mathrm{hem}}} \tag{21}$$

For certain collector types where the thermal performance cannot be determined under normal incidence, other angles than normal incidence may be defined as reference angle. Such deviating models have to be described very clearly in the test report to prevent from miscalculations when using any simulation tools.

The longitudinal plane (index L) runs parallel to the optical axis of the collector and the transversal plane (index T) is perpendicular to the optical axis. The angles θ_{L} and θ_{T} are the projections of the incidence angles θ_{i} (given in a spherical coordinate system) onto the longitudinal and transversal planes, respectively, see Figure 16.



Key

1 sun position
2 transversal plane
3 longitudinal plane
4 collector normal
5 collector plane
6 example vacuum tube

Figure 16 — Symmetry planes and angles relevant for the determination of the IAM

For the correlation between θ, θ_L and θ_T, the Formulae (22) and (23) hold:

$$\theta_L(\theta,\gamma) = \tan^{-1}\left(\frac{\sin(\theta)\cos(\gamma)}{\cos(\theta)}\right) \tag{22}$$

$$\theta_T(\theta,\gamma) = \tan^{-1}\left(\frac{\sin(\theta)\sin(\gamma)}{\cos(\theta)}\right) \tag{23}$$

are the projected incidence angles onto the two symmetry planes, thus:

$$\tan^2\theta = \tan^2\theta_L + \tan^2\theta_T \tag{24}$$

For most collectors, the incident angle modifier can be approximated by the product of two separate incident angle modifiers in the perpendicular collector symmetry planes as defined in Figure 16:

$$K_{hem}(\theta_L,\theta_T) = K_{hem}(\theta_L,0)\cdot K_{hem}(0,\theta_T) \tag{25}$$

These two incidence angle modifier functions shall be determined. For those collectors for which the incidence angle effects are deemed symmetrical with direction of incidence, it is sufficient to measure the incident angle effects for one direction only to fully characterize the incident angle modifier.

Depending on the collector type, several standard functions describing the incidence angle modifier are available such as the Ambrosetti function shown in Formula (26):

$$K(\theta) = 1 - \tan^{\kappa}\left(\frac{\theta}{2}\right) \tag{26}$$

For many collector constructions however, simple functions are not suitable to describe the incidence angle modifier. In these cases, lists of individual values, tabulated in steps of 10°, shall be used. Smaller steps than 10° may be added if deemed necessary.

$\boldsymbol{\theta}$	0	10	20	30	40	50	60	70	80	90
$\boldsymbol{K(\theta)}$	$K(0)$	$K(10)$	$K(20)$	$K(30)$	$K(40)$	$K(50)$	$K(60)$	$K(70)$	$K(80)$	$K(90)$

The incidence angle modifier for any incidence angle θ may then be interpolated using the lookup table and the linearized approximation shown in Formula (27):

$$K(\theta) = \left[K\left(\left\lfloor\frac{\theta}{10}\right\rfloor\cdot 10\right)\left(\left\lfloor\frac{\theta+10}{10}\right\rfloor - \frac{\theta}{10}\right) + K\left(\left\lfloor\frac{\theta}{10}\right\rfloor\cdot 10 + 10\right)\left(\frac{\theta}{10} - \left\lfloor\frac{\theta}{10}\right\rfloor\right)\right] \tag{27}$$

where the open brackets denote rounded to next lower integer.

For most collectors, $K(0°) = 1$ and $K(90°) = 0$; however, for some specific designs, other fix points are possible. In case of asymmetric collectors, such table representation shall be extended to cover incidence angle from $\theta = -90°$ to $\theta = +90°$.

26.2.1 Steady-state

For steady-state measurements, Formula (11) is modified with the incidence angle modifier $K_{hem}(\theta_L, \theta_T)$ in Formula (28):

$$\dot{Q} = A_G\left[\begin{array}{l}\eta_{0,hem} G_{hem} K_{hem}(\theta_L,\theta_T) - a_1(\vartheta_m - \vartheta_a) - a_2(\vartheta_m - \vartheta_a)^2 - a_3 u'(\vartheta_m - \vartheta_a) + \\ a_4\left(E_L - \sigma T_a^4\right) - a_6 u' G - a_7 u'\left(E_L - \sigma T_a^4\right) - a_8(\vartheta_m - \vartheta_a)^4\end{array}\right] \tag{28}$$

26.2.2 Quasi dynamic

The collector incidence angle modifiers, modelled as $K_b(\theta_L,\theta_T)$ for direct radiation and K_d for diffuse radiation are mandatory parts of the collector model. K_d is modelled as a collector constant. These parameters are identified simultaneously together with all other collector parameters.

26.3 Test procedures

26.3.1 Steady-state liquid heating collectors

26.3.1.1 General

The collector shall be operated using similar conditions as for the thermal performance measurements (flow rate, wind speed, etc.). The mean temperature of the heat transfer fluid shall be controlled as closely as possible (preferably within ±1 K) to the ambient air temperature. The efficiency value shall be determined in accordance with 23.4.2. The collector shall be tested at diffuse irradiance levels of always less than 30 %. During each test period, the orientation of the collector shall be such that the collector is maintained within ±2° of the angle of incidence for which the test is being conducted.

While measuring the incidence angle modifier in one plane of an optical unsymmetrical collector, the incidence angle within the other plane shall be kept to a value where the incidence angle modifier does not differ by more than 2 % from the one at normal incidence.

Care shall be taken that the measurement of the incident angle modifier is not affected by inappropriate tilt angles. Special care shall be taken that the pyranometer is placed exactly in the collector plane as small deviations induce considerable measuring errors.

The measurements shall be made at least at two different incidence angles between 20° and 70°. For collectors with unusual optical performance characteristics, it is advisable to make these measurements at more than two angles.

One of the following two methods shall be used for the determination of the IAM.

26.3.1.2 Method 1

This method is applicable for testing indoors using a solar simulator with the characteristics specified in 19.2.3 or outdoors using a two-axis movable test rack so that the orientation of the collector can be arbitrarily adjusted with respect to the direction of the incident solar radiation.

The collector shall be operated under stable conditions at different fixed angles for time periods required to reach stable instantaneous efficiencies.

26.3.1.3 Method 2

This method is applicable for testing outdoors using a stationary test rack on which the collector orientation cannot be arbitrarily adjusted except for the inclination angle.

The efficiency value shall be determined in such a way that one value of efficiency is taken before solar noon and a second value after solar noon. The average incidence angle between the collector and the solar beam for both data points is the same. The efficiency of the collector for the specific incidence angle shall be considered equal to the average of the two values.

26.3.2 Air collectors

The incidence angle modifier of air collectors can be measured as with liquid heating collectors. One of the three flow rates used for the efficiency measurement shall be used in this measurement.

26.4 Calculation of the collector incidence angle modifier

Regardless of which experimental method is used, values for the thermal efficiency of the collector shall be determined for each of the measured values of incidence angles. The measured performance $\eta_{hem}(\theta_L, \theta_T)$ shall be recalculated using Formula (11) to match the $\eta_{0,hem}$ conditions and to give $\eta_{0,hem}(\theta_L, \theta_T)$. The incidence angle modifier is then deduced by dividing by the thermal efficiency for normal incidence.

$$K_{hem}(\theta_L, \theta_T) = \frac{\eta_{hem}(\theta_L, \theta_T)}{\eta_{0,hem}} \quad (29)$$

26.5 Reporting

The result shall always be presented as a table indicating the incidence angle modifier in steps of 10° (smaller steps than 10° may be added if deemed necessary) in longitudinal and transversal direction. The data that were not measured shall be calculated using the mathematical model used for the determination (see 26.2):

$\boldsymbol{\theta}$	0	10	20	30	40	50	60	70	80	90
$\boldsymbol{K_L(\theta)}$										
$\boldsymbol{K_T(\theta)}$										

The mathematical model used for the calculation shall be described in the test report. The orientation of longitudinal and transversal axes shall be described to prevent misunderstandings.

For steady-state measurements, the diffuse incidence angle modifier constant K_d shall be determined as described in Formula (B.3) and indicated in the test report.

27 Determination of the pressure drop

27.1 General

The pressure drop across a collector is an important parameter for designers of solar collector systems. Any fluid can be used for the measurement but it has to be specified together with the test results. The standard test temperature of the fluid shall be (20 ± 2) °C. Other temperatures are possible but have to be indicated together with the test results.

The heat transfer fluid shall flow as specified by the manufacturer. Particular attention shall be paid to the selection of appropriate pipefittings at the collector entry and exit ports to prevent inducing unwanted additional pressure drop. The collector shall be shielded from radiation during the whole test.

The pressure drop shall be determined for different flow rates, which span the range likely to be used in real operation. At least five measurements shall be made at values equally spaced over the flow rate range. At each operation point, the pressure shall reach steady-state conditions for at least 5 min.

27.2 Liquid heating collectors

27.2.1 Apparatus and procedure

The collector shall be coupled to a test loop conforming broadly to Clause 22, although less instrumentation is required than for collector efficiency testing.

The following data shall be measured in accordance with Clause 22:

a) fluid temperature at the collector inlet;

b) fluid flow rate;

c) heat transfer fluid pressure drop between the collector inlet and outlet connections.

The heat transfer fluid pressure drop across the collector shall be measured with a device having a standard uncertainty of 5 % of the measured value or ±10 Pa, whichever is higher.

27.2.2 Pressure drop caused by fittings

The fittings used to measure the fluid pressure may themselves cause a drop in pressure. A zero check on the pressure drop shall be made by removing the collector from the fluid loop and repeating the tests with the pressure-measuring fittings directly connected together. The pressure drop caused by the test equipment shall be used to correct the measured pressure drop of the collector.

27.2.3 Test conditions

The test shall be carried out at a constant pressure corresponding to the intended operating pressure. The fluid flow rate shall be held constant to within ±1 % of the nominal value during test measurements.

27.3 Air heating collectors

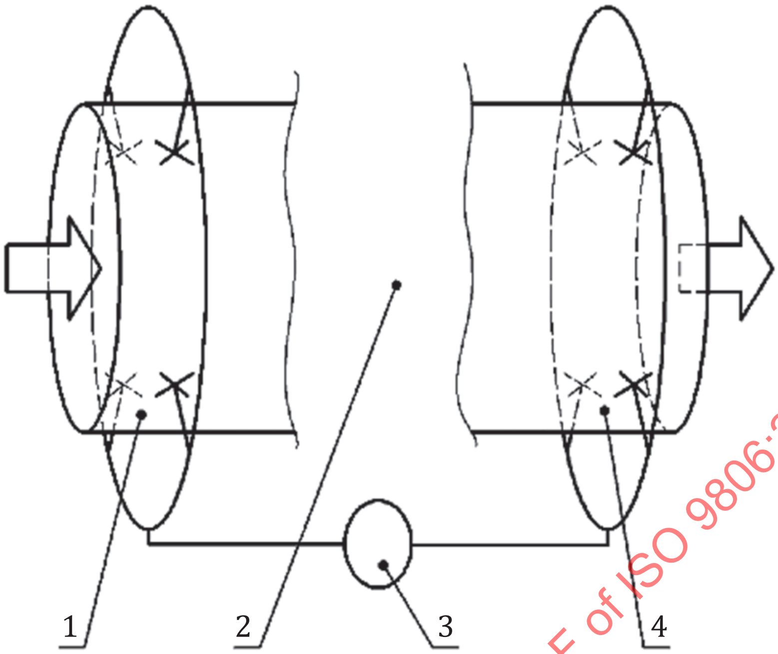
27.3.1 Apparatus and procedure

Measuring devices shall be positioned upstream and downstream of the collector as illustrated in Figure 17. A zero check on the pressure drop shall be made by removing the collector from the fluid loop and repeating the tests with the pressure-measuring fittings directly connected together. The pressure drop caused by the fittings shall be used to correct the measured pressure drop of the collector.

For open to ambient collectors, the inlet pressure is always the ambient pressure.

Pressure-measuring points shall have four external manifold pressure taps, as shown in Figure 17. The pressure in the test circuit and the pressure drop of the solar collector shall be measured using static pressure tap holes and either a manometer or a differential-pressure transducer. The edges of the holes on the inside surface of the duct shall be free of burrs. The hole diameter shall not exceed 40 % of the wall thickness or 1,6 mm. Provision shall be made for determining the absolute pressure of the entering transfer fluid.

The static pressure drop of an air-heating collector and static pressure upstream or downstream of the collector shall be determined with instruments that have an accuracy of ±10 Pa.



Key

1 air inlet test duct

2 solar collector

3 differential pressure measuring device

4 air outlet test duct

Figure 17 — Measurement of pressure drop of air heating collectors

27.4 Calculation and presentation of results

The pressure drop shall be presented as table and graphically as a function of the fluid flow rate for each of the tests performed, using the format sheets given in A.16.9.

For most collectors, the pressure drop can be approximated by a second order polynomial function as given in Formula (30):

$$\Delta p = a\dot{V} + b\dot{V}^2 \tag{30}$$

The parameters a and b shall be derived by least square curve fitting of the measured pressure drops at different flows. If this this simple model is not applicable, a list of measured pressure drop data shall be presented in the test report.

Annex A
(normative)

Test reports

A.1 General

Test reports may be issued on single tests or complete test sequences. Any deviations from the procedures as defined in this document shall be described including the technical reasons for such deviations.

A.2 Collector description

A.2.1 General

For the identification of the solar collector, the description shall be as complete as possible and shall include at least the characteristics listed below, if applicable. Numbers shall be indicated with the indicated precision. Additional information may be important depending on the test sample. In case the information is given by the manufacturer, this must be clearly stated. Manufacturer information has to be checked for plausibility by the test laboratory.

A.2.2 General Information for sample identification

Name of manufacturer
Brand Name
Serial No
Collector Type (Flat-plate, ETC, PVT, Tracked, Evacuated, etc.)
Drawing(s) Document No (if available)
Collector mounting possibilities (On-roof, In-roof, Façade, On Stand, etc.)
For collectors with integrated electrical components (ventilator, pumps, PV-panel…), they shall be described together with their technical data:

A.2.3 Protection mechanisms

Self-protecting collector (5.2.2.3)
(Yes, No)

If yes, a full description of the self-protection mechanism(s) together with their protection thresholds and set points, together with the modified test procedures and test results shall be given in the relevant result sheets of this annex.

Freeze resistant collector (14.2)
(Yes, No)

If yes, a full description of the mechanism(s) and/or collector properties guaranteeing freeze resistance shall be given in the relevant result sheets of this annex.

Freeze resistant heat pipes (14.3)
(Yes, No)

If yes, a full description of the mechanism(s) and/or heat-pipe properties guaranteeing freeze resistance shall be given in the relevant result sheets of this annex.

A.2.4 Operational range

Minimum and maximum operation temperature	°C
Maximum operation pressure (At maximum temperature of operation)	Pa
Minimum and maximum installation inclination (measured from horizontal)	°
Recommended heat transfer fluids	
Minimum, recommended, maximum flow rate	kg/h
Other limitations	

A.2.5 Dimensions and general information

Gross length, width, height (length from bottom to top, width from left to right, when oriented as tested)	mm
Gross area, A_G (as defined in 21.8, 2 digits precision)	m^2
Aperture area, A_{Ap} (as defined in ISO 9488, 2 digits precision)	m^2
Absorber area, A_{Abs} (as defined in ISO 9488, 2 digits precision)	m^2
Weight empty	kg
Fluid content	l

A.2.6 Frame, enclosure, casing

Enclosure material(s)	
Joining method(s) (pop rivets, screws, glued, etc.)	

A.2.7 Absorber

Material(s)	
Number of absorber elements (fins, tubes, etc.)	
Absorber element length, width	mm
Absorber total length, total width	mm
Absorber thickness (1 digit precision)	mm
Solar absorptance α	%

Hemispherical emittance ε	%
Absorber Coating (type, brand name)	
Bond between riser and fin/plate (mechanical, soldering, ultrasonic welding, laser welding, etc.)	

A.2.8 Hydraulic System

Flow pattern as tested (clear description and/or drawing)	
Number of risers	
Riser material	
Riser length	mm
Riser outer/inner diameter	mm
Distance between risers	mm
Manifold material	
Manifold length	mm
Manifold outer/inner diameter	mm
Collector hydraulic connector type/size	mm

A.2.9 Air collectors

Absorber surface	m^2
Type of absorber (overflow/ underflow/ flow through, etc.)	
Absorber "heat exchanger" surface (substitution of "Fin width" and "Fin thickness" for air heating collectors)	
Air filtration (air collectors only)	

A.2.10 Glazing/transparent cover

Material	
Glass type (tempered, toughened, safety glass, etc.)	
Thickness	mm
Inner/outer diameter (for tube collectors)	mm
Solar transmittance	%
Glazing surface characteristics (clear, textured, coated, etc.)	

A.2.11 Insulation(s)

Material	
Thickness	mm
Thermal conductivity	W/m^{2}K

A.2.12 Heat Pipes

Material	
External diameter of pipe and condenser	mm
Liquid type	
Liquid mass	g

A.2.13 Reflector(s)

Type of reflector (CPC, Flat, etc.)	
Material	
Length, width	mm
Reflectance (hemispherical)	%
Reflectance (diffuse)	%

A.2.14 Additional Information

Photograph(s) of the collector
Comments on the collector design
Schematic diagram of collector mounting

A.3 Test sequence and summary of main results

See Table A.1 for a result summary table. Full details shall be given in the individual test result sheets.

Table A.1 — Result summary table

Test		Date/Start-End	Summary of main test results
Delivery of test sample / Initial visual inspection			
Air leakage rate test			
Rupture or collapse test			
Standard stagnation temperature			
Exposure or half-exposure			
External thermal shock	First		
	Second		
Internal thermal shock	First		
	Second		
Rain penetration			
Freeze resistance			
Internal pressure			
Mechanical load	Positive		
	Negative		
Impact resistance			

Table A.1 *(continued)*

Test	Date/Start-End	Summary of main test results
Delivery of test sample / Initial visual inspection		
Air leakage rate test		
Rupture or collapse test		
Standard stagnation temperature		
Exposure or half-exposure		
Thermal performance		
Pressure drop measurement		
Final inspection		

A.4 Internal pressure test for fluid channels

A.4.1 Test condition

Test method	
Test fluid	
Ambient temperature	°C
Test duration	min

A.4.2 Test results

Maximum test pressure	
Any evident problems, damages and failures according to Clause 17 (description and photos)	
Other observations and remarks	

A.5 Air leakage rate test for closed loop air heating collectors

A.5.1 Test condition

Test method	
Volumetric flow	kg/m^3
Ambient temperature	°C

Fluid temperature	°C
Intermediate pressure	Pa
Test duration at each pressure	S

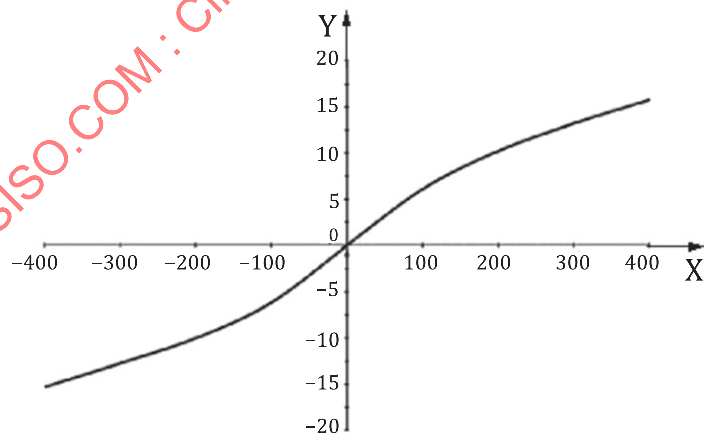
A.5.2 Test results

Maximum test pressure	
Any evident problems, damages and failures according to Clause 17 (Description and photos)	
Other observations and remarks	

The results shall be presented as a table of values (Table A.2) and as a graph (Figure A.1) covering at least the specified operating range of the collector.

Table A.2 — Values of the volumetric pressure and leakage flow

Collector pressure over ambient pressure (Pa)	Leakage volumetric flow rate ($V_{p,L}$) (m^3/s)



Key

X collector pressure (Pa)

Y leakage volumetric flow rate (m^3/h)

Figure A.1 — Leakage rate curve of an air heating collector

A.6 Rupture or collapse test

A.6.1 Test condition

Ambient temperature	°C
Fluid temperature	°C
Test pressure	Pa
Test irradiance (if applicable)	W/m^2
Test duration	s

A.6.2 Test results

Any evident problems, damages and failures according to Clause 17 (description and photos)
Observations and remarks

A.7 Determination of standard stagnation temperature

A.7.1 Test condition

Test location (indoor/outdoor)		
Collector inclination	°	
Average ambient temperature		°C
Average hemispherical irradiance		W/m^2
Location for temperature sensor		
Fluid specifications, flow rate, fluid temperature (if a fluid was circulated)		
Method used to determine the standard stagnation temperature (measurement/ calculation)		

A.7.2 Test results

Standard stagnation temperature at 1 000 W/m^2 and 30 °C	
Any evident problems, damages and failures according to Clause 17 (description and photos)	
Observations and remarks	

A.8 Exposure test

A.8.1 Initial outdoor exposure

Location for initial outdoor exposure (address/coordinates)	
Collector tilt angle during initial outdoor exposure (measured from horizontal)	°
Collector azimuth angle during initial outdoor exposure (measured from due south)	°
Test date (start/end)	DD/MM/YYYY
Collector tested as façade collector (Y/N)	
Location of temperature measurement (description/photos, if applicable)	

A.8.2 Test conditions for Method 1

In Tables A.3 and A.4, full details shall be given of the climatic conditions for all days during the test, including the initial outdoor exposure if irradiance and ambient temperature was measured.

Table A.3 — Climatic conditions for all days during the test

Date DD/MM/YYYY	**H** MJ/m^2	ϑ_a °C	**Location** indoor/outdoor
Total days of outdoor exposure: ____ days			
Total hemispherical irradiation on collector: _____ MJ/m^2			

Table A.4 — Data record of fulfilled exposure test requirements

Date/Time	G W/m²	ϑ_a °C	Time periods min	Location indoor/outdoor
Summary Total time t = ____h with irradiation G > _____ W/m² and ambient temperature ϑ_a > ____ °C				

A.8.3 Test conditions for Method 2

Fluid used	
Flow rate	kg/h
Fluid temperature	°C
Test date (start/end)	DD/MM/YYYY
Description of self-protection mechanism and description of adapted test procedure (for self-protecting collectors only, 5.2.2.3)	
Location of temperature measurement (description/photos, if applicable)	

A.8.4 Test conditions for Method 3

Average radiation on collector plane	W/m²
Average ambient temperature	°C
Test date (start/end)	DD/MM/YYYY
Location of temperature measurement (description/photos, if applicable)	

A.8.5 Test results

Climate class tested (A+, A, B, C, indicate G and ϑ_a for Class C)	
Any evident problems, damages and failures according to Clause 17 (description and photos)	
Other observations and remarks	

A.9 External thermal shock test

A.9.1 Test conditions

Test method (indoor simulator, outdoor, etc.)	
Collector tilt angle (measured from horizontal)	°
Average irradiance during test	W/m^2
Minimum irradiance during test	W/m^2
Average ambient air temperature	°C
Minimum ambient air temperature	°C

A.9.2 Test results

Climate class tested (A+, A, B, C, indicate G and ϑ_a for Class C)	
Any evident problems, damages and failures according to Clause 17 (description and photos)	
Other observations and remarks	

A.10 Internal thermal shock test

A.10.1 Test conditions

Test method (indoor simulator, outdoor, etc.)	
Collector tilt angle (measured from horizontal)	°
Average irradiance during test	W/m²
Minimum irradiance during test	W/m²
Average ambient air temperature	°C
Minimum ambient air temperature	°C

A.10.2 Test results

Climate class tested (A+, A, B or C, indicate G and ϑ_a for Class C)
Any evident problems, damages and failures according to Clause 17 (description and photos)
Other observations and remarks

A.11 Rain penetration test

A.11.1 Test conditions

Description of collector mounting (in-roof, on-roof, open frame, etc.)	
Collector tilt angle (measured from horizontal)	°
Number and description of position(s) of spray nozzles	

A.11.2 Test results

Any evident problems, damages and failures according to Clause 17 (description and photos)	
Other observations and remarks	

A.12 Freeze resistance test

A.12.1 Test conditions

Collector type (freeze-resistant when filled with water/drain down/heat pipe collector)	
Collector tilt angle (measured from horizontal)	°

A.12.2 Test results

Any evident problems, damages and failures according to Clause 17 (description and photos)	
Other observations and remarks	

A.13 Mechanical load test

A.13.1 Positive pressure test of the collector and the fixings

A.13.1.1 Test conditions

Description of the collector mounting kit used in the test	
Test method used to apply positive pressure (water, suction cups, gravel, air pressure, etc.)	

A.13.1.2 Test results

Maximum test load without damage	Pa
Any evident problems, damages and failures according to Clause 17 (description and photos)	
Other observations and remarks	

A.13.2 Negative pressure test of the collector and fixings

A.13.2.1 Test conditions

Description of the collector mounting kit used in the test	
Test method used to apply negative pressure (suction cups, air pressure, etc.)	

A.13.2.2 Test results

Maximum negative test load without damage	Pa
Any evident problems, damages and failures according to Clause 17 (description and photos)	
Other observations and remarks	

A.14 Impact resistance test

A.14.1 Test conditions

Test method (ice ball test, steel ball test)	
Impact direction (vertical, horizontal)	
List of all points of impact (description if possible illustrated by photos)	
Description of self-protection mechanism and description of adapted test procedure (for self-protecting collectors only, 5.2.2.3)	
Maximum ice ball diameter without damage (if applicable)	mm

A.14.2 Test results

Maximum ball diameter without damage (if ice ball testing)	mm
Maximum drop height (1 digit precision) without damage (if steel ball testing)	m
Any evident problems, damages and failures according to Clause 17 (description and photos)	
Other observations and remarks	

A.15 Final inspection

Evaluate and rate each potential problem as described in Clause 17.

Table A.5 — Final inspection record

Collector component	Potential problem	Evaluation
a) Collector box/fasteners	Cracking/warping/corrosion/rain penetration/permanent deformation/Accumulation of humidity/etc.	
b) Mountings/structure	Strength/safety/loosening/fatiguing/etc.	
c) Seals/gaskets	Cracking/loss of adhesion/elasticity/brittleness/etc.	
d) Cover	Cracking/breaking/crazing/buckling/delamination/permanent warping and deformation/outgassing/etc.	
e) Absorber as a whole	Deformation/corrosion/buckling/etc.	
f) Absorber coating	Cracking/crazing/blistering/discolouration/peeling/flaking/etc.	
g) Reflectors	Deformation/cracking/crazing/blistering/discolourtion/buckling/peeling/flaking/etc.	
h) Absorber tubes and headers/Flow passages/hoses inside the collector	Deformation/corrosion/leakage/loss of bonding/irreversible swelling/etc.	
i) Absorber mountings	Permanent deformation/corrosion/rupture/etc.	
j) Insulation	Water retention/outgassing/swelling/degradation/scorching/singeing/any other detrimental changes that could adversely affect collector performance/fouling/etc.	
k) Corrosion and other deterioration caused by chemical action. Anywhere in the collector	Corrosion shall be considered severe if it impairs the function of the collector or if there is evidence that it will progress	
l) Retention of water. Anywhere in the collector	Excessive retention of water anywhere in the collector	
m) Heat pipes	Loss of fluid/loss of pressure/severe deformation/etc.	
n) Self-protection systems	Any problem	
o) Other components	Any other abnormality resulting in a reduction of thermal performance or service life time	