BRITISH STANDARD

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12975-2:2006
Incorporating
Corrigendum No. 1

Thermal solar systems and components — Solar collectors —

Part 2: Test methods

The European Standard EN 12975-2:2006 has the status of a British Standard

ICS 27.160

National foreword

This British Standard is the official English language version of EN 12975-2:2006. It supersedes BS EN 12975-2:2001 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee RHE/25, Solar heating, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

BSI committee RHE/25, Solar heating, would like to draw users attention to the fact that for solar collectors using absorbers that contain silicone rubber to enclose the fluid, the absorber should be tested in accordance with the requirements for organic materials.

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

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the *BSI Catalogue* under the section entitled “International Standards Correspondence Index”, or by using the “Search” facility of the *BSI Electronic Catalogue* or of British Standards Online.

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English Version

Thermal solar systems and components - Solar collectors - Part 2: Test methods

Installations solaires thermiques et leurs composants - Capteurs solaires - Partie 2 : Méthode d'essai

Thermische Solaranlangen und ihre Bauteile - Kollektoren - Teil 2: Prüfverfahren

This European Standard was approved by CEN on 6 February 2006.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

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Contents

Foreword

This European Standard (EN 12975-2:2006) has been prepared by Technical Committee CEN/TC 312 “Thermal solar systems and components”, the secretariat of which is held by ELOT.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2006, and conflicting national standards shall be withdrawn at the latest by September 2006.

This European Standard supersedes EN 12975-2:2001.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

Introduction

This standard specifies test methods for determining the ability of a liquid heating solar collector to resist the influence of degrading agents. It defines procedures for testing collectors under well-defined and repeatable conditions.

This standard also provides test methods and calculation procedures for determining the steady-state and quasi-dynamic thermal performance of glazed liquid heating solar collectors. It contains 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.

This standard also provides methods for determining the thermal performance of unglazed liquid heating solar collectors. Unglazed collectors are in most cases used for heating swimming pools or other low temperature consumers. In general the collectors are put together on-site, connecting absorber strips with manifolds. Real absorber areas are mostly between ten to one hundred square meters. For unglazed absorbers, readily fabricated modules with a specific size are seldom used. Therefore, during the test, it should be checked that a realistic flow pattern and flow velocity is used.

This standard also provides test methods and calculation procedures for determining the steady-state as well as the all-day thermal performance parameters for liquid heating solar collectors, under changing weather conditions. It contains methods for conducting tests outdoors during whole days and under stationary inlet temperature conditions and natural solar irradiance and natural and/or simulated wind conditions. Important effects for the all-day performance of the collector, as the dependence on incident angle, wind speed, diffuse fraction of solar irradiance, thermal sky radiation and thermal capacity are taken into account. Dependence on flowrate is not included in this standard.

Some of the advantages of the proposed extension of the present steady-state test methods of all-day testing are:

- shorter and less expensive outdoor test, suitable for European climate conditions.
- much wider range of collectors can be tested with the same method.
- at the same time, a much more complete characterisation of the collector is achieved.
- collector model is still directly compatible with that of the present basic test standards, and only correction terms are applied in this extended approach.
- all additions are based on long agreed collector theory.
- at any time, full backwards comparability to steady-state can be established by evaluating only periods of the test days that correspond to steady-state test requirements.

- ▪ same test equipment can be used as for stationary testing with only minor changes, which will also improve the accuracy of steady-state testing.
- ▪ commonly available standard PC software can be used for the parameter identification, such as spreadsheets or more advanced statistical packages that have Multiple Linear Regression (MLR) as an option.

1 Scope

This European Standard specifies test methods for validating the durability, reliability and safety requirements for liquid heating collectors as specified in EN 12975-1. This standard also includes three test methods for the thermal performance characterisation for liquid heating collectors.

It is not applicable to those collectors in which the thermal storage unit is an integral part of the collector to such an extent that the collection process cannot be separated from the storage process for the purpose of making measurements of these two processes.

It is basically applicable to tracking concentrating collectors, thermal performance testing as given in 6.3 (quasi dynamic testing) is also applicable to most concentrating collector designs, from stationary non-imaging concentrators as CPCs to high concentrating tracking designs. Parts of the solar radiation measurement should be adjusted in case of a tracking collector and in case a pyrheliometer is used to measure beam radiation.

Collectors that are custom built (built in; e.g. roof integrated collectors that do not compose of factory made modules and are assembled directly on the place of installation) cannot be tested in their actual form for durability, reliability and thermal performance according to this standard. Instead, a module with the same structure as the ready collector may be tested. The module gross area should be at least 2 m^2. The test is valid only for larger collectors than the tested module.

2 Normative references

The following referenced documents are indispensable for the application of this European Standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1991 (all parts), *Eurocode 1: Actions on structures*

EN 12975-1:2006, *Thermal solar systems and components – Solar collectors – Part 1: General requirements*

EN ISO 9488, *Solar energy – Vocabulary (ISO 9488:1999)*

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

3 Terms and definitions

For the purposes of this European Standard, the terms and definitions given in EN ISO 9488 apply.

4 Symbols and units

a_1	heat loss coefficient at $(T_m - T_a)=0$	$Wm^{-2}K^{-1}$
a_2	temperature dependence of the heat loss coefficient	$Wm^{-2}K^{-2}$
A_A	absorber area of collector	m^2
A_a	aperture area of collector	m^2
A_G	gross area of collector	m^2
AM	optical air mass	
b_u	collector efficiency coefficient (wind dependence)	m^{-1} s
b_o	constant for the calculation of the incident angle modifier	
b_1	heat loss coefficient at $(T_m - T_a)=0$	$Wm^{-2}K^{-1}$
b_2	collector efficiency coefficient	$Wsm^{-3}K^{-1}$
c_1	heat loss coefficient at $(T_m - T_a)=0$	$Wm^{-2}K^{-1}$
c_2	temperature dependence of the heat loss coefficient	$Wm^{-2}K^{-2}$
c_3	wind speed dependence of the heat loss coefficient	$Jm^{-3}K^{-1}$
c_4	sky temperature dependence of the heat loss coefficient	$Wm^{-2}K^{-1}$
c_5	effective thermal capacity	$J\ m^{-2}K^{-1}$
c_6	wind dependence in the zero loss efficiency	sm^{-1}
c_f	specific heat capacity of heat transfer fluid	$Jkg^{-1}K^{-1}$
C	effective thermal capacity of collector	JK^{-1}
D	date	YYMMDD
E_L	longwave irradiance ($\lambda > 3 \mu m$)	Wm^{-2}
E_β	longwave irradiance on an inclined surface outdoors	Wm^{-2}
E_s	longwave irradiance	Wm^{-2}
F	radiation view factor	
F'	collector efficiency factor	
G	hemispherical solar irradiance	Wm^{-2}
G^*	global hemispherical solar irradiance	Wm^{-2}
G''	net irradiance	Wm^{-2}
G_b	direct solar irradiance (beam irradiance)	Wm^{-2}

G_d	diffuse solar irradiance	Wm^{-2}
LT	local time	h
K_θ	incidence angle modifier	
$K_{\theta b}$	incidence angle modifier for direct radiation	
$K_{\theta d}$	incidence angle modifier for diffuse radiation	
m	thermally active mass of the collector	kg
$\dot{m}$	mass flowrate of heat transfer fluid	kgs^{-1}
$\dot{Q}$	useful power extracted from collector	W
$\dot{Q}_L$	power loss of collector	W
SF	safety factor	
t	time	s
t_a	ambient or surrounding air temperature	°C
t_{dp}	atmospheric dew point temperature	°C
t_e	collector outlet (exit) temperature	°C
t_{in}	collector inlet temperature	°C
t_m	mean temperature of heat transfer fluid	°C
t_s	atmospheric or sky temperature	°C
t_{stg}	stagnation temperature	°C
T	absolute temperature	K
T_a	ambient or surrounding air temperature	°C
T^*_m	reduced temperature difference (= $(t_m - t_a)/G^*$)	m^2KW^{-1}
T_s	atmospheric or equivalent sky radiation temperature	K
U	measured overall heat loss coefficient of collector, with reference to T^*_m	$Wm^{-2}K^{-1}$
U_L	overall heat loss coefficient of a collector with uniform absorber temperature t_m	$Wm^{-2}K^{-1}$
u	surrounding air speed	ms^{-1}

V_f	fluid capacity of the collector	m^3
Δp	pressure difference between fluid inlet and outlet	Pa
Δt	time interval	s
ΔT	temperature difference between fluid outlet and inlet (t_e - t_{in})	K
α	solar absorptance	
β	tilt angle of a plane with respect to horizontal	degrees
γ	azimuth angle	degrees
ε	hemispherical emittance	
ω	solar hour angle	degrees
θ	angle of incidence	degrees
Φ	latitude	degrees
λ	wavelength	µm
η	collector efficiency, with reference to T^*_m	
η_o	zero-loss collector efficiency (η at $T^*_m = 0$), reference to T^*_m	
σ	Stefan-Boltzmann constant	$Wm^{-2}K^{-4}$
ρ	density of heat transfer fluid	kgm^{-3}
τ_c	collector time constant	s
τ	transmittance	
$(\tau\alpha)_e$	effective transmittance-absorptance product	
$(\tau\alpha)_{ed}$	effective transmittance-absorptance product for diffuse solar irradiance	
$(\tau\alpha)_{en}$	effective transmittance-absorptance product for direct solar radiation at normal incidence	
$(\tau\alpha)_{e\theta}$	effective transmittance-absorptance product for direct solar radiation at angle of incidence θ	

NOTE 1 In the field of solar energy the symbol G is used to denote solar irradiance, rather than the generic symbol E for irradiance.

NOTE 2 C is often denoted $(mC)_e$ in basic literature (see also Annex F)

NOTE 3 For more information about thermal performance coefficients (parameters) c1 to c6, see Annex F.

5 Reliability testing of liquid heating collectors

5.1 General

The details regarding the number of collectors and sequences used to carry out the qualifications tests detailed in the list below (Table 1) shall be given in the report.

For some qualification tests, a part of the collector may have to be tampered with in some way, for example a hole may have to be drilled in the back of the collector to attach a temperature sensor to the absorber. In these cases care should be taken to ensure that any damage caused does not affect the results of subsequent qualification tests, for example by allowing water to enter into a previously raintight collector.

Table 1 - Test List

Subclause	Test
5.2	Internal pressure
5.3	High-temperature resistance [a, b]
5.4	Exposure [b]
5.5	External thermal shock [c]
5.6	Internal thermal shock [c]
5.7	Rain penetration [d]
5.8	Freeze resistance [e]
5.9	Mechanical load
5.10	Impact resistance (optional test)
6.1-6.2-6.3	Thermal performance [f]

[a] For organic absorbers, the high-temperature resistance test shall be performed first in order to determine the collector stagnation temperature needed for the internal pressure test.

[b] The high temperature and exposure test shall be carried out on the same collector

[c] The external and internal thermal shock tests may be combined with the exposure test or the high-temperature resistance test.

[d] The rain penetration test shall be carried out only for glazed collectors.

[e] The freeze resistance test shall be carried out only for collectors claimed to be freeze resistant.

[f] The Thermal performance test shall be carried out on a collector that had not been used for other tests.

NOTE Regarding the durability and reliability of elastic materials it is recommended to refer to ISO 9808 and ISO 9553.

5.2 Internal pressure tests for absorbers

5.2.1 Inorganic absorbers

5.2.1.1 Objective

The absorber shall be pressure-tested to assess the extent to which it can withstand the pressures which it might meet in service.

5.2.1.2 Apparatus and procedure

The apparatus, shown in Figure A.1, consists of a hydraulic pressure source (electrical pump or hand pump), 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 absorber of air before pressurisation. The inorganic absorber shall be filled with water at room temperature and pressurised to the test pressure for the test period (see 5.2.1.3.2). This pressure shall be maintained while the absorber is inspected for swelling, distortion or ruptures.

5.2.1.3 Test conditions

5.2.1.3.1 Temperature

Inorganic absorbers shall be pressure-tested (see 5.2.1.3.2) at ambient temperature within the range 5 °C to 30 °C.

5.2.1.3.2 Pressure

The test pressure shall be 1,5 times the maximum collector operating pressure specified by the manufacturer.

The test pressure shall be maintained for 15 min.

5.2.1.4 Results

The collector shall be inspected for leakage, swelling and distortion. The results of this inspection shall be reported together with the values of pressure and temperature used and the duration of the test.

5.2.2 Absorbers made of organic materials (plastics or elastomers)

5.2.2.1 Objective

The absorber shall be pressure-tested (see 5.2.1.3.2) to assess the extent to which it can withstand the pressures which it might meet in service while operating at elevated temperature. The tests shall be carried out at elevated temperatures, because the pressure resistance of an organic absorber may be adversely affected as its temperature is increased. One of the methods described in 5.2.2.2.2 through 5.2.2.2.4 may be chosen.

5.2.2.2 Apparatus and procedure

5.2.2.2.1 General

The apparatus consists of either a hydraulic or a pneumatic pressure source, and a means of heating the absorber to the required test temperature.

The characteristics of a solar irradiance simulator shall be the same as those of the simulator used for efficiency testing of liquid heating solar collectors.

A temperature sensor shall be attached to the absorber to monitor its temperature during the test. The sensor shall be positioned at two-thirds of the absorber height and half the absorber width. It shall be fixed firmly in a position to ensure good thermal contact with the absorber. The sensor shall be shielded from solar radiation.

The test conditions specified in 5.2.2.3 shall be maintained for at least 30 min prior to test and for the full duration of the test.

The pressure in the absorber shall be raised in stages as specified in 5.2.2.3, and the absorber shall be inspected for swelling, distortion or rupture after each increase in pressure. The pressure shall be maintained while the absorber is being inspected.

For safety reasons, the collector shall be encased in a transparent box to protect personnel in the event of explosive failure during this test.

One of the methods described in 5.2.2.2.2 through 5.2.2.2.4 may be chosen.

5.2.2.2.2 Organic absorbers for use in unglazed collectors (test temperature < 90 °C)

Where the maximum test temperature is below 90 °C, absorbers may be submerged in a heated water bath and pressure-tested. The pressurised fluid supply to the absorber shall be fitted with a safety valve, air-bleed valve (if required) and pressure gauge having a standard uncertainty better than 5 %. The apparatus is shown in Figure A.2.

5.2.2.2.3 Organic absorbers for use with oil-based fluids (test temperature > 90 °C)

When the test temperature exceeds 90 °C, the absorber may be connected to a hot oil circuit. The absorber and hot oil circuit are then pressurised. The hot oil circuit shall be fitted with a safety valve, air-bleed valve and pressure gauge having a standard uncertainty better than 5 %.

The absorber may be heated by any of the following methods:

a) connecting a heater in the oil circuit (see Figure A.3);

b) heating the whole collector in a solar irradiance simulator (see Figure A.4);

c) heating the whole collector outdoors under natural solar irradiance (see Figure A.4).

Safety measures should be taken to protect personnel from hot oil in the event of explosive failure during this test.

5.2.2.2.4 Organic absorbers - high temperature pneumatic pressure test

The absorber may be pressure-tested using compressed air, when heated by either of the following methods:

a) heating the whole collector in a solar irradiance simulator (see Figure A.5);

b) heating the whole collector outdoors under natural solar irradiance (see Figure A.5).

The compressed air supply to the absorber shall be fitted with a safety valve and a pressure gauge having a standard uncertainty better than 5 %.

5.2.2.3 Test conditions

5.2.2.3.1 Temperature

For absorbers made of organic materials, the test temperature shall be the maximum temperature which the absorber will reach under stagnation conditions.

The reference conditions given in Table 2 shall be used.

The calculations employed to determine the test temperature are included in Annex C and shall either:

- use measured collector performance characteristics, or

- extrapolate from average values, measured in the high-temperature resistance test (see 5.3.3), of the global solar irradiance (natural or simulated) on the collector plane, the surrounding air temperature and the absorber temperature.

Table 2 - Climate reference conditions to determine test temperatures for internal pressure test of organic absorbers

Climate parameter	**Value for all climate classes**
Global solar irradiance on collector plane, G in W/m^2	1000
Surrounding air temperature, t_a in °C	30

5.2.2.3.2 Pressure

The test pressure shall be 1,5 times the maximum collector operating pressure specified by the manufacturer.

For absorbers made of organic materials, the pressure shall be raised to the test pressure in equal stages of 20 kPa (approximately) and maintained at each intermediate pressure for 5 min. The test pressure shall then be maintained for a least 1 h.

5.2.2.4 Results

The collector shall be inspected for leakage, swelling and distortion. The results of the inspection shall be reported.

Full details of the test procedure used, including the temperature, intermediate pressures and test periods used, shall be reported with the test results.

5.3 High-temperature resistance test

5.3.1 Objective

This test is intended to assess rapidly whether a collector can withstand high irradiance levels without failures such as glass breakage, collapse of plastic cover, melting of plastic absorber, or significant deposits on the collector cover from outgassing of collector material.

5.3.2 Apparatus and procedure

The collector shall be tested outdoors, or in a solar irradiance simulator. A schema for testing is shown in Figure A.6.

The characteristics of the solar irradiance simulator to be used for the high-temperature resistance test shall be those of the solar irradiance simulator used for efficiency testing of liquid heating solar collectors.

The collector shall be mounted outdoors or in a solar simulator, and shall not be filled with fluid. All of the fluid pipes except for one shall be sealed to prevent cooling by natural circulation of air.

A temperature sensor shall be attached to the absorber to monitor its temperature during the test. The sensor shall be positioned at two-thirds of the absorber height and half the absorber width. It shall be fixed firmly in a position to ensure good thermal contact with the absorber. The sensor shall be shielded from solar radiation.

NOTE 1 When testing collectors, such as evacuated tubular collectors, for which it is not appropriate to measure the stagnation temperature at the absorber, the temperature sensor should be placed at a suitable location in the collector, and this location should be clearly described with the test results.

NOTE 2 In some cases, such as evacuated collectors, it may be difficult to attach a thermocouple to the absorber. In such cases, instead of attaching a thermocouple to the absorber, the testing laboratory may partially fill the absorber with a special fluid, seal the absorber and measure the temperature of the fluid directly or measure the pressure in the absorber. The relationship between the internal pressure in the absorber and its temperature should be known from the standard vapour pressure/temperature relationship for the fluid.

NOTE 3 It is recommended to perform the determination of the stagnation temperature together with the high-temperature resistance test.

The test shall be performed for a minimum of 1 h after steady-state conditions have been established, and the collector shall be subsequently inspected for signs of damage as specified in 5.3.4.

5.3.3 Test conditions

The set of reference conditions given in Table 3 or conditions resulting in the same collector temperature according to Equation C.1, shall be used for all climate classes.

Table 3 - Climate reference conditions for high-temperature resistance test

Climate parameter	**Value for all climate classes**
Global solar irradiance on collector plane, G in W/m^2	>1000
Surrounding air temperature, t_a in °C	20 - 40
Surrounding air speed in m/s	< 1

5.3.4 Results

The collector shall be inspected for degradation, shrinkage, outgassing and distortion.

The results of the inspection shall be recorded together with the average values of solar irradiance (natural or simulated) on the collector plane, surrounding air temperature and speed, and absorber temperature (and the pressure of the special fluid in the absorber, if that method is used) recorded during the test.

5.4 Exposure test

5.4.1 Objective

The exposure test provides a low-cost reliability test sequence, indicating (or simulating) operating conditions which are likely to occur during real service and also allows the collector to "settle", such that subsequent qualification tests are more likely to give repeatable results.

5.4.2 Apparatus and procedure

The collector shall be mounted outdoors (see Figure A.7), but not filled with fluid. All except one of the fluid pipes shall be sealed to prevent cooling by natural circulation of air. One shall be left open to permit free expansion of air in the absorber.

The air temperature shall be recorded to a standard uncertainty of 1 K and the global irradiance on the plane of the collector recorded using a pyranometer of class I or better in accordance with ISO 9060. Irradiation and mean air temperature values shall be recorded at least every 5 min and rainfall shall be recorded daily. The collector shall be exposed until the test conditions have been met.

At the end of the exposure, a visual inspection shall be made for signs of damage as specified in 5.4.4.

5.4.3 Test conditions

The set of reference conditions given in Table 4 shall be used.

The collector shall be exposed until at least 30 days (which need not be consecutive) have passed with the minimum irradiation *H* shown in Table 4. The irradiation is determined by recording irradiance measurements using a pyranometer.

The collector shall also be exposed for at least 30 h to the minimum irradiance level *G* given in Table 4, as recorded by a pyranometer, when the surrounding air temperature is greater than the value shown in Table 4 or conditions resulting in the same collector temperature according to Equation C.1. These hours shall be made up of periods of at least 30 min.

NOTE In regions where these conditions cannot be met during certain periods of the year, the 30-h exposure to high irradiance levels (Table 4) can be conducted in a solar irradiance simulator having characteristics identical to those of a simulator used for efficiency testing of liquid heating solar collectors. The 30-h exposure test should be conducted after the collector has completed at least 10 days, but no more than 15 days, of the exposure to the minimum irradiation level (Table 4).

If the external and internal thermal shock tests are combined with the exposure test, the first external and internal shocks shall be caused during the first 10 of the 30 h defined above, and the second during the last 10 of the 30 h.

Table 4 - Climate reference conditions for exposure test as well as for external and internal thermal shock tests

Climate parameter	Value for all climate classes
Global solar irradiance on collector plane, G in W/m^2	850
Global daily irradiation on collector plane, H in MJ/m^2	14
Surrounding air temperature, t_a in °C	10
NOTE Values given are minimum values for testing.	

5.4.4 Results

The collector shall be inspected for damage or degradation. The results of the inspection shall be reported together with a record of the climatic conditions during the test, including daily irradiation, surrounding air temperature and rain.

5.5 External thermal shock test

5.5.1 Objective

Collectors may 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.

5.5.2 Apparatus and procedure

The collector shall be mounted either outdoors or in a solar irradiance simulator, but shall not be filled with fluid. All except one of the fluid pipes shall be sealed to prevent cooling by natural circulation of air. One shall be left open to permit free expansion of air in the absorber (see Figure A.8).

A temperature sensor may be optionally attached to the absorber to monitor its temperature during the test. The sensor shall be positioned at two-thirds of the absorber height and half the absorber width. It shall be fixed firmly in a position to ensure good thermal contact with the absorber. The sensor shall be shielded from solar radiation.

NOTE 1 When testing collectors, such as evacuated tubular collectors, for which it is not appropriate to measure the stagnation temperature at the absorber, the temperature sensor should be placed at a suitable location in the collector, and this location should be clearly described with the test results.

NOTE 2 In some cases, such as evacuated collectors, it may be difficult to attach a thermocouple to the absorber. In such cases, instead of attaching a thermocouple to the absorber, the testing laboratory may partially fill the absorber with a special fluid, seal the absorber and measure the pressure in the absorber. The relationship between the internal pressure in the absorber and its temperature should be known from the standard vapour pressure/temperature relationship for the fluid.

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

The collector shall be maintained under a high level of solar irradiance for a period of 1 h before the water spray is turned on. It is then cooled by the water spray for 15 min before being inspected.

The collector shall be subjected to two external thermal shocks.

5.5.3 Test conditions

The set of reference conditions given in Table 4 shall be used.

The specified operating conditions shall be:

- solar (or simulated solar) irradiance G greater than the value shown in Table 4.

- surrounding air temperature t_a greater than the value shown in Table 4.

Or conditions resulting in the same collector temperature according to Equation C.1

The water spray shall have a temperature of less than 25 °C and a flowrate in the range 0,03 kg/s to 0,05 kg/s per square metre of collector aperture.

If the temperature of the water which first cools the collector is likely to be greater than 25 °C (for example if the water has been sitting in a pipe in the sun for some time), then the water shall be diverted until it has reached a temperature of less than 25 °C before being directed over the collector.

5.5.4 Results

The collector shall be inspected for any cracking, distortion, condensation, water penetration or loss of vacuum. The results of the inspection shall be reported. The measured values of solar irradiance, surrounding air temperature, absorber temperature (if measured), water temperature and water flowrate shall also be reported.

5.6 Internal thermal shock test

5.6.1 Objective

Collectors may from time to time be exposed to a sudden intake of cold heat transfer fluid on hot sunny days, causing a severe 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.

5.6.2 Apparatus and procedure

The collector shall be mounted either outdoors or in a solar irradiance simulator (see Figure A.9), but shall not be filled with fluid. One of its fluid pipes shall be connected via a shutoff valve to the heat transfer fluid source and the other shall be left open initially to permit the free expansion of air in the absorber and also to permit the heat transfer fluid to leave the absorber (and be collected). If the collector has more than two fluid pipes, the remaining openings shall be sealed in a way that ensures the designed flow pattern within the collector.

A temperature sensor may be optionally attached to the absorber to monitor its temperature during the test. The sensor shall be positioned at two-thirds of the absorber height and half the absorber width. It shall be fixed firmly in a position to ensure good thermal contact with the absorber. The sensor shall be shielded from solar radiation.

NOTE 1 When testing collectors, such as evacuated tubular collectors, for which it is not appropriate to measure the stagnation temperature at the absorber, the temperature sensor should be placed at a suitable location in the collector, and this location should be clearly described with the test results.

NOTE 2 In some cases, such as evacuated collectors, it may be difficult to attach a thermocouple to the absorber. In such cases, instead of attaching a thermocouple to the absorber, the testing laboratory may partially fill the absorber with a special fluid, seal the absorber and measure the pressure in the absorber. The relationship between the internal pressure in the absorber and its temperature should be known from the standard vapour pressure/temperature relationship for the fluid.

The collector shall be maintained under a high level of solar irradiance for a period of 1 h before it is cooled by supplying it with heat transfer fluid for at least 5 min or until the absorber temperature drops below 50 °C.

The collector shall be subjected to two internal thermal shocks.

5.6.3 Test conditions

The set of reference conditions given in Table 4 shall be used.

The specified operating conditions shall be:

- solar (or simulated solar) irradiance G greater than the value shown in Table 4;

- surrounding air temperature t_a greater than the value shown in Table 4.

or conditions resulting in the same collector temperature according to Equation C.1

The heat transfer fluid shall have a temperature of less than 25 °C. The recommended fluid flowrate is at least 0,02 kg/s per square metre of collector aperture (unless otherwise specified by the manufacturer).

5.6.4 Results

The collector shall be inspected for any cracking, distortion, deformation, water penetration or loss of vacuum. The results of the inspection shall be reported. The measured values of solar irradiance, surrounding air temperature, absorber temperature (if measured), heat transfer fluid temperature and heat transfer fluid flowrate shall also be reported.

5.7 Rain penetration test

5.7.1 Objective

This test is applicable only for glazed collectors and is intended to assess the extent to which glazed collectors are substantially resistant to rain penetration. They shall normally not permit the entry of either free-falling rain or driving rain. Collectors may have ventilation holes and drain holes, but these shall not permit the entry of drifting rain.

5.7.2 Apparatus and procedure

5.7.2.1 General

The collector shall have its fluid inlet and outlet pipes sealed (unless hot water is circulated through the absorber, see 5.7.2.2), as shown in Figure A.10, and be placed in a test rig at the shallowest angle to the horizontal recommended by the manufacturer. If this angle is not specified, then the collector shall be placed at a tilt of 30° to the horizontal. Collectors designed to be integrated into a roof structure shall be mounted in a simulated roof and have their underside protected. Other collectors shall be mounted in a conventional manner on an open frame or a simulated roof.

The collector shall be sprayed on exposed sides, using spray nozzles or showers.

5.7.2.2 Detection of ingress of water

The collector shall be mounted and sprayed as explained above while the absorber in the collector is kept warm (minimum 50 °C). This can be done either by circulating hot water at about 50 °C through the absorber or by exposing the collector to solar radiation. The penetration of water into the collector shall be determined by inspection (looking for water droplets, condensation on the cover glass or other visible signs) and by one of the following methods:

a) by weighing the collector (standard uncertainty better than 5 g/m^2 collector area); or
b) by means of humidity measurement (standard uncertainty better than 5 %) or
c) by means of measuring the condensation level.

The heating up of the collector should be started before the spraying of the water in order to ensure that the collector box is dry before testing.

In cases of collectors having wood in the backs (or other special cases), the laboratory shall take all necessary measures during the conduction of the test so that the final result will not be influenced or altered by the special construction of the collector.

5.7.3 Test conditions

The collector shall be sprayed with water at a temperature lower than 30 °C with a flowrate of more than 0,05 kg/s per square metre of sprayed area. The duration of the test shall be 4 h.

5.7.3.1 Weighing method

If the weighing method is chosen, the collector shall be put on the scale before the start of the test on three consecutive occasions. The weights recorded shall not vary by more than ± 5 g/m^2 collector area.

5.7.3.2 Humidity measurement method

When measuring the penetration of water into the collector by means of humidity measurement, an absolute humidity sensor is placed in the air gap between absorber and glazing. Collector and sensor are connected to a hot fluid loop for at least five hours before the rain is switched on in order to stabilise. When testing outdoors, in order to minimize disturbances of the measurement, the collector shall be shaded during the whole test. The humidity shall be monitored from five hours before the raining till at least five hours after the raining. Ingress of water might also be detected at a later stage, during the “Final Inspection” (5.11).

5.7.3.3 Condensation level method

If the condensation level method is chosen, the penetration of water is determined by measuring the condensation level on the cover glass and by measuring the water that comes out of the collector when tipping it.

The heating of the collector shall be started at least 30 min before the spraying of water and shall continue until it can be ensured that the collector box is dry before testing. This shall be done by circulating hot water (or other fluid) above 50 ^{o}C through the absorber before but also during the complete test. The water will thereafter condense on the inside of the glazing, which is being cooled by cold water on the outside. After 2 h an intermediate inspection of condensation on the cover glass shall be done in order to facilitate the reporting of the places where water penetrates.
After finishing the spraying the inspection of condensation should be done after a short time for ventilating, in order to distinguish collectors with good ventilation qualifications that are without accumulation of humidity inside the collector. However, the inspection should be done within one minute after finishing the spraying before the collector will make any temperature changes.

5.7.4 Results

The collector shall be inspected for water penetration. The results of the inspection, i.e. the extension of water penetration and the places where water penetrated shall be reported.

5.8 Freeze resistance test

5.8.1 Objective

This test is intended to assess the extent to which water heating collectors which are claimed to be freeze resistant can withstand freezing, and freeze/thaw cycling. This test is not intended for use with collectors for which it is clearly stated in the installation manual that they may only be used with an antifreeze fluid.

Two test procedures are recommended:

- one for collectors which are claimed to be freeze-resistant when filled with water, and

- one for collectors which are claimed to resist freezing after being drained.

5.8.2 Apparatus and procedure

5.8.2.1 Freeze-resistant collectors

For collectors which are claimed to be able to withstand freezing, the collector shall be mounted in a cold chamber (see Figure A.11). The collector shall be fitted correctly, shut completely and inclined at the shallowest angle to the horizontal recommended by the manufacturer. If no angle is specified by the manufacturer, then the collector shall be inclined at an angle of 30° to the horizontal. Unglazed collectors shall be tested in a horizontal position unless this is excluded by the manufacturer. Next, the collector shall be filled with water at the operating pressure.

The cold-chamber temperature shall be cycled, and 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.

5.8.2.2 Collectors with drain-down protection

For collectors which employ a drain-down system to protect them from freezing damage, the collector shall be mounted in a cold chamber (see Figure A.11). The collector shall be then inclined at the shallowest angle to the horizontal recommended by the manufacturer. If no angle is specified by the manufacturer, then the collector shall be inclined at an angle of 30° to the horizontal. Unglazed collectors shall be tested in a horizontal position unless this is excluded by the manufacturer. The collector shall be next filled with water, kept at operating pressure for 10 min and then drained using the device installed by the manufacturer.

If, 5 min after the start of the drain process, the amount of drained water from the collector corresponds to approximately 95 % of the total water which filled that collector, then in that case, no test in cold chamber is required.

The cold-chamber temperature shall be cycled.

The temperature shall be measured inside the absorber close to the inlet.

After the last cycle the collector shall be refilled with water at operating pressure.

5.8.3 Test conditions

The contents of the absorber shall be maintained at (-20 ± 2) °C for at least 30 min during the freezing part of the cycle, and are raised to above 10 °C during the thawing part of the cycle. The duration of the thawing part of the cycle shall be at least 30 min.

The collector shall be subjected to three freeze-thaw cycles.

5.8.4 Results

The number of cycles carried out shall be reported. The collector shall be inspected for leakage, breakage, distortion and deformation. These shall be reported together with the absorber temperatures reached during the cycles and the times spent by the collector at the test temperatures. The tilt angle used for the test shall also be reported.

5.9 Mechanical load test

5.9.1 Positive pressure test of the collector

5.9.1.1 Objective

This test is intended to assess the extent to which the transparent cover of the collector and the collector box are able to resist the positive pressure load due to the effect of wind and snow.

5.9.1.2 Apparatus and procedure

The collector shall be placed horizontally on an even ground. On the collector a foil shall be laid and on the collector frame a wooden or metallic frame shall be placed, high enough to contain the required amount of gravel or similar material (see Figure A.12).

The gravel, preferably type 2-32 mm, shall be weighed in portions and distributed in the frame so that everywhere the same load is created (pay attention to the bending of the glass), until the desired height is reached.

The test can also be carried out installing the collector in accordance with 5.9.2.2 and loading the cover using suction cups, gravel or other suitable means (e.g. water).

As a further alternative, the necessary load may be created by applying an air pressure on the collector cover.

The load may also be created by applying a negative pressure on the collector cover. In this case, apparatus in accordance to EN 12211 can be used. However this method cannot be applied on all collector types.

5.9.1.3 Test conditions

The test pressure shall be increased at maximum steps of 250 Pa until a failure occurs or up to the value specified by the manufacturer. The test pressure shall be at least 1000 Pa. A failure can be the destruction of the cover and also the permanent deformation of the collector box or the fixings.

NOTE A permanent deformation should be assigned to a load value, while it is completely relieved after every load increment of 250 Pa and the distortion is measured compared to the beginning of the test sequence. The value of an inadmissible permanent deformation amounts to max. 0,5 %. (Example: 10 mm distortions at 2 m length of collector frame).

5.9.1.4 Results

The pressure at which any failure of the collector cover or the box or fixings occurs shall be reported together with details of the failure. If no failure occurs, then the maximum pressure which the collector sustained shall be reported.

The maximum positive pressure is the pressure reached before occurring a failure. The permissible positive pressure is the maximum pressure divided by the safety factor SF+ = 1,5:

$F_{perm+} = F_{max+} \;/\; SF+ \text{ with } SF+ = 1,5$

NOTE When the test is done with an on-roof mounting system the test results are also valid for the roof integrated mounting system.

5.9.2 Negative pressure test of the collector

5.9.2.1 Objective

This test is intended to assess the extent to which the fixings between the collector cover and collector box are able to resist uplift forces caused by the wind.

For the design of the statics of the mounting system the national and European Guidelines for Structural Planning according to EN 1991 have to be applied.

5.9.2.2 Apparatus and procedure

The collector shall be installed horizontally on a stiff frame by means of its mounting fixtures. The frame which secures the cover to the collector box shall not be restricted in any way.

A lifting force which is equivalent to the specified negative pressure load shall be applied evenly over the cover. The load shall be increased in steps up to the final test pressure. If the cover has not been loosened at the final pressure, then the pressure may be stepped up until failure occurs. The time between each pressure step shall be the time needed for the pressure to stabilise.

Either of two alternative methods may be used to apply pressure to the cover:

- Method (a): The load may be applied to the collector cover by means of a uniformly distributed set of suction cups (see Figure A.13).
- Method (b): For collectors which have an almost airtight collector box, the following procedure may be used to create a negative pressure on the cover (see Figure A.14). Two holes are made through the collector box into the airgap between the collector cover and absorber, and an air source and pressure gauge are connected to the collector airgap through these holes. A negative pressure on the cover is created by pressurising the collector box. For safety reasons the collector shall be encased in a transparent box to protect personnel in the event of failure during this test.

During the test, the collector shall be visually inspected and any deformations of the cover and its fixings reported. The collector shall be examined at the end of the test to see if there are any permanent deformations.

5.9.2.3 Test conditions

The test pressure shall be increased in steps of 250 Pa until a failure occurs or up the value specified by the manufacturer. The test pressure shall be at least 1000 Pa. A failure can be the destruction of the cover and also the permanent deformation of the collector box or the fixings.

NOTE A permanent deformation should be assigned to a load value, while it is completely relieved after every load increment of 250 Pa and the distortion is measured compared to the beginning of the test sequence. The value of an inadmissible permanent deformation amounts to max. 0,5 %. (Example: 10 mm distortions at 2 m length of collector frame).

5.9.2.4 Results

The pressure at which any failure of the collector cover or the box or fixings occurs shall be reported together with details of the failure. If no failure occurs, then the maximum pressure which the collector sustained shall be reported.

The maximum negative pressure is the pressure reached before occurring a failure. The permissible negative pressure is the maximum pressure divided by the safety factor SF- = 2:

$F_{perm-} = F_{max-}$ / SF- with SF- = 2

5.10 Impact resistance test (optional)

5.10.1 Objective

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

5.10.2 Apparatus and procedure

5.10.2.1 General

The testing of the solar collector to determine its impact resistance can be done by one of two methods, i.e. by using steel balls or ice balls.

5.10.2.2 Method 1

The collector shall be mounted either vertically or horizontally on a support (see Figure A.15). The support may be stiff enough so that there is negligible distortion or deflection at the time of impact.

Steel balls shall be used to simulate a heavy 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 the fall is the vertical distance between the point of release and the horizontal plane containing the point of impact.

The point of impact shall be no more than 5 cm from the edge of the collector cover, and no more than 10 cm from the corner of the collector cover, but it shall be moved by several millimetres each time the steel ball is dropped.

A steel ball shall be dropped onto the collector 10 times from the first test height, then 10 times from the second test height, etc. until the maximum test height is reached (as specified by the manufacturer). The test is to be stopped when the collector sustains some damage or when the collector has survived the impact of 10 steel balls at the maximum test height.

NOTE This method does not correspond to the physical effect of hailstones as the deformation energy absorbed by the ice particles is not being considered.

5.10.2.3 Method 2

The apparatus consists of the following equipment:

a) Moulds of suitable material for casting spherical ice balls of the required diameter (25 mm).

b) A freezer, controlled at -10 °C ± 5 °C.

c) A storage container for storing the ice balls at a temperature of -4 °C ± 2 °C.

d) A launcher capable of propelling an ice ball at the specified velocity (as specified by the manufacturer), within ± 5 %, so as to hit the collector within the specified impact location. The path of the ice ball from the launcher to the collector may be horizontal, vertical or at any intermediate angle.

e) A rigid frame for supporting the collector, with the impact surface normal 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.

f) A balance for determining the mass of an ice ball to a standard uncertainty of ± 2 %.

g) An instrument for measuring the velocity of the ice ball to a standard uncertainty of ± 2 ms^{-1}. The velocity sensor shall be no more than 1 m from the surface of the collector.

As an example, Figure A.16 shows in schematic form a suitable apparatus comprising a horizontal pneumatic launcher, a vertical collector support and a velocity meter which measures electronically the time it takes the ice ball to traverse the distance between two light beams.

The testing procedure shall be the following:

a) Using the moulds and the freezer, make sufficient ice balls of the required size for the test, including some for the preliminary adjustment of the launcher.

b) Examine each one for cracks, size and mass. An acceptable ball shall meet the following criteria:

- no cracks visible to the unaided eye;
- diameter within ± 5 % of the ball (25 mm);
- mass within ± 5 % of the ball (25 mm).

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

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

e) Fire a number of trial shots at a simulated target in accordance with step g) below and adjust the launcher until the velocity of the ice ball, as measured with the velocity sensor in the prescribed position, is within ± 5 % of the required hailstone test velocity.

f) Install the collector at room temperature in the prescribed mount, with the impact surface normal to the path of the ice ball.

g) Take an ice ball from the storage container and place it in the launcher. Take aim at the impact location and fire. The time between the removal of the ice ball from the container and impact on the collector shall not exceed 60 s.

The point of impact shall be no more than 5 cm from the edge of the collector cover, and no more than 10 cm from the corner of the collector cover, but it shall be moved by several millimetres each time the ice ball is launched.

An ice ball shall be launched onto the collector 10 times; the test shall be stopped when the collector sustains some damage or when the collector has survived the impact of 10 ice balls.

5.10.3 Test conditions

If the test is conducted according to method 1, the steel ball shall have a mass of 150 g ± 10 g and the following series of test heights shall be used: 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.

If the test is conducted according to method 2, the ice ball shall have a diameter of 25 mm ± 5 %, a mass of 7,53 g ± 5 % and its velocity shall be 23 m/s ± 5 %.

5.10.4 Results

The collector shall be inspected for damage. The results of the inspection shall be reported, together with the height from which the steel ball was dropped (if method 1 is used) and the number of impacts which caused the damage.

NOTE As test method 2 is closer to reality, this method (5.10.2.3) is preferable.

5.11 Final inspection

When the full tests have been completed, the collector shall be dismantled and inspected. All abnormalities shall be reported and accompanied by a photograph.

5.12 Test report

The format sheets given in Annex B shall be completed for each test, together with the introductory format sheet (B.1) reporting a summary of main results, including the test methods.

6 Thermal performance testing of liquid heating collectors

The thermal performance of glazed solar collectors shall be tested according to either 6.1 or 6.3.

6.1 Glazed solar collectors under steady state conditions (including pressure drop)

6.1.1 Collector mounting and location

6.1.1.1 General

The way in which a collector is mounted will influence the results of thermal performance tests. Collectors to be tested shall therefore be mounted in accordance with 6.1.1.2 to 6.1.1.8. Full-size collector modules shall be tested, because the edge losses of small collectors may significantly reduce their overall performance.

6.1.1.2 Collector mounting frame

The collector mounting frame shall in no way obstruct the aperture of the collector, and shall not significantly affect the back or side insulation. Unless otherwise specified (for example, when the collector is part of an integrated roof array), an open mounting structure shall be used which allows air to circulate freely around the front and back of the collector. 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 which 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.

6.1.1.3 Tilt angle

The collector shall be tested at tilt angles such that the incidence angle modifier for the collector varies by no more than ± 2 % from its value at normal incidence. For single glazed flat plate collectors, this condition will usually be satisfied if the angle of incidence of direct solar radiation at the collector aperture is less than 20°.

NOTE For many collectors, the influence of tilt angle is small, but it can be an important variable for specialized collectors such as those incorporating heat pipes.

6.1.1.4 Collector orientation outdoors

The collector may be mounted outdoors in a fixed position facing the equator, but this will result in the time available for testing being restricted by the acceptance range of incidence angles. A more versatile approach is to move the collector to follow the sun in azimuth, using manual or automatic tracking.

6.1.1.5 Shading from direct solar irradiance

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

6.1.1.6 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 to come isotropically from the hemispherical field of view of the collector.

In order to minimize the errors resulting from this approximation, the collector shall be located where there will be no significant solar radiation reflected onto it from surrounding buildings or surfaces during the tests, and where there will be no significant obstructions in the field of view. With some collector types, such as evacuated tubular collectors, it may be equally important to minimize reflections on both the back and the front fields of view.

Not more than 5 % of the collector's field of view shall be obstructed, and it is particularly important to avoid buildings or large obstructions subtending an angle of greater than approximately 15° to the horizontal in front of the 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.

Surfaces to be avoided in the collector's field of view include large expanses of glass, metal or water. In most solar simulators the simulated beam approximates direct solar irradiance only. In order to simplify the measurement of simulated irradiance, it is necessary to minimize reflected irradiance. This can be achieved by painting all surfaces in the test chamber with a dark (low reflectance) paint.

6.1.1.7 Thermal irradiance

The 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.

6.1.1.8 Air speed

The performance of many collectors is sensitive to air speeds. In order to maximize the reproducibility of results, collectors shall be mounted such that air can freely pass over the aperture, back and sides of the collector. The mean air speed, parallel to the collector aperture, shall be between the limits specified in 6.1.4.3. Where necessary, artificial wind generators shall be used to achieve these air speeds. Collectors designed for integration into a roof may have their backs protected from the wind; if so, this shall be reported with the test results.

6.1.2 Instrumentation

6.1.2.1 Solar radiation measurement

6.1.2.1.1 Pyranometer

6.1.2.1.1.1 General

A class I or better, as specified in ISO 9060, pyranometer shall be used to measure the global short-wave radiation from both the sun and the sky. The recommended practice for use given in ISO/TR 9901 should be observed. Before each test the pyranometer should be checked for dust, soiling etc. on the outer dome and it should be cleaned if necessary.

A class I or better pyranometer equipped with a shading ring or alternatively a pyrheliometer together with a pyranometer shall be used to measure the diffuse short-wave radiation.

6.1.2.1.1.2 Precautions for effects of temperature gradient

The pyranometer used during the test(s) shall be placed in a typical test position and allowed to equilibrate for at least 30 min before data-taking commences.

6.1.2.1.1.3 Precautions for effects of humidity and moisture

The pyranometer shall be provided with a means of preventing accumulation of moisture that may condense on surfaces within the instrument and affect its reading. An instrument with a desiccator that can be inspected is required. The condition of the desiccator shall be observed on a regular basis.

6.1.2.1.1.4 Precautions for infrared radiation effects on pyranometer accuracy

Pyranometers used to measure the irradiance of the solar irradiance simulator shall be mounted in such a way as to minimize the effects on its readings of the infrared radiation of wavelength above 3 µm from the simulator light source.

6.1.2.1.1.5 Mounting of pyranometers outdoors

The pyranometer shall be mounted such that its sensor is coplanar, within a tolerance of ± 1° with the plane of the collector aperture. It shall not cast a shadow onto the collector aperture at any time during the test period. The pyranometer shall be mounted so as to receive the same levels of direct, diffuse and reflected solar radiation as are received by the collector.

NOTE For angles of incidence of 50°, a deviation of ± 1° leads to an error of 2 % when measuring the solar irradiance.

For outdoor testing, the pyranometer shall be mounted at the midheight of the collector. The body of the pyranometer and the emerging leads of the connector shall be shielded to minimize solar heating of the electrical connections. Care shall also be taken to minimize energy reflected and reradiated from the solar collector onto the pyranometer.

6.1.2.1.1.6 Use of pyranometers in solar irradiance simulators

Pyranometers may be used to measure the distribution of simulated solar irradiance over the collector aperture, and the variation in simulated irradiance with time (see 6.1.5.6). Alternatively, other types of radiation detector may be used, provided that they have been evaluated and calibrated for simulated solar radiation in question.

The pyranometer(s) shall be mounted such that its sensor(s) is (are) coplanar, with a tolerance of ±1° with the plane of the collector aperture. The pyranometer(s) shall not cast a shadow onto the collector aperture at any time during the test period. The pyranometer(s) shall be mounted so as to receive the same levels of indirect, diffuse and reflected solar radiation as are received by the collector.

The method and equipment used to measure any variation in simulated irradiance with time during the test period, shall be well proven to give the required accuracy.

NOTE E.g. for the most commonly used type of solar simulator, using an electrical arc in a sealed beam parabolic reflector as the light source, the mounting of a pyranometer in a typical test position at the midheight of the collector as described for outdoor testing, will not be adequate. Especially, when the lamp array is powered from unstabilized mains power supply and from 3 different phases. For solar simulators of this kind not equipped with stabilized power supply, integration of power supply voltage during each test period is recommended. Solar simulators equipped with stabilized power supply, capable of stabilizing the power supply voltage within ± 0,5 %, normally will need no integration of simulated irradiance during (each) test period. For most types of solar simulators, the relationship between the spatially integrated value of the simulated solar irradiance and the integrated power supply voltage during each test period, can be found. In all cases, sufficient knowledge of burn in and life time characteristics of the lamp type used, is assumed.

6.1.2.1.2 Measurement of the angle of incidence of direct solar radiation

A simple device for measuring the angle of incidence of direct solar radiation can be produced by mounting a pointer normal to a flat plate on which graduated concentric rings are marked. The length of the shadow cast by the pointer may be measured using the concentric rings and used to determine the angle of incidence. The device shall be positioned in the collector plane and to one side of the collector.

6.1.2.2 Thermal radiation measurement

6.1.2.2.1 Measurement of thermal irradiance outdoors

The variations of thermal irradiance outdoors are not normally taken into account for collector testing. However, a pyrgeometer may be mounted in the plane of the collector aperture and to one side at midheight, to determine the thermal irradiance at the collector aperture.

6.1.2.2.2 Determination of thermal irradiance indoors and in solar simulators

6.1.2.2.2.1 Measurement

The thermal irradiance may be measured using a pyrgeometer as indicated in 6.1.2.2.1. for outdoor measurements. Pyrgeometer shall be well ventilated in order to minimize the influence of solar or simulated solar irradiance. For indoor testing, the thermal irradiance shall be determined to a standard uncertainty of 10 Wm^{-2}.

6.1.2.2.2.2 Calculation

Provided that all sources and sinks of thermal radiation in the field of view of the collector can be identified, the thermal irradiance at the collector aperture may be calculated using temperature measurements, surface emittance measurements and radiation view factors. The thermal irradiance incident on a collector surface (designated 1), from a hotter surface (designated 2) is given by

$$\sigma \varepsilon_2 F_{12} T_2^{\,4} \qquad (1)$$

Or, more usefully, the additional thermal irradiance (compared with that which would be present if surface 2 had been a perfect black body at ambient temperature) is given by

$$\sigma F_{12} \left(\varepsilon_2 T_2^{\,4} - T_a^{\,4} \right) \qquad (2)$$

Radiation view factors are given in textbooks on radiation heat transfer. The thermal irradiance at the collector aperture may also be calculated from a series of measurements made for small solid angles in the field of view. Such measurements can be made using a pyrheliometer with and without a glass filter to identify the thermal component of the global irradiance.

6.1.2.3 Temperature measurements

6.1.2.3.1 General

Three temperature measurements are required for solar collector testing. 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.

6.1.2.3.2 Measurement of heat transfer fluid inlet temperature (t_{in})

6.1.2.3.2.1 Required accuracy

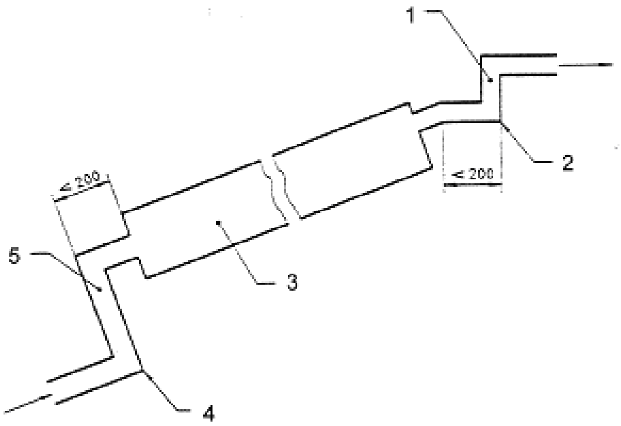
The temperature of the heat transfer fluid at the collector inlet shall be measured to a standard uncertainty of 0,1 K, but in order to check that the temperature is not drifting with time, a very much better resolution of the temperature signal to ± 0,02 K is required.

NOTE This resolution is needed for all temperatures used for collector testing (i.e. over the range 0 °C to 100 °C) which is a particularly demanding accuracy for recording by data logger, as it requires a resolution of one part in 4.000 or a 12-bit digital system.

6.1.2.3.2.2 Mounting of sensors

The sensor for temperature measurement shall be mounted at no more than 200 mm from the collector inlet, and insulation shall be placed around the pipework 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 pipework, an orifice or a fluid-mixing device shall be placed upstream of the sensor, and the sensor probe shall point upstream and in a pipe where the flow is rising (to prevent air from being trapped near the sensor), as shown in Figure 1.

Dimensions in millimetres



Key

1 Temperature transducer (t_e ΔT)
2 Pipework bend or mixing device
3 Solar collector
4 Pipework bend or mixing device
5 Temperature transducer (t_{in} ΔT)

Figure 1 - Recommended transducer positions for measuring the heat transfer fluid inlet and outlet temperatures

6.1.2.3.3 Determination of heat transfer fluid temperature difference (ΔT)

The difference between the collector outlet and inlet temperatures (ΔT) shall be determined to a standard uncertainty of <0,05 K. Standard uncertainties approaching 0,02 K can be achieved with modern well-matched and calibrated transducers, and hence it is possible to measure heat transfer fluid temperature differences of 1 K or 2 K with a reasonable accuracy. Delta-T sensors shall be calibrated in the relevant temperature range.

6.1.2.3.4 Measurement of surrounding air temperature (t_a)

6.1.2.3.4.1 Required accuracy

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

6.1.2.3.4.2 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 midheight 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 to one side of the collector and not more than 10 m from it. 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 ± 1 K.

6.1.2.4 Measurement of collector liquid flowrate

Mass flowrates may be measured directly or, alternatively, if the density is known, they may be determined from measurements of volumetric flowrate and temperature. The standard uncertainty of the liquid flowrate measurement shall be within ± 1 % of the measured value, in mass per unit time. The flowmeter shall be calibrated over the range of fluid flowrates and temperatures to be used during collector testing.

NOTE The temperature of the fluid in volumetric flowmeters should be known with sufficient accuracy to ensure that mass flowrates can be determined to within the limits specified by the manufacturer.

6.1.2.5 Measurement of air speed

6.1.2.5.1 General

The heat losses from a collector increase with increasing air speed over the collector, but the influence of air speed direction is not well understood. Measurements of air speed direction are therefore not used for collector testing.

The relationship between the meteorological wind speed and the air speed over the collector depends on the location of the test facility, so 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.

6.1.2.5.2 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 ms^{-1} for both indoor and outdoor testing. Under outdoor conditions the surrounding air speed is seldom constant, and gusting frequently occurs. The measurement of an average air speed is therefore required during the test period. This may be obtained either by an arithmetic average of sampled values or by a time integration over the test period.

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

During indoor testing, the air speed may vary from one end of the collector to the other. A series of air speed measurements shall therefore be taken, at a distance of 10 mm to 50 mm in front of the collector aperture, at equally spaced positions over the collector area.

An average value shall then be determined. Air speed measurements indoors in stable conditions shall be made before and after performance test points to avoid obscuring the collector aperture.

When testing outdoors in locations where the mean wind speed is below 2 ms^{-1} , an artificial wind generator shall be used, and anemometer measurements shall be fitted for the continuous measurement of air velocity. This anemometer shall be mounted on a board so that there is continuous surface pointing towards the wind generator from the collector edge to 0,3 m behind the anemometer. The uniformity of air speed in the field of collector aperture shall be checked. The wind speed shall be measured while adjusting the wind generator, using a hand held anemometer in a height of 10 mm to 50 mm above the collector aperture plane.

In windy locations, wind speed measurement shall be made near to the collector at the mid height of the collector. The sensor shall not be shielded from the wind and it shall not cast a shadow on the collector during the test periods.

NOTE The recorded value of the wind speed is different to the air speed above the collector aperture.

6.1.2.6 Elapsed time

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

6.1.2.7 Instrumentation/data recorders

In no case shall the smallest scale division of the instrument or instrument system exceed twice the specified standard uncertainty. For example, if the specified standard uncertainty is 0,1 K, the smallest scale division shall not exceed 0,2 °C. Digital techniques and electronic integrators shall have a standard uncertainty equal to or better than 1,0 % of the measured value.

Analog and digital recorders shall have an error equal to or better than 0,5 % of the full-scale reading and have a time constant of 1s or less. The peak signal indication shall be between 50 % and 100 % of full scale. The input impedance of recorders shall be greater than 1000 times the impedance of the sensors or 10 MΩ whichever is higher.

6.1.2.8 Collector area

The collector area (absorber, gross or aperture) shall be measured to a standard uncertainty of 0,3 %. Area measurements shall take place at a collector temperature of (20 ± 10) °C and under operating pressure if the absorber is made of organic material.

6.1.2.9 Collector fluid capacity

The fluid capacity of the collector shall be measured to a standard uncertainty of no more than 10 %. Measurements may be made either by weighing the collector when empty and again when filled with fluid, or by filling and emptying the collector to determine the mass of fluid which it will contain.

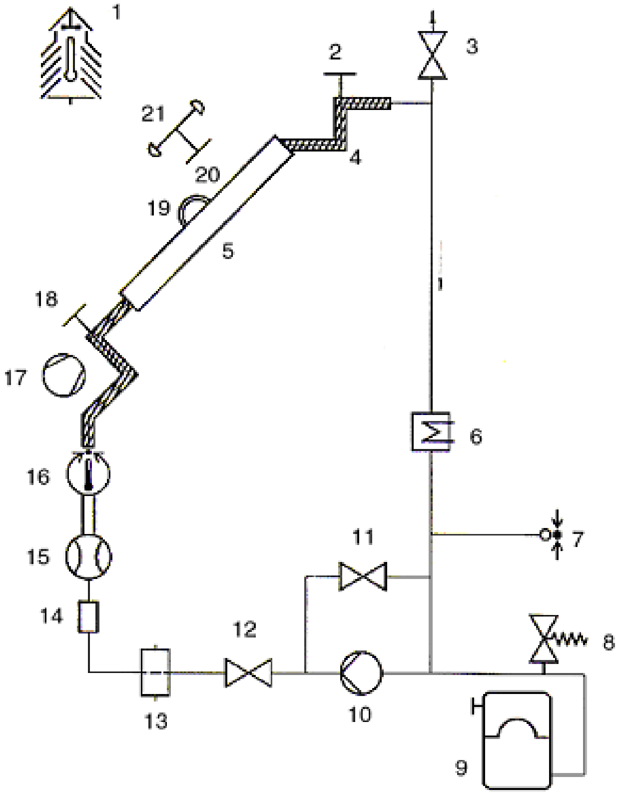
The temperature of the fluid shall be kept within ± 2 K of the ambient temperature.

As an alternative, a determination by calculation, which is based on the geometrical circumstances, can be given.

6.1.3 Test installation

6.1.3.1 General consideration

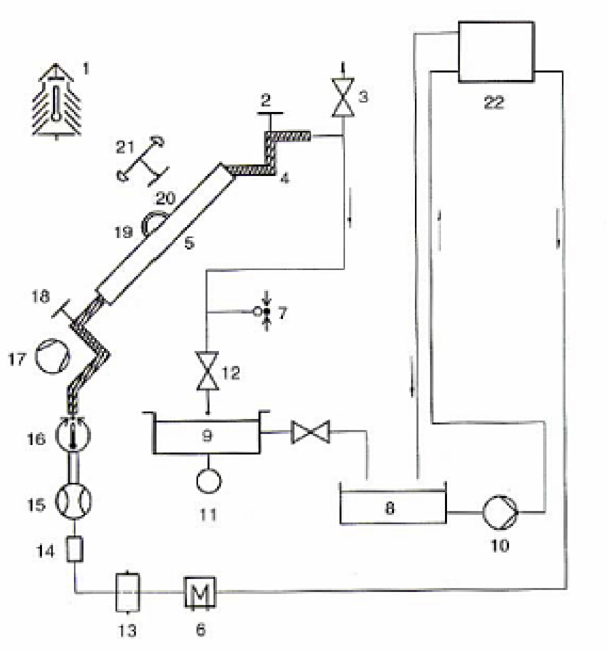
Examples of test configurations for testing solar collectors employing liquid as the heat transfer fluid are shown in Figures 2 and 3. These are schematic only, and are not drawn to scale.



Key

1	Surrounding air temperature sensor
2	Temperature sensor (t_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	Flowmeter
16	Secondary temperature regulator
17	Artificial wind generator
18	Temperature sensor (t_{in})
19	Pyrgeometer
20	Pyranometer
21	Anemometer

Figure 2 – Example of a closed test loop



Key

- 1 Surrounding air temperature sensor
- 2 Temperature sensor (t_e)
- 3 Air vent
- 4 Insulated pipe
- 5 Solar collector
- 6 Heater/cooler for primary temperature control
- 7 Pressure gauge
- 8 Reservoir
- 9 Weighing vessel
- 10 Pump
- 11 Balance
- 12 Flow control valve
- 13 Filter (200 µm)
- 14 Sight glass
- 15 Flowmeter
- 16 Secondary temperature regulator
- 17 Artificial wind generator
- 18 Temperature sensor (t_{in})
- 19 Pyrgeometer
- 20 Pyranometer
- 21 Anemometer
- 22 Constant head tank

Figure 3 – Example of an open test loop

6.1.3.2 Heat transfer fluid

The heat transfer fluid used for collector testing may be water or a fluid recommended 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. These values are given for water in Annex I.

Some fluids may need to be changed periodically to ensure that their properties remain well defined.

The mass or volume flowrate of the heat transfer fluid shall be the same throughout the test sequence used to determine the thermal efficiency curve, time constant and incident angle modifiers for a given collector.

6.1.3.3 Pipework and fittings

The piping used in the collector loop shall be resistant to corrosion and (for testing of glazed collectors) suitable for operation at temperatures up to 95 °C. If nonaqueous fluids are used, then compatibility with system materials shall be confirmed. Pipe lengths shall generally be kept short. In particular, the length of piping between the outlet of the fluid temperature regulator and the inlet to the collector shall be minimized, to reduce the effects of the environment on the inlet temperature of the fluid.

This section of pipe shall be insulated to ensure a rate of heat loss of less than 0,2 WK^{-1}, and shall be protected by a reflective weatherproof coating. Pipework between the temperature sensing points and the collector (inlet and outlet) shall be protected with insulation and reflective (for outdoor measurements also weatherproof) covers to beyond the positions of the temperature sensors, such that the calculated temperature gain or loss along either pipe portion does not exceed ± 0,01 K under test conditions. Flow-mixing devices such as pipe bends are required immediately upstream of temperature sensors (see 6.1.2.3).

NOTE 1A short length of transparent tube should be installed in the fluid loop so that air bubbles and any other contaminants will be observed if present. The transparent tube should be placed close to the collector inlet but should not influence the fluid inlet temperature control or temperature measurements.

A variable area flowmeter is convenient for this purpose, as it simultaneously gives an independent visual indication of the flowrate. An air separator and air vent should be placed at the outlet of the collector, and at other points in the system where air can accumulate.

NOTE 2 Filters should be placed upstream of the flow measuring device and the pump, in accordance with normal practice (a nominal filter size of 200 µm is usually adequate).

6.1.3.4 Pump and flow control devices

The fluid pump 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 control of the collector inlet temperature or the measurements of the fluid temperature rise through the collector. With some types of pump, a simple bypass loop and manually controlled needle valve may provide adequate flow control. Where necessary, an appropriate flow control device may be added to stabilize the mass flowrate.

The pump and flow controller shall be capable of maintaining the mass or volume flowrate through the collector stable to within 1 % despite temperature variations, at any inlet temperature chosen within the operating range.

6.1.3.5 Temperature regulation of the heat transfer fluid

The collector test loop shall be capable of maintaining a constant collector inlet temperature at any temperature level chosen within the operating range. Since the rate of energy collection in the collector is deduced by measuring instantaneous values of the fluid inlet and outlet temperatures, it follows that small variations in inlet temperature could lead to errors in the rates of energy collection deduced. It is particularly important to avoid any drift in the collector inlet temperature.

NOTE 1Test loops may contain two stages of fluid inlet temperature control, as shown in Figures 2 and 3. The primary temperature controller should be placed upstream of the flowmeter and flow controller. A secondary temperature regulator should be used to adjust the fluid temperature just before the collector inlet. This secondary regulator should normally not be used to adjust the fluid temperature by more than ± 2 K.

NOTE 2A secondary temperature controller close to the collector inlet is useful, provided that it does not introduce problems with measuring the ‘mean cup‘‘ inlet temperature. On the other hand, bypasses should also remain allowed as a means to reduce the influence of heat loss and to improve the control characteristics of the heating circuits. A constant and high flowrate through the heaters will allow PID controlling with fast I and D action, while any flowrate through the collector can be chosen.

6.1.4 Outdoor steady-state performance test

6.1.4.1 Test installation

The collector shall be mounted in accordance with the specifications given in 6.1.1, and coupled to a test loop as described in 6.1.3. The heat transfer fluid shall flow from the bottom to the top of the collector, or as recommended by the manufacturer.

6.1.4.2 Preconditioning of the collector

The collector shall be visually inspected and any damage recorded. The collector aperture cover shall be thoroughly cleaned. If moisture is formed on the collector components, then the heat transfer fluid shall be circulated at approximately 80 °C for as long as is necessary to dry out the insulation and collector enclosure.

If this form of preconditioning is carried out, then it shall be reported with the test results. The collector pipework shall be vented of trapped air by means of an air valve or by circulating the fluid at a high flowrate, as necessary. The fluid shall be inspected for entrained air or particles, by means of the transparent tube built into the fluid loop pipework. Any contaminants shall be removed.

The empty collector shall be exposed to irradiation for 5 h at the level of more than 700 $\mathrm{Wm^{-2}}$.

6.1.4.3 Test conditions

At the time of the test, the hemispherical solar irradiance at the plane of the collector aperture shall be greater than 700 $\mathrm{Wm^{-2}}$.

NOTE 1If the manufacturer has limitations on operation with respect to maximum irradiance but not less than 800 $\mathrm{Wm^{-2}}$, this can be requested with the test. That maximum value should be clearly reported.

The angle of incidence of direct solar radiation at the collector aperture 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. For single glazed flat plate collectors, this condition will usually be satisfied if the angle of incidence of direct solar radiation at the collector aperture is less than 20°.

However, much lower angles may be required for particular designs. In order to characterize collector performance at other angles, an incident angle modifier may be determined (see 6.1.7).

Where diffuse solar irradiance is less than 30 %, its influence may be neglected. The collector shall not be tested at diffuse irradiance levels of greater than 30 %.

The average value of air speed parallel to the collector aperture, taking into account spatial variations over the collector and temporal variations during the test period, shall be 3 $\mathrm{ms^{-1}}$ ± 1 $\mathrm{ms^{-1}}$.

Unless otherwise specified, the fluid flowrate shall be set at approximately 0,02 kgs^{-1} per square metre of collector aperture area. It shall be held stable to within ±1 % of the set value during each test period, and shall not vary by more than ± 10 % of the set value from one test period to another.

The testing at other flowrates may be accommodated by adhering to manufacturer's specification.

In some collectors the recommended fluid flowrate may be close to the transition region between laminar and turbulent flow. This may cause instability of the internal heat transfer coefficient and hence variations in measurements of collector efficiency. In order to characterize such a collector in a reproducible way, it may be necessary to use a higher flowrate, but this shall be clearly stated with the test results.

NOTE 2 In the transition regime, the flowrate should first be set high (turbulent) and then reduced to the setpoint value. This will prevent transition from laminar to turbulent during the measurements.

Measurements of fluid temperature difference of less than 1 K shall not be included in the test results because of the associated problems of instrument error.

6.1.4.4 Test procedure

The collector shall be tested over its operating temperature range under clear sky conditions in order to determine its performance characteristic. Data points, which satisfy the requirements given below shall be obtained for at least four fluid inlet temperatures spaced evenly over the operating temperature range of the collector. If possible, one inlet temperature shall be selected such that the mean fluid temperature in the collector lies within ± 3 K of the ambient air temperature, in order to obtain an accurate determination of η_0. If water is the heat transfer fluid, the maximum temperature shall be at least around 80 °C. A maximum value of T_m^* of at least 0,09 is recommended if test conditions permit.

At least four independent data points shall be obtained for each fluid inlet temperature, to give a total of 16 data points. If test conditions permit, an equal number of data points shall be taken before and after solar noon for each fluid inlet temperature. The latter is not required if the collectors are moved to follow the sun in azimuth and altitude using automatic tracking.

During a test, measurements shall be made as specified in 6.1.4.5. These may then be used to identify test periods from which satisfactory data points can be derived.

6.1.4.5 Measurements

The following data shall be measured:

- gross collector area A_G , the absorber area A_A and the aperture area A_a;
- fluid capacity
- hemispherical solar irradiance at the collector aperture
- diffuse solar irradiance at the collector aperture (only outdoors)
- angle of incidence of direct solar radiation
  (alternatively, this angle may be determined by calculation)
- air speed parallel to the collector aperture
- surrounding air temperature
- temperature of the heat transfer fluid at the collector inlet

- temperature of the heat transfer fluid at the collector outlet
- flowrate of the heat transfer fluid

6.1.4.6 Test period (steady-state)

The test period for a steady state data point shall include a pre-conditioning period of at least 4 times the time constant of the collector (if known), or not less than 15 min (if time constant is not known), with the correct fluid temperature at the inlet, followed by a steady state measurement period of at least 4 times the time constant of the collector (if known), or not less than 10 min (if time constant is not known).

A collector is considered to have been operating in steady-state conditions over a given measurement period if none of the experimental parameters deviate from their mean values over the measurement period by more than the limits given in Table 5. To establish that a steady state exists, average values of each parameter taken over successive periods of 30 s shall be compared with the mean value over the measurement period.

Table 5 - Permitted deviation of measured parameters during a measurement period

Parameter	Permitted deviation from the mean value
(Global)Test solar irradiance	± 50 Wm^{-2}
Surrounding air temperature (indoor)	± 1 K
Surrounding air temperature (outdoor)	± 1,5 K
Fluid mass flowrate	± 1 %
Fluid temperature at the collector inlet	± 0,1 K

6.1.4.7 Presentation of results

The measurements shall be collated to produce a set of data points which meet the required test conditions (see 6.1.4.3), including those for steady-state operation. These shall be presented using the data format sheets given in Annex D.

6.1.4.8 Computation of collector output

6.1.4.8.1 General

The actual useful power extracted, $\dot{Q}$, is calculated from:

$$\dot{Q} = \dot{m} c_f \Delta T \qquad (3)$$

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

6.1.4.8.2 Solar energy intercepted by the collector

Provided that the angle of incidence is less than 20°, the use of an incident angle modifier, as described in 6.1.7, is not required for single glazed flat plate collectors.

The solar energy intercepted is A·G where the area is A_A when referred to the absorber area of the collector and A_a when referred to the aperture area of the collector. Introducing the collector efficiency, the actual useful power extracted, $\dot{Q}$, can also be written as

$$\dot{Q} = AG\eta \tag{4}$$

6.1.4.8.3 Reduced temperature difference

When the mean temperature of the heat transfer fluid t_m is used, where

$$t_\mathrm{m} = t_\mathrm{in} + \frac{\Delta T}{2} \tag{5}$$

the reduced temperature difference is calculated as:

$$T^*_\mathrm{m} = \frac{t_\mathrm{m} - t_\mathrm{a}}{G} \tag{6}$$

6.1.4.8.4 Modeling of instantaneous efficiency

6.1.4.8.4.1 General

The instantaneous efficiency η shall be calculated by statistical curve fitting, using the least squares method, to obtain an instantaneous efficiency curve of the form

$$\eta = \eta_0 - a_1 T_\mathrm{m}^* - a_2 G (T_\mathrm{m}^*)^2 \tag{7}$$

Normally a second-order curve shall be used which can be achieved by least squares regression. A second-order fit shall not be used if the value deduced for a_2 is negative. The test conditions shall be recorded on the data format sheets given in Annex D.

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

6.1.4.8.4.2 Instantaneous efficiency based on absorber area / aperture area

With reference to the reduced temperature difference T^*_m the equations for instantaneous efficiency are :

$$\eta = \eta_0 - a_1 \frac{t_m - t_a}{G} - a_2 G \left(\frac{t_m - t_a}{G} \right)^2 \qquad (8)$$

6.1.4.8.4.3 Conversion of thermal performance test characteristics

To convert the thermal performance test characteristics the following basic conversions shall be used:

$$\eta_{0A} = \eta_{0a} \frac{A_a}{A_A} \qquad (9)$$

$$a_{1A} = a_{1a} \frac{A_a}{A_A} \qquad (10)$$

$$\mathrm{a}_{2\mathrm{A}} = \mathrm{a}_{2\mathrm{a}} \frac{A_\mathrm{a}}{A_\mathrm{A}} \qquad (11)$$

6.1.4.8.5 Collector output

Using Equation 4 and 8 the collector output per modul can be written as:

$$\dot{Q} = A \cdot G \cdot \left(\eta_0 - a_1 \frac{(t_m - t_a)}{G} - a_2 \frac{(t_m - t_a)}{G} \right) \qquad (4.1)$$

Where the area is A_A when referred to the absorber area of the collector and A_a when referred to the aperture area of the collector.
The collector output per modul shall be presented graphically as a function of the temperature difference between mean fluid and ambient temperature (t_m – t_a) using G = 1000W/m². The product $AG\eta_0$ shall be referred to as W_{peak}.

6.1.5 Steady-state efficiency test using a solar irradiance simulator

6.1.5.1 General

The performance of most collectors is better in direct solar radiation than in diffuse and at present there is little experience with diffuse solar simulation. This test method is therefore designed for use only in simulators 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 aperture.

6.1.5.2 The solar irradiance simulator for steady-state efficiency testing

A simulator for steady-state efficiency testing shall have the following characteristics:

The lamps shall be capable of producing a mean irradiance over the collector aperture of at least 700 Wm^{-2}. Values in the range 300 Wm^{-2} to 1000 Wm^{-2} may also be used for specialized tests, provided that the accuracy requirements given in Table 5 can be achieved and the irradiance values are noted in the test report.

At any time the irradiance at a point on the collector aperture shall not differ from the mean irradiance over the aperture by more than ± 15 %. The spectral distribution of the simulated solar radiation shall be approximately equivalent to that of the solar spectrum at optical air mass 1,5.

Where collectors contain spectrally selective absorbers or covers, 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.

$$\text{Effective}(\tau\alpha) = \frac{\int_{0,3\mu m}^{3\mu m} \tau(\lambda)\alpha(\lambda)\mathrm{G}(\lambda)\mathrm{d}\lambda}{\int_{0,3\mu m}^{3\mu m} \mathrm{G}(\lambda)\mathrm{d}\lambda} \qquad (12)$$

Measurement of the solar simulator's spectral qualities shall be 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.

For certain lamp types, i.e. metal halide designs, it is recommended that the initial spectral determination 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) and reported (see 6.1.2.2).

The thermal irradiance at the collector shall not exceed that of a blackbody cavity at ambient air temperature by more than 5 % of global irradiance.

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.

NOTE 1Additional requirements concerning collimation apply to measurement of the incident angle modifier (see 6.1.7.2).

The method used for measuring the irradiance during the test period shall produce values of mean irradiance which agree with those determined by spatial integration to within ± 1%.

NOTE 2 The spectral distribution of the lamps (indoors) and of the sky (outdoors) can and do lead to very wide discrepancies in spectrally selective absorbers or covers.

6.1.5.3 Test installation

Collector mounting and location requirements outlined in 6.1.1 shall be followed.

A wind generator shall be used with a solar simulator to produce an air flow in accordance with 6.1.1.8.

6.1.5.4 Preconditioning of the collector

The procedure outlined in 6.1.4.2 shall be followed.

6.1.5.5 Test procedure

The collector shall be tested over its operating temperature range in approximately the same way as specified for outdoor testing (see 6.1.4.4).

However, eight test points shall be adequate for testing in solar simulators provided that at least four different inlet temperatures are used, and adequate time is allowed for temperatures to stabilize. One inlet temperature should lie within ± 3 K of the ambient air temperature, if possible. During a test, measurements shall be made as specified in 6.1.5.6. These may then be used to identify test periods from which satisfactory data points can be derived.

6.1.5.6 Measurements during tests in solar irradiance simulators

6.1.5.6.1 General

Measurements shall be made as specified in 6.1.4.

6.1.5.6.2 Measurement of simulated solar irradiance

NOTE Simulated solar irradiance usually varies spatially over the collector aperture as well as varying with time during a test. It is therefore essential to employ a procedure for integrating the irradiance over the collector aperture. Time variations in irradiance are usually caused by fluctuations in the electricity supply and changes in lamp output with temperature and running time. Some lamps take more than 30 min to reach a stable working condition when warming up from cold.

Pyranometers may be used to measure the irradiance of simulated solar radiation in accordance with 6.1.2.1. Alternatively, other types of radiation detector may be used, provided they have been calibrated for simulated solar radiation. Details of the instruments and the methods used to calibrate them shall be reported with the test results. The distribution of irradiance over the collector aperture shall be measured using a grid of maximum spacing 150 mm, and the spatial mean deduced by simple averaging.

6.1.5.6.3 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 6.1.5.8.

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, and at least annually. The mean thermal irradiance in the collector test plane and the date when it was last measured shall be reported with collector test results.

6.1.5.6.4 Ambient air temperature in simulators

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

6.1.5.7 Test period

The test period may be determined in the same way as for outdoor steady-state testing.

The more stable environment of an indoor test facility may allow steady-state conditions to be maintained more easily than outdoors, but adequate time shall still be allowed to ensure proper steady-state operation of the collector as specified in 6.1.4.6.

6.1.5.8 Test conditions

The test conditions described in 6.1.4.3 for outdoor testing shall be observed with the following additions:

- thermal irradiance in the plane of the collector aperture shall not exceed that from a blackbody cavity at ambient air temperature by more than 5 % of the global irradiance.

- air issuing from the wind generator shall not differ in temperature from ambient air by more than ± 1 K.

6.1.5.9 Computation and presentation of results

The analysis presented in 6.1.4.8 for outdoor testing is also applicable to solar simulator tests, and the results shall be presented on the format sheets shown in Annex D.

6.1.6 Determination of the effective thermal capacity and the time constant of a collector

6.1.6.1 General

The effective thermal capacity and the time constant of a collector are important parameters, which determine its transient performance.

A collector can usually be considered as a combination of masses, each at a different temperature. 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.

Unfortunately, the effective thermal capacity depends on the operating conditions and is not a collector parameter with a unique value. Several different test methods have been used to measure or calculate the effective thermal capacity of collectors and it has been shown that similar results can be obtained by using quite different methods. Just as there is no unique value of effective thermal capacity, there is no unique overall time constant for a collector. For most collectors, the dominant influence on the response time is the fluid transit time, and hence the first-order response varies with the fluid flowrate. Other collector components respond with different times to give an effective overall time constant, which depends on the operating conditions.

6.1.6.2 Determination of effective thermal capacity

The effective thermal capacity of the collector C (expressed as Joules per Kelvin) is calculated as the sum, for each constituent element of the collector (glass, absorber, liquid contained, insulation), of the product of its mass m_i (expressed in kilograms), its specific heat c_i (expressed as joules per kilogram Kelvin) and a weighting factor p_i :

$$C = \sum_{i} p_i m_i c_i \qquad (13)$$

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 6.

Table 6 - Values of weighting factors

Elements	p_i
Absorber	1
Insulation	0,5
Heat transfer liquid	1
External glazing	0,01*a_1
Second glazing	0,2*a_1
Third glazing	0,35*a_1

For drain-back and drain-down systems, the capacity should be reported for the collector while it is filled with water and while it is empty.

Effective thermal capacity may also be measured by applying the procedures described in Annex G.

6.1.6.3 Test procedure for collector time constant (optional)

Testing shall be performed either outdoors or in a solar irradiance simulator. In either case, the solar irradiance on the plane of the collector aperture shall be greater than 700 Wm^{-2}. The heat transfer fluid shall be circulated through the collector at the same flowrate as that used during collector thermal efficiency tests. The aperture of the collector shall be shielded from the solar radiation by means of a solar-reflecting cover, and the temperature of the heat transfer fluid at the collector inlet shall be set approximately equal to the ambient air temperature. When a steady state has been reached, the cover shall be removed and measurements continued until steady-state conditions have been achieved again. For the purpose of this test, a steady-state condition is assumed to exist when the outlet temperature of the fluid varies by less than *0,05 K per minute. The following quantities shall be measured in accordance with 6.1.2:

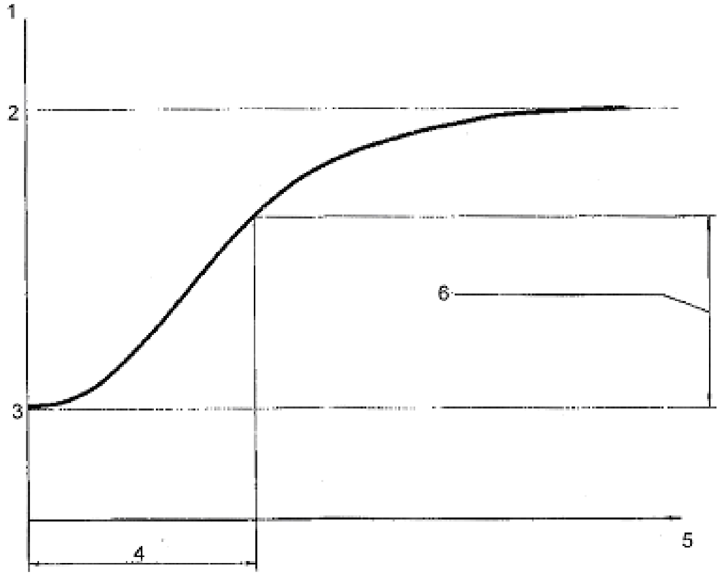
- Collector fluid inlet temperature (t_{in});

- Collector fluid outlet temperature (t_e);

- Surrounding air temperature (t_a);

6.1.6.4 Calculation of collector time constant (optional)

The difference between the temperature of the fluid at the collector outlet and that of the surrounding air (t_e - t_a) shall be plotted against time, beginning with the initial steady-state condition (t_e - t_a)$_0$ and continuing until the second steady state has been achieved at a higher temperature (t_e - t_a)$_2$ (see Figure 4).



Key

1 $t_e - t_a$
2 $(t_e - t_a)_2$
3 $(t_e - t_a)_o$
4 τ_c
5 Time
6 0,632 $((t_e - t_a)_2 - (t_e - t_a)_o)$

Figure 4 - Collector time constant

The time constant τ_c of the collector is defined as the elapsed time between the removal of the cover and the point where the collector outlet temperature rises to 63,2 % of the total increase from $(t_e - t_a)_0$ to $(t_e - t_a)_2$. If the response time of the temperature sensors is significant when compared with that measured for the collector, then it shall be taken into account in calculating the test results.

6.1.7 Collector incidence angle modifier

6.1.7.1 General

The effective transmittance - absorbance product $(\tau\alpha)_e$ can be replaced by the value at normal incidence $(\tau\alpha)_{en}$ provided that another factor called the incidence angle modifier, K_θ, is introduced in Equation (14).

$$\eta = F' K_\theta (\tau\alpha)_{en} - a_1 \frac{t_m - t_a}{G} - a_2 G \left(\frac{t_m - t_a}{G} \right)^2 \qquad (14)$$

Hence:

$$(\tau\alpha)_{\mathrm{e}} = K_{\theta}(\tau\alpha)_{\mathrm{en}} \qquad (15)$$

Figure 5 shows the variation of K_{θ} with angle of incidence for two solar collectors.

For those collectors (e.g. evacuated tube collectors and CPC collectors) for which the incidence angle effects are not symmetrical with direction of incidence, it is necessary to measure the incident angle effects from more than one direction to fully characterize the incident angle modifier.

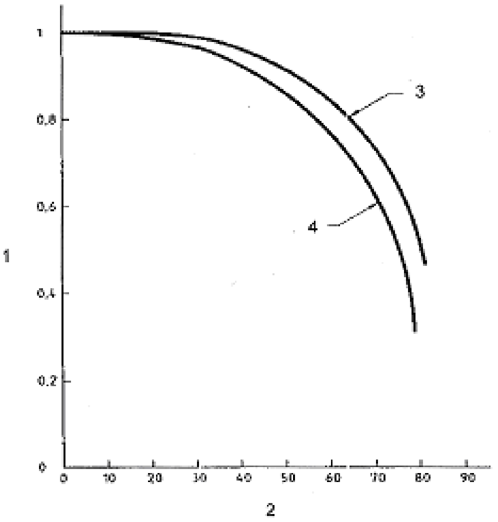
The complex individual incident angle modifier can be estimated by considering it to be the product of the separate incident angle modifiers, $K_{\theta L}$ and $K_{\theta T,}$ for two perpendicular symmetry planes (Equation 15.1).

$$K_{\theta} = K_{\theta L} \bullet K_{\theta T} \qquad (15.1)$$

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 θL and θT are the projections of the incidence angle θ onto the longitudinal and transversal planes, respectively.

For the correlation between θ, θL and θT, the following equation holds:

$$\tan^2\theta = \tan^2\theta L + \tan^2\theta T \qquad (15.2)$$



Key

1 Incidence angle modifier K_{θ}
2 Angle of incidence (degrees)
3 Single - K_{θ} glazed cover
4 Double – Glazed cover

Figure 5 - Typical incidence angle modifiers K_θ

The significance of the incidence angle modifier to the test procedures outlined in this standard is that the thermal efficiency values are determined for the collector at or near normal incidence conditions. Therefore, the y intercept η of the efficiency curve is equal to $F'(\tau\alpha)_{en}$, for a flat plate collector. A separate measurement shall be conducted to determine the value of K_θ so that the performance of the collector can be predicted under a wide range of conditions and/or time of day using Equation (14).

6.1.7.2 Solar irradiance simulator for the measurement of incidence angle modifiers

For the measurement of the incidence angle modifier, only solar irradiance simulators with the following collimation specification 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.

6.1.7.3 Test procedures

6.1.7.3.1 General

The testing of the solar collector to determine its incidence angle modifier may be done by one of two methods. However, during each test period, the orientation of the collector shall be such that the collector is maintained within ± 2,5° of the angle of incidence for which the test is being conducted. The solar irradiance on the plane of the aperture shall be greater than 300 W/m².

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

NOTE 1 Care should be taken that the measurement of the incident angle modifier is not affected by inappropriate tilt angles.

NOTE 2 For angles of incidence of 50°, a deviation of ± 1° leads to an error of 2 % when measuring the solar irradiance.

6.1.7.3.2 Method 1

This method is applicable for testing indoors using a solar simulator with the characteristics specified in 6.1.5.2, or outdoors using a movable test rack (altazimuth collector mount) 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 orientated so that the test angle of incidence between it and the direct solar radiation for the test condition is 50°. For conventional flat plate collectors, this angle will be sufficient. For some collectors with unusual optical performance characteristics, or if it is required for system simulation, angles of 20°, 40°, 60° and others may be necessary.

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 6.1.4.4.

6.1.7.3.3 Method 2

This method is applicable for testing outdoors using a stationary test rack on which the collector orientation cannot be arbitrarily adjusted with respect to direction for incident solar radiation (except for adjustments in tilt).

The mean temperature of the heat transfer fluid shall be controlled, if possible, to within ± 1 K of the ambient air temperature. 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.

The efficiency value shall be determined in general in accordance with the method described in 6.1.4.4. As with Method 1, data shall be collected for angle of incidence of 50°. For some collectors with unusual optical performance characteristics or if it is required for system simulation, angles of 20°, 40°, 60° and others may be necessary.

NOTE More experience is required to confirm whether this method is applicable to special geometries, such as tubular collectors.

6.1.7.4 Calculation of collector incidence angle modifier

Regardless of which experimental method in 6.1.7.3. is used, values for the thermal efficiency of the collector shall be determined for each value of angle of incidence. For conventional flat plate collectors, only one angle of incidence is needed which is 50° (It is noted that a rating standard using this test method may require that K_θ be measured for a different set of angles of incidence). The mean fluid temperature is held very close to the ambient air temperature so that

$(t_m - t_a) \approx 0$. The relationship between K_θ and the efficiency is:

$$K_\theta = \frac{\eta}{F'(\tau\alpha)_{en}} \tag{16}$$

Since $F'(\tau\alpha)_{en}$ will have already been obtained as the y -axis intercept of the efficiency curve, values of K_θ can be computed for the different angles of incidence (see 6.1.7.3.). If the mean fluid temperature cannot be controlled to equal the ambient air temperature within ± 1 K, each value of K_θ shall be computed as:

$$K_\theta = \frac{\eta + a_1 \frac{t_m - t_a}{G} + a_2 G \left(\frac{t_m - t_a}{G} \right)^2}{F'(\tau\alpha)_{en}} \tag{17}$$

Due to more exact results Equation (17) should be used generally.

Alternatively, each data point may be plotted on the same graph with the efficiency curve determined in accordance with 6.1.4 or 6.1.5, and a curve drawn through each point parallel to the efficiency curve and made to intersect the y- axis. The values of the y intercept are the efficiency values that would have resulted had the mean fluid temperature been controlled to equal ambient air temperature. Therefore, these values may be used in conjunction with Equation (17) to compute the different values of K_θ.

6.1.8 Determination of the pressure drop across a collector

If determination of pressure drop across a collector is required, this should be done according to Annex L.

6.2 Unglazed solar collectors under steady state conditions (including pressure drop)

6.2.1 Collector mounting and location

6.2.1.1 General

Specification given in 6.1.1.1 applies.

6.2.1.2 Mounting

The collector shall be mounted in the manner specified by the manufacturer.

The collector mounting frame shall in no way obstruct the aperture of the collector, and shall not significantly affect the back or side insulation, unless otherwise specified (for example, when the collector is part of an integrated roof array).

Collectors designed to be mounted directly on standard roofing material may be mounted over a simulated roof section. In case of roof integrated collectors, a model consisting of a small scale collector placed on an artificial roof should be prepared for the purpose of the tests.

If mounting instructions are not specified, the collector shall be mounted on an insulated backing with a quotient of the materials thermal conductivity to its thickness of 1 Wm^{-2} K^{-1} ± 0,3 Wm^{-2} K^{-1} and the upper surface painted matt white and ventilated at the back.

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

The collector shall be mounted such that the lower edge is not less than 0,5 m above the local ground surface. Collector arrays constructed from pipe or strip components shall be mounted with the pipes (or strips) spaced 10 mm or one diameter (width of strip) apart, whichever is the smaller. If a different pipe or strip spacing is specified in the manufacturers' installation instructions then the recommended spacing shall be used. If the collector is delivered with mounting spacers or any device fixing the spacing of the pipes (or strips) then the collector shall be tested as delivered and its geometry shall be reported in the test report.

Currents of warm air, such as those which 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.

The performance of some forms of unglazed solar collectors is a function of module size. If the collector is supplied in fixed units of area greater than 1 m^2 then a sufficient number of modules shall be linked together to give a test system aperture of at least 3 m^2. If the collector is supplied in the form of strips the minimum built-up module area shall be 3 m^2 (gross area).

6.2.1.3 Tilt angle

The collector shall be tested at tilt angles so that the incidence angle with direct solar radiation θ is less than 30°, or at angles of tilt so that the incidence angle modifier varies by less than ± 2 % from normal incidence. Before deciding on a tilt angle it may be necessary to check the incidence angle modifier at two angles prior to commencing the tests.

NOTE For most unglazed collectors, the influence of tilt angle and radiation incidence angle on collector efficiency is small and unglazed collectors are commonly installed at low inclinations. However care should be taken to avoid air locks at low inclinations.

6.2.1.4 Collector orientation outdoors

The collector orientation shall conform to 6.1.1.4.

6.2.1.5 Shading from direct solar irradiance

The collector shall be shaded from direct solar irradiance in accordance with 6.1.1.5.

6.2.1.6 Diffuse and reflected solar irradiance

The collector shall diffuse and reflect solar radiation in accordance with 6.1.1.6.

6.2.1.7 Thermal irradiance

The 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.

The major difference between indoor and outdoor testing of unglazed collectors is the long wave thermal irradiance. The relative long wave radiation in a simulator shall not be higher than ± 50 Wm^{-2} (typically -100 Wm^{-2} for outdoor conditions).

6.2.1.8 Air speed

The performance of unglazed collectors is sensitive to air speed adjacent to the collector.

In order to maximize the reproducibility of results, unglazed collectors shall be mounted so that air can freely pass over the front side of the collector, and exposed back and sides of the collector. Collectors designed for integration into a roof may have their backs protected from the wind, but this shall be reported with the test results.

The average surrounding air speed at a distance of 100 mm above and parallel to the collector aperture shall cover the range 0 ms^{-1} to 3,5ms^{-1} subject to the tolerance specified in Table 7. If these conditions cannot be achieved under natural conditions then an artificial wind generator shall be used. If a wind generator is used the turbulence level shall be in the range of 20 % to 40 % to simulate natural wind conditions. The turbulence level shall be checked at the leading edge of the collector 100 mm above the collector surface. The turbulence level shall be monitored using a linearised hot wire anemometer with a frequency response of at least 100 Hz. If the absorber is not mounted directly on a roof or a sheet of backing material, the air speed shall be controlled and monitored on the front and back of the absorber.

6.2.2 Instrumentation

6.2.2.1 Solar radiation measurement

Specification given in 6.1.2.1 applies.

6.2.2.2 Thermal radiation measurement

6.2.2.2.1 Measurement of long wave irradiance

A pyrgeometer mounted in the plane of the collector shall be used to measure global hemispherical long wave radiation.

6.2.2.2.2 Precaution for effects of temperature gradient

The pyrgeometer used during the tests shall be placed in the same plane as the collector absorber and allowed to equilibrate for at least 30 min before measuring.

6.2.2.2.3 Precautions for effects of humidity and moisture

The pyrgeometer shall be provided with a means of preventing accumulation of moisture that may condense on surfaces within the instrument and affect its reading. An instrument with a desiccator that can be inspected is required. The condition of the desiccator shall be observed prior to and following each daily measurement sequence.

6.2.2.2.4 Precautions for effect of short wave heating

The influence of short wave solar heating effects should be minimised.

6.2.2.3 Temperature measurements

Temperatures shall be measured in accordance with 6.1.2.3.

6.2.2.4 Measurement of collector liquid flowrate

Liquid flowrates shall be measured in accordance with 6.1.2.4.

6.2.2.5 Measurement of air speed

6.2.2.5.1 General

Air speed shall be measured in accordance with 6.1.2.5.1.

6.2.2.5.2 Required accuracy of air speed

The speed of the surrounding air over the front surface of the collector shall be measured to a standard uncertainty of 0,25 ms^{-1}. Under outdoor conditions the surrounding air speed is seldom constant and gusting frequently occurs. The measurement of an average air speed is therefore required during the test period. This may be obtained either by an arithmetic average of sampled values or by a time integration over the test period.

NOTE It should be taken into consideration that anemometers have starting limits which lie between 0,5 ms^{-1} and 1 ms^{-1}. Therefore, considerable errors may occur for air velocities less than 1 ms^{-1}.

6.2.2.5.3 Mounting of sensors

The wind speed shall be measured while adjusting the wind generator, using a hand held anemometer at a height of 10 mm to 50 mm above the collector aperture plane. A permanently installed anemometer shall be placed at one edge of the collector in order to supervise the operation of the wind generator. This anemometer shall be mounted on a board so that there is a continuous surface pointing towards the wind generator from the collector edge to 0,3 m behind the anemometer.

NOTE The recorded value of the wind speed is not the air speed above the collector aperture.

A series of measurements shall be taken at nine equally spaced positions over the collector area. An average value shall then be determined. For a collector that does not have back insulation or is not mounted on a simulated roof surface, the air speed shall be measured over the front and back surfaces. The average air speed on the front and back surface shall be used in the data correlation.

During the test the air speed shall be monitored at a convenient point that has been calibrated relative to the mean air speed over the collector. The anemometer shall not cast a shadow on the collector during the tests.

6.2.2.6 Pressure measurements

The inlet pressure to the collector and the pressure drop across the collector shall be measured with a device having an error of 5 % of the measured value or ± 10 Pa. If the collector is supplied in modules the pressure drop shall be specified per module. For strip absorbers the pressure shall be specified per metre run of strip.

6.2.2.7 Elapsed time

Elapsed time shall be measured in accordance with 6.1.2.6.

6.2.2.8 Instrumentation/data recorders

Instrumentation and data recorders shall conform to 6.1.2.7.

6.2.2.9 Collector area

The collector area shall conform to 6.1.2.8.

6.2.2.10 Collector fluid capacity

The collector fluid capacity shall conform to 6.1.2.9.

6.2.3 Test installation

The test installation shall be in accordance with 6.1.3.

6.2.4 Outdoor steady state efficiency test

6.2.4.1 Test installation

The test installation shall conform to 6.1.4.1.

6.2.4.2 Preconditioning of the collector

The collector shall be preconditioned in accordance with 6.1.4.2.

6.2.4.3 Test conditions

At the time of the test, the net irradiance at the plane of the collector aperture shall be greater than 650 Wm^{-2}.

NOTE If the manufacturer has limitations on operation with respect to maximum irradiance but not less than 800 Wm^{-2}, this can be requested with the test. That maximum value should be clearly stated in the report.

The angle of incidence of direct solar radiation at the collector aperture shall be in the range in which the incidence angle modifier for the collector varies by no more than ± 2 % from its value at normal incidence. An angle of incidence modifier shall be calculated so that collector performance can be characterized at other angles.

The average value of the surrounding air speed, taking into account spatial variations over the collector and temporal variations during the test period, shall lie in the range defined in 6.1.5.5.

Unless otherwise specified, the fluid flowrate shall be set at approximately 0,04 kg/s per square metre of collector gross area. It shall be held stable to within ± 1 % of the set value during each test period, and shall not vary by more than ± 10 % of the set value from one test period to another.

The testing at a lower flowrate may be accommodated by adhering to manufacturers specification.

In some collectors the recommended fluid flowrate may be close to the transition region between laminar and turbulent flow. This may cause instability of the internal heat transfer coefficient and hence variations in measurements of collector efficiency. In order to characterize such a collector in a reproducible way, it may be necessary to use a higher flowrate, but this shall be clearly stated with the test results.

Measurements of fluid temperature difference of less than 1 K shall not be included in the test results because of the associated problems of instrument accuracy.

6.2.4.4 Test procedure

The collector shall be tested over its operating temperature range under clear sky conditions in order to determine its efficiency characteristic. Data points which satisfy the requirements given below shall be obtained according to Table 7.

One inlet temperature shall be selected so that the mean fluid temperature in the collector lies within ± 3 K of the ambient air temperature, in order to obtain an accurate determination of η_0.

NOTE 1 Under consideration of the condition that the fluid inlet temperature shall be higher than the dew point temperature of the surrounding air, the inlet temperature should be chosen such that $T_m = T_a \pm 3$ K applies. However, the inlet temperature should in no case be lower than the dew point temperature.

Table 7 - Range of thermal performance test conditions

Test point	Net irradiance Wm^{-2}	Tm (mean temperature) K	Air Speed parallel to Collector ms^{-1}
1	>650	$T_m = T_a \pm 3$ K	< 1
2	>650	$T_m = T_a \pm 3$ K	$1{,}5 \pm 0{,}5$
3	>650	$T_m = T_a \pm 3$ K	$3 \pm 0{,}5$
4	>650	$T_m = T_a + 0{,}5\ (\Delta t_{max}) \pm 3$ K	< 1
5	>650	$T_m = T_a + 0{,}5\ (\Delta t_{max}) \pm 3$ K	$1{,}5 \pm 0{,}5$
6	>650	$T_m = T_a + 0{,}5\ (\Delta t_{max}) \pm 3$ K	$3 \pm 0{,}5$
7	>650	$T_m = T_a + \Delta t_{max} \pm 3$ K	< 1
8	>650	$T_m = T_a + \Delta t_{max} \pm 3$ K	$1{,}5 \pm 0{,}5$
9	>650	$T_m = T_a + \Delta t_{max} \pm 3$ K	$3 \pm 0{,}5$

Δt_{max} is the expected maximum temperature difference between absorber mean temperature and ambient temperature in real operation.

NOTE 2 For typical swimming pool applications this Δt_{max} will usually be limited to about 10 K or less.

At least two independent data points shall be obtained for each fluid inlet temperature. If test conditions permit, an equal number of data points shall be taken before and after solar noon for each fluid inlet temperature. The latter is not required if the collectors are moved to follow the sun in azimuth and altitude using automatic tracking.

During a test, measurements shall be made as specified in 6.2.4.5. These may then be used to identify test periods from which satisfactory data points can be derived.

6.2.4.5 Measurements

The following data shall be measured:

- collector gross area A_G and absorber area A_A, measured at operating pressure conditions;
- fluid capacity;
- global solar irradiance at the collector area;
- diffuse solar irradiance at the collector area (only outdoors) ;
- long wave thermal irradiance in the collector plane (or dew point temperature t_{dp}.);
- surrounding air speed;

- surrounding air temperature;
- temperature of the heat transfer fluid at the collector inlet;
- temperature of the heat transfer fluid at the collector outlet;
- flowrate of the heat transfer fluid.

6.2.4.6 Test period (steady state)

Specification given in 6.1.4.6 applies, taking into account Table 8.

Table 8 - Permitted deviation of measured parameters during a measurement period

Parameter	Symbol	Deviation from the mean value
Total short wave solar irradiance	G	± 50 Wm^{-2}
Long wave thermal irradiance	E_L	± 20 Wm^{-2}
Surrounding air temperature	t_a	± 1 K
Fluid mass rate	$\dot{m}$	± 1 %
Collector fluid inlet temperature	t_{in}	± 0,1 K
Surrounding air speed	u	± 0,5 ms^{-1}

6.2.4.7 Presentation of results

Specification given in 6.1.4.7 applies.

6.2.4.8 Computation of collector output

6.2.4.8.1 General

Specification given in 6.1.4.8.1 apply, with the following additions:

The test results shall be used to compute efficiency η from the following equation:

$$\eta = \frac{\dot{Q}}{AG''} \qquad (18)$$

G'' is the net irradiance determined by the equation

$$G'' = G + (\varepsilon/\alpha)(E_L - \sigma T_a^4) \qquad (19)$$

the value (ε/α) shall be taken 0,85 unless the manufacturer can supply a measured value.

E_L is the measured longwave irradiance in the collector plane.

$\dot{Q}$ is the useful power output, calculated from: $\dot{Q} = \dot{m}\, c_f\, (t_e - t_{in})$ (20)

A value of c_f appropriate to the mean fluid temperature shall be used.

If the fluid mass flowrate $\dot{m}$ is obtained from volumetric flowrate measurements, then the density shall be determined for the fluid at the temperature in the flowmeter.

The test data shall be correlated by curve fitting using the least squares method to obtain an efficiency function of the form

$$\eta = \eta_0\,(1 - b_u u) - (b_1 + b_2 u)\,\frac{(t_m - t_a)}{G''} \qquad (21)$$

η_0, b_u, b_1, and b_2 are coefficients to be determined by curve fitting.

If instrumentation is not available for measuring long wave irradiance E_L, the following clear sky long wave model may be used to determine sky emittance ε_s from measured dew point temperature t_{dp}.

$$\varepsilon_s = 0{,}711 + 0{,}56\,\frac{t_{dp}}{100} + 0{,}73\left(\frac{t_{dp}}{100}\right)^2 \qquad (22)$$

where the dew point temperature t_{dp} shall be measured to a standard uncertainty of 0,5 K.

The long wave irradiance is calculated by the expression:

$$E_S = \varepsilon_S \sigma T_a^4 \qquad (23)$$

If the collector is inclined there will be thermal radiation exchange with both the sky and ground.

The relative long wave irradiance E_β on a collector inclined at an angle β is given by:

$$E_\beta = \varepsilon_s \sigma T_a^4\,\frac{1+\cos\beta}{2} + \varepsilon_g \sigma T_a^4\,\frac{1-\cos\beta}{2} \qquad (24)$$

The ground temperature will have little influence on long wave radiation on a collector inclined at less than 45° since the view factor between a collector and the ground is only 0,15 for β=45°

In this case, Equation (24) can be written as:

$$E_\beta = \varepsilon_s \sigma T_a{}^4 \frac{1+\cos\beta}{2} \qquad (25)$$

Thus, in Equation (19) the longwave irradiance E_L in the collector plane is equal to E_β when the collector is located outdoors

NOTE 1 Positive E_L values are a downward oriented irradiance onto a surface with a temperature of 0 K.

NOTE 2 When calculating E_s Equation 23 should be used.

6.2.4.8.2 Solar energy intercepted by the collector

The solar energy intercepted is *AG*'' and so in this case

$$\eta = \frac{\dot{Q}}{AG''} \qquad (26)$$

6.2.4.8.3 Reduced temperature difference

Specification given in 6.1.4.8.3 applies, by replacing *G* by *G*''.

6.2.4.8.4 Modeling of instantaneous efficiency

6.2.4.8.4.1 General

Specification given in 6.1.4.8.4.1 applies, by replacing *G* by *G*''.

6.2.4.8.4.2 Instantaneous efficiency

Specification given in 6.1.4.8.4.2 applies, by replacing *G* by *G*''.

6.2.4.8.5 *Graphical presentation of the collector output*

Specification given in 6.1.4.8.5 applies, by replacing *G* by *G*''.

6.2.5 Steady-state efficiency test using a solar irradiance simulator

6.2.5.1 General

Specification given in 6.1.5.1 applies.

6.2.5.2 The solar irradiance simulator for steady-state efficiency testing

Specification given in 6.1.5.2 applies.

6.2.5.3 Test installation

Specification given in 6.1.5.3 applies.

6.2.5.4 Preconditioning of the collector

Specification given in 6.1.5.4 applies.

6.2.5.5 Test procedure

The collector shall be tested over its operating temperature range in order to determine its efficiency characteristic. One inlet temperature shall be selected such that the mean fluid temperature in the collector lies within ± 3 K of the ambient air temperature, in order to obtain an accurate determination of η_0.

The range of thermal performance test conditions is specified in Table 7.

At least two independent data points shall be obtained for each fluid inlet temperature.

During a test, measurements shall be made as specified in 6.2.4.5.

6.2.5.6 Measurements during tests in solar irradiance simulators.

Measurements shall be in accordance with 6.1.5.6.

6.2.5.7 Test period

The test period shall conform to 6.1.5.7.

6.2.5.8 Test conditions

Test conditions shall be in accordance with 6.1.5.8.

6.2.5.9 Computation and presentation of results

Results shall conform to 6.1.5.9.

6.2.6 Determination of the effective thermal capacity and the time constant of a collector

6.2.6.1 General

The effective thermal capacity and the time constant of a collector are important parameters which determine its transient performance.

A collector can usually be considered as a combination of masses, each at a different temperature. 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.

Unfortunately, the effective thermal capacity depends on the operating conditions and is not a collector parameter with a unique value. Several different test methods have been used to measure the effective thermal capacity of collectors and it has been shown that similar results can be obtained by using quite different methods.

Just as there is no unique value of effective thermal capacity, there is no unique overall time constant for a collector. For most collectors, the dominant influence on the response time is the fluid flowrate. Other collector components respond with different times to give an effective overall time constant which depends on the operating conditions.

6.2.6.2 Determination of effective thermal capacity

The effective thermal capacity of the collector *C* (expressed as joules per kelvin) shall be calculated as the sum, for each constituent element of the collector (absorber, heat removal fluid), of the product of its mass m_i of collector (expressed in kilograms), times its specific heat c_i (expressed as joules per kilogram kelvin)

$$C = \sum_i m_i c_i \qquad (27)$$

Effective thermal capacity may also be measured by applying the procedures described in Annex G.

6.2.6.3 Test procedure for collector time constant

The test procedure shall be in accordance with 6.1.6.3.

6.2.6.4 Calculation of collector time constant

The time constant shall be calculated in accordance with 6.1.6.4.

6.2.7 Incidence angle modifier (optional)

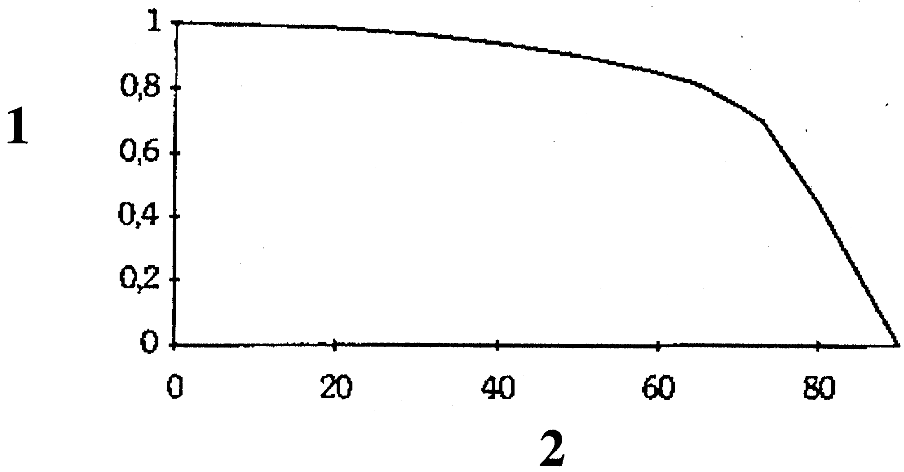
6.2.7.1 General

For solar beam incidence which is not near normal, the efficiency η_0 in Equation (21) may be replaced by $K_\theta \eta_0$, where K_θ is the incidence angle modifier.

$$\eta = K_\theta \eta_o \,(1- b_u u) - (b_1+b_2 u)\, \frac{t_m - t_a}{G''} \qquad (28)$$

Figure 6 shows the typical variation of K_θ with incidence angle for an unglazed solar collector.

For those collectors for which the incidence angle effects are not symmetrical with direction of incidence specifications given in 6.1.7.1 apply.



Key

1 Incidence angle modifier K_θ

2 Incidence angle (degrees)

Figure 6 - Typical incidence angle modifier

The significance of the incidence angle modifier to the test procedures outlined in this clause is that the thermal efficiency values are determined for the collector at or near normal incidence conditions. Therefore, the y intercept η of the efficiency curve is equal to η_0.

A separate measurement shall be conducted to determine the value of K_θ so that the performance of the collector can be predicted under a wide range of conditions and/or time of day using Equation (28).

6.2.7.2 Solar irradiance simulator for the measurement of incidence angle modifiers

Specification given in 6.1.7.2 applies.

6.2.7.3 Test procedures

Specification given in 6.1.7.3 applies.

6.2.7.4 Calculation of collector incidence angle modifier

Regardless of which experimental method in 6.2.7.3. is used, values for the thermal efficiency of the collector shall be determined for each value of angle of incidence.

For unglazed collectors, only one angle of incidence is needed which is 50°.

NOTEA rating standard using this test method may require that K_θ be measured for a different set of angles of incidence.

The mean temperature of the fluid shall be held very close to the ambient air temperature so that $(t_m - t_a) \approx 0$.

The relationship between K_θ and the efficiency is:

$$K_\theta = \frac{\eta(\theta)}{\eta_0} \tag{29}$$

Since η_0 will have already been obtained as the y-axis intercept of the efficiency curve, values of K_θ can be computed for the different angles of incidence (see 6.2.7.3). If the mean fluid temperature cannot be controlled to equal the ambient air temperature within ± 1 K, the value of K_θ shall be computed as:

$$K_\theta = \frac{\eta(\theta) + (b_1 + b_2 u)\left(\frac{t_m - t_a}{G''}\right)}{\eta_0 (1 - b_u u)} \tag{30}$$

Due to more exact results Equation (17) should be used generally. Alternatively, each data point may be plotted on the same graph with the efficiency curve determined in accordance with 6.2.4 or 6.2.5, and a curve drawn through each point parallel to the efficiency curve and made to intersect the y-axis.

The values of the y intercept are the efficiency values that would have resulted had the mean fluid temperature been controlled to equal ambient air temperature. Therefore, these values may be used in conjunction with Equation (28) to compute the different values of K_θ.

6.2.8 Determination of the pressure drop across a collector

If determination of pressure drop across a collector is required, this should be done according to Annex L.

6.3 Glazed and unglazed solar collectors under quasi-dynamic conditions

6.3.1 Collector mounting and location

6.3.1.1 General

Collectors shall be located and mounted in accordance with 6.1.1.1.

6.3.1.2 Collector mounting

Glazed collectors shall conform to 6.1.1.2 and unglazed collectors shall conform to 6.2.1.2.

6.3.1.3 Tilt angle

Glazed collectors shall conform to 6.1.1.3 and unglazed collectors shall conform to 6.2.1.3.

6.3.1.4 Collector orientation outdoors

The collector shall be mounted outdoors in a fixed position facing the equator, within ± 5°.

NOTE The azimuthal deviation of collector (or pyranometer) from due south, should be taken into account when calculating the angle of incidence of solar radiation onto the collector aperture. Larger deviations from south may be acceptable, but will lead to a non-symmetrical angular distribution of beam radiation in Figure 8 (see 6.3.4.6.2). This may lead to slightly biased incidence angle dependence of the collector. The actual incidence angle should be calculated with a standard uncertainty better than ± 1°.

In case of concentrating collectors, the tracking device of the manufacturer should be used if possible. In case of non imaging stationary collectors as CPCs, they should be mounted so that the beam radiation from the sun falls within the angular acceptance range of the design.

6.3.1.5 Shading from direct solar irradiance

Shading shall be in accordance with 6.1.1.5.

6.3.1.6 Diffuse and reflected solar irradiance

Specification given in 6.1.1.6 applies. Last section of 6.1.1.6, text about solar simulator tests is not applicable.

6.3.1.7 Thermal irradiance

The 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 minimise the influence of thermal radiation. For example, the outdoor field of view of the collector shall not include chimneys, cooling towers or hot exhausts. Shielding is important both in front of and behind the collector.

6.3.1.8 Surrounding Air Speed

Glazed collectors shall conform to 6.1.1.8 and unglazed collectors shall conform to 6.2.1.8.

6.3.2 Instrumentation

6.3.2.1 Solar radiation measurement

Measurements shall conform to 6.1.2.1.

6.3.2.1.1 Pyranometer

Pyranometers shall conform to 6.1.2.1.1 with the following exception: Subclause 6.1.2.1.1.5 is not applicable.

6.3.2.2 Thermal radiation measurement

Measurements shall be in accordance with 6.2.2.2.

6.3.2.3 Temperature measurements

Measurements shall conform to 6.1.2.3.

6.3.2.4 Measurement of collector liquid flowrate

Measurements shall be in accordance with 6.1.2.4.

6.3.2.5 Measurement of air speed

6.3.2.5.1 General

Measurements shall be in accordance with 6.1.2.5.1.

6.3.2.5.2 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 ms^{-1} (glazed collectors) and 0,25 ms^{-1} (unglazed collectors). Under outdoor conditions the surrounding air speed is seldom constant, and gusting frequently occurs. The measurement of an average air speed is therefore required during the test period. This may be obtained by a time integration over the test period.

6.3.2.5.3 Mounting of sensors

When testing outdoors in locations where the mean air speed lies below 2 ms^{-1}, an artificial wind generator shall be used, and anemometer measurements shall be fitted for continuous measurement of air velocity. This anemometer shall be mounted on a board so that there is continuous surface pointing towards the wind generator from the collector edge to 0,3 m behind the anemometer. The uniformity of air speed in the field of collector aperture shall be checked as the air speed may vary from one end of the collector to the other. A series of air speed measurement shall therefore be taken, at a distance of 100 mm in front of the collector aperture and equally spaced positions over the collector area. An average value shall then be determined and related to the continuous measurement.

In windy locations, the wind speed measurement shall be made near to the collector at the mid height of the collector. The sensor shall not be shielded from the wind and it shall not cast a shadow on the collector during test periods.

6.3.2.6 Pressure measurements

Measurements shall be in accordance with 6.2.2.6.

6.3.2.7 Elapsed time

Time shall be measured in accordance with 6.1.2.6.

6.3.2.8 Instrumentation/data recorders

Instruments shall conform to 6.1.2.7.

6.3.2.9 Collector area

The collector area shall conform to 6.1.2.8.

6.3.2.10 Collector fluid capacity

Fluid capacity shall conform to 6.1.2.9.

6.3.3 Test installation

The installation shall be tested in accordance with 6.1.3.

6.3.4 Outdoor efficiency test

6.3.4.1 Test installation

The installation shall be tested in accordance with 6.1.4.1.

6.3.4.2 Preconditioning of the collector

The collector shall be preconditioned in accordance with 6.1.4.2.

6.3.4.3 Test conditions

In the following, test requirements are given for what can be called a quasi-dynamic test method (QDT). To facilitate the understanding and acceptance of this kind of approach, the recommended test sequence and other test requirements given here are closely connected to those widely accepted for steady-state testing of solar thermal collectors, as outlined in 6.1 and 6.2. Basically the demand on suitable test data are the same for both types of approaches, and hence the recommended test sequence will allow also for conventional steady-state parameter identification, by obtaining and cutting out those measurement data sequences corresponding to steady-state requirements. The test method and recommended test sequence, will combine and allow for the evaluation of the effective thermal capacitance, incidence angle modifier - (IAM), wind speed - as well as sky temperature - dependence of the collector efficiency. In the collector parameter identification phase the collector model of actual useful power is used.

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 greater than 1 ms^{-1} and less than 4 ms^{-1}. Wind generators may be used if necessary to achieve sufficient wind speeds.

Unless otherwise specified, the fluid flowrate shall be set at approximately 0,02 kgs^{-1} per square metre of collector reference area (A). It shall be held stable to within ± 1 % of the set value during each test period, and shall not vary by more than ± 10 % of the set value from one test period to another. Testing at other flowrates can be accommodated by adhering to manufacturer's specification.

In some collectors the recommended fluid flowrate may be close to the transition region between laminar and turbulent flow. This may cause instability of the internal heat transfer coefficient and hence variations in measurements of collector efficiency. In order to characterise such a collector in a reproducible way, it may be necessary to use a higher flowrate, but this shall be clearly stated with the test results.

Measurements of fluid temperature difference of less than 1,0 K shall not be included in the test results, because of the associated problems of instrument accuracy.

NOTE As the quasi-dynamic method is based on the minimisation of the error in the power output of the collector (not efficiency as in stationary testing described in 6.1 and 6.2) the relative error of low fluid temperature differences will no longer cause a problem. Therefore the limitation to 1,0 K temperature difference can be removed in a later revision of the standard and more data from each test day can be used.

6.3.4.4 Test procedure

The collector shall be tested over its operating temperature range under outdoor conditions in order to determine its efficiency characteristics. Data points which satisfy the requirements given below shall be obtained for at least 4 fluid inlet temperatures spaced evenly over the operating temperature range of the collector.

If possible, one inlet temperature shall be selected such that the mean fluid temperature in the collector lies within ± 3 K of the ambient air temperature at around solar noon, in order to obtain an accurate determination of η_0. The inlet temperature shall be kept above the dew point, so that condensation of water on the absorber is avoided, which otherwise would result in erroneous test results. Weather conditions shall be as described in 6.3.4.6, sequence type 1 and 2.

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 highest operating range of the collector, as measured at about solar noon. For unglazed collectors only 3 fluid inlet temperatures are requested. The second shall then be chosen to be close to the middle of the operating range of the collector. Weather conditions shall be as described in 6.3.4.6, sequence type 3.

Depending on type of collector, the highest fluid inlet temperature shall be chosen as specified in 6.1.4.4 and 6.2.4.4.

The change in inlet temperature should 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.

NOTE 1 If comparison with steady-state parameters is to be done, at least 4 data points with the required duration, should be obtained for each fluid inlet temperature. If test conditions permit, an equal number of data points should be taken before and after solar noon for each fluid inlet temperature.

NOTE 2 As the collector model used here, more accurately describes the collector performance, the importance of 4 measuring points as well as independent data points within these is reduced or eliminated. In a later revision of this method, only 3 measuring points should be considered. The more complete characterisation of the collector also leads to fewer restrictions on the collector designs and a wider range of collectors will be covered by this test method.

During a test, measurements shall be made as specified in 6.3.4.5. These may then be used to identify test periods from which satisfactory test data can be derived.

6.3.4.5 Measurements and data acquisition

6.3.4.5.1 Measurements

The following measurements shall be carried out:

- aperture area A_a, the absorber area A_A and the gross collector area A_G ;
- fluid capacity;
- global solar irradiance at the collector aperture;
- diffuse solar irradiance at the collector aperture;

- incident longwave radiation at the collector aperture;
- angle of incidence of direct solar radiation or may be determined by calculation;
- azimuth and tilt angle of the collector aperture (standard uncertainty better than ± 1°);
- surrounding air speed;
- surrounding air temperature;
- temperature of the heat transfer fluid at the collector inlet;
- temperature of the heat transfer fluid at the collector outlet;
- flowrate of the heat transfer fluid.

6.3.4.5.2 Data acquisition requirements

Sampling rate: 1s to 6 s

Averaging interval: 5 –min to 10 min

Each data line (record) shall contain a unique time label (standard uncertainty better than ± 1 min), giving the possibility to calculate the angle of incidence of solar radiation onto the collector for each such data line (time period). See also under 6.3.1.4.

The following on line calculations should be performed and included in the measurement database:

- useful output power of the collector or Q
- time derivative of t_m in the collector, i.e. dt_m/dt as (t_m new - t_m old) / (sampling interval for t_{in} and t_e)

The calculation of time derivative dt_m/dt should be performed on-line as it has a big impact on the final results.

Sampling rate and averaging interval as for measured values.

NOTE If the measurement system allows for on line calculation of collector model output with expected collector parameters, this will be a very useful tool to detect any measurement error or problem. If not and in general, it is recommended to plot a diagram of measured output versus modelled output after each test day.

6.3.4.6 Test period

6.3.4.6.1 General

The recommended test sequence consists of 4-5 days. The number of actual days will, as for all outdoor collector testing, be dependent on the actual weather conditions on the test site. The data record shall contain data equivalent to all important normal operating conditions (enough variability and dynamic range), to give decoupled collector parameters. This is done similar to the stationary method (see 6.1 and 6.2), by varying the inlet temperature to the collector within its design range. If sufficient data has been recorded after 4-5 days, this data shall be evaluated for each test day, following the guidelines outlined below in 6.3.4.6.2.

6.3.4.6.2 Description of test sequences

The minimum length of a test sequences according to the requirements of 6.3.4.3 shall be 3 h. The test sequence under η_0 - conditions as specified in 6.3.4.4 should 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.

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 as specified in 6.3.4.4.

The relative order of the different test sequences is not critical, but may be adjusted to the actual weather on the test site.

6.3.4.6.3 Optional test: Dependence of tilt angle

If dependence of tilt angle shall be evaluated, one extra test day shall be added.

During this day, the collector shall be tested at the other requested tilt angle and at the high operating temperature (Day type 4). This additional test database may be evaluated with extended MLR, together with and at the same time as all other collector parameters.

NOTE Extended MLR, see note 2 under 6.3.4.8.1.

6.3.4.6.4 Evaluation of test data

In the following, guidelines for evaluating the suitability of the data recorded are outlined.

It is reminded that when evaluating the suitability of test data the following criteria should be satisfied:

- Tout-Tin>1 K
- Tin stable within ± 1K
- flowrate stable within ± 1% of the set value during test day or test sequence and 10 % from one sequence to another

During evaluation of the test data a pre-conditioning period of at least 4 times the time constant of the collector (if known), or not less than 15 min (if time constant is not known), with the correct fluid temperature at the inlet shall be skipped to ensure that the initial state of the collectors fades away and does not influence the result of the parameter identification.

It is also noted that outliners that cannot be explained shall not be excluded from the data set.

For clearness reasons, most requirements are given in the form of idealised diagrams, showing important relationships between different test conditions, 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 and shall be included in the test report.

Figure 7 shows $t_m - t_a$ versus G^* 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 $F'(\tau\alpha)_{en}$ and the collector heat losses.

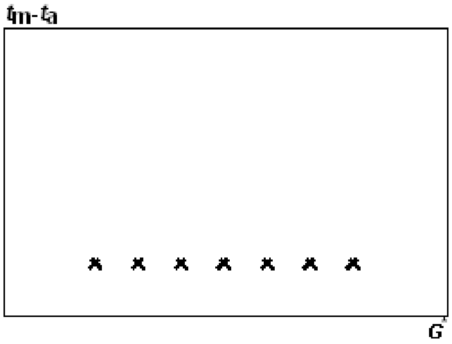


Figure 7 - t_m-t_a versus G^*

Figure 8 and 9 show if the data includes enough data at high and low incident angle of the beam irradiance to identify $K_{\theta b}(\theta)$ and if enough data at high diffuse radiation levels was taken to identify $K_{\theta d}$.

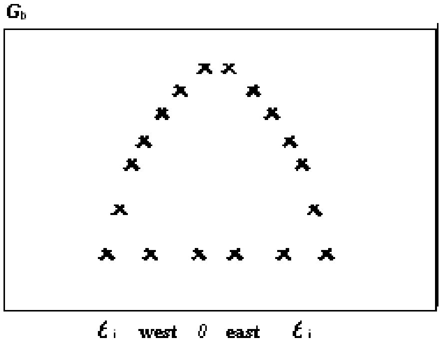


Figure 8 - G_b versus θ_i

NOTE Measurement data with higher G_b-values (upper curve), will give $K_{\theta b}(\theta)$. The lower values will give $K_{\theta d}$.

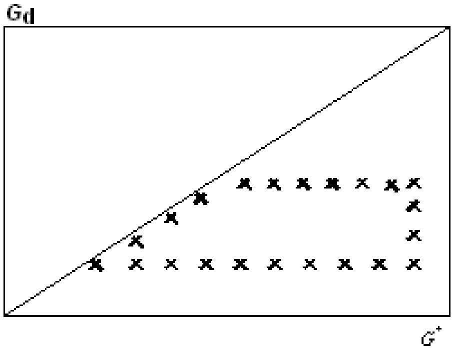


Figure 9 - G_d versus G^*

If wind speed dependence of the collector was considered Figure 10 shall be included. Figure 10 shows the ideal distribution of the relationship of wind speed versus G^*.

The wind speeds as described in 6.3.4.3 should be considered.

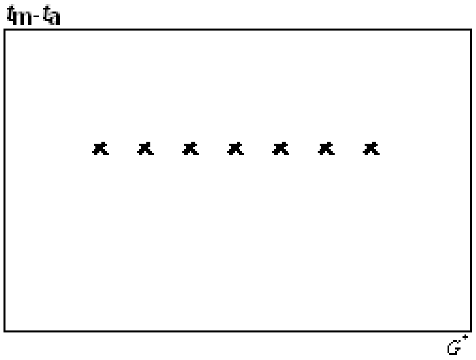


Figure 10 - wind speed versus G^*

6.3.4.7 Presentation of test results

The test results shall be presented in a report using the data format sheets, given in Annex D and Annex E and with the text and content adjusted in accordance with what is given by 6.3 (see also under 6.3.4.8.4). The measurements shall be collated to produce a set of data points, which meet the requirements of the test conditions and provide sufficient information in the test data. In addition to what is given by Annex D and E, the measurement data used for collector parameter identification shall be presented in four diagrams, 1 to 4 as described under 6.3.4.6.4, Figure 7 to Figure 10. A diagram 5, showing measured collector output versus modelled output, shall also be included in the test report. Diagram 5 shall include all test data used for collector parameter identification in one diagram (see also 6.3.4.5.2, note). The incidence angle modifier (IAM), $K_{\theta b}(\theta)$, shall be presented in a diagram 6 as indicated in Figure 5 or 6.

In addition to the collector performance coefficients as requested by Annex D or E, the full set of quasi-dynamic performance coefficients as identified by Equation (32), should be included in the test report.

6.3.4.8 Parameter identification and computation of useful collector output

6.3.4.8.1 Collector parameter identification tool

Multiple Linear Regression (MLR), is a non iterative very fast matrix method, that is available in most standard programme packages with statistical functions, such as spreadsheets or more specialised statistical programmes like MINITAB or SISS. Linear, in this instance means that the model has to be written as a sum of terms with the parameters p_n as a multiplier in front of the terms.

For example: $Yout = p_0 + p_1 \cdot f(x_1,x_2) + p_2 \cdot g(x_1, x_3, x_4) + p_3 \cdot h(x_2, x_5)$. (31)

The sub models $f(x..)$ $g(x..)$ and $h(x..)$ in each term can be highly non-linear.

The MLR method allows for fully free selection of data from the test database, according to any test specification before applying the MLR parameter identification.

This selection can be made afterwards from measurements during a few days.

NOTE 1 To give an example, this means e.g., that test data with $G^* > 700\ \mathrm{Wm}^{-2}$, $dt_m/dt < 0{,}002\ \mathrm{Ks}^{-1}$, $u > 2\ \mathrm{ms}^{-1}$ and $t_a - t_s > 10\mathrm{K}$ could be selected for the MLR parameter identification, if those test requirements are considered. Even for an extensive database, the parameter identification will need only a few seconds of computer time, making MLR very versatile also in development and research.

NOTE 2 For several years, a special case of MLR (extended MLR) has also been tested out, which makes it possible to identify the same parameter in different subsets of the database. This has made it possible to identify for example the zero loss efficiency angle by angle without the need to have an equation and also in two axis θ_L and θ_t. $K_{\theta b}(\theta_t)$ is than generalised and replaced by $K_{\theta b}(\theta_L, \theta_t)$ in Equation (32). The parameters can still be identified with standard MLR software in the same run. This is very useful for special collectors as ETC, CPC or unglazed collectors with round separate absorber tubes that cannot be modelled with the standard IAM equations. The derived IAM results can be used directly in simulation programmes like TRNSYS, WATSUN or MINSUN. Recently it was also found, that the heat loss factor can be identified in successive ranges of ΔT. This overcomes the problem of a slight correlation between the ΔT and ΔT^2 terms. The heat loss coefficient can also be modelled in this way for collectors with special heat loss effects as heat pipe collectors or other special designs.

Other non linear methods, provided that they are minimizing the error in the output power of the collector as in the MLR method, can be used as parameter identification tool as beside the MLR method.

6.3.4.8.2 The Collector Model

This model is basically the same as the steady-state model used in 6.1 and 6.2, but with some extra correction terms. Here the dependence of direct and diffuse radiation, wind speed, sky temperature, incidence angle effects and effective thermal capacitance are modelled. For more information see Annex H.

$$\dot{Q} / A = F'(\tau\alpha)_{en} K_{\theta b}(\theta)\, G_b + F'(\tau\alpha)_{en} K_{\theta d}\, G_d - c_6\, u\, G^* - c_1\,(t_m - t_a) - c_2\,(t_m - t_a)^2 -$$

$$- c_3\, u\,(t_m - t_a) + c_4\,(E_L - \sigma T_a^{\,4}) - c_5\, dt_m/dt \qquad (32)$$

where the area is A_A when referred to the absorber area of the collector and A_a when referred to the aperture area of the collector (see Annex J).

NOTE Kelvin degrees are used for convenience in the radiation term. At all other places Celsius degrees are used, see Clause 4.

6.3.4.8.3 Use of the Collector Model for different collector types

The collector model as described in 6.3.4.8.2, should cover most collector designs available on the market, except ICS collectors. If the full collector model should be applied for a certain type of collector (or collector design) or not, will in general be given by the result of the parameter identification, but for all types of collectors, the use of $F'(\tau\alpha)_{en}$, $K_{\theta b}(\theta)$, $K_{\theta d}$ and the coefficients c_1, c_2, and c_5 are mandatory and they should be identified.

NOTE 1 For sun tracking, high concentrating collectors the inclusion of $K_{\theta d}$ may not always be significant and should therefore be determined by the T-ratio of the parameter identification as given below.

Then $K_{\theta b}(\theta) = 1{,}0$ and $K_{\theta d} = 0$ should be used in Equation (32) and the parameter identification should be repeated.

If the coefficients c_3, c_4, and c_6 shall be included in the collector model, will be determined by the T-ratio (parameter value / standard deviation of parameter value) of the parameter identification. The T-ratio should be greater than 2 for those parameters presented in the test results. If the T-ratio is less than 2, (enough variability in the input data is assumed), the coefficient shall be set to zero and the parameter identification should be repeated with the adjusted collector model.

For unglazed collectors, the use of the full collector model is mandatory.

NOTE 2 Empirically found, the full collector model including capacitance, diffuse and incidence angle corrections is very accurate. If the model does not fit to the data, in most cases the problem will be found in the collector, the test installation or the measurements.

6.3.4.8.4 Graphical presentation of test results

To conform with the presentation of test results, when testing in accordance with 6.1 and 6.2, the test results shall be presented in the form of a power curve as a function of the temperature difference between mean fluid and ambient temperature ($t_m - t_a$), which shall be calculated from the power function, Equation 32, using the value of $G^* = 1000\ Wm^{-2}$ and a diffuse fraction of 15 %, i.e. $G_d = 150\ Wm^{-2}$. The parameter dt_m/dt is set to zero and θ_i to 15° ($dt_m/dt = 0$ and $\theta_i = 15$) to adjust to stationary operating conditions around solar noon (Equation 32.1). If wind speed dependence of the heat losses and the zero loss efficiency are used in the collector model for glazed collectors (c_3>0 and c_6>0) as outlined in 6.3.4.8.3, the wind speed $u = 3\ ms^{-1}$ should be used in the equation. If sky temperature dependence of the heat loss coefficient is used in the collector model (c_4>0), then $(E_L - \sigma T_a^4) = -100\ Wm^{-2}$ should be used in the equation.

$$\dot{Q} = (AG^*)(F'(\tau\alpha)_{en} K_{\theta b}(15)\cdot 0.85 + F'(\tau\alpha)_{en} K_{\theta d}\cdot 0.15 - c_6 \cdot (3m/s) - c_1 (t_m - t_a)$$

$$- c_2 (t_m - t_a)^2 - c_3 (3m/s)(t_m - t_a) - c_4 (100W/m^2)) \qquad (32.1)$$

Graphical presentation of test results for unglazed collectors should be made accordingly, but with reference to Annex E.
The product $(AG^*)(F'(\tau\alpha)_{en} K_{\theta b}(15)\cdot 0.85 + F'(\tau\alpha)_{en} K_{\theta d}\cdot 0.15)$ shall be referred to as W_{peak}.

NOTE $(E_L - \sigma T_a^4)$ has normally a negative value as the effective sky radiation temperature is lower than the ambient air temperature. A net longwave irradiance of minus 100 Wm^{-2} will correspond to about a clear sky condition when

t_a = 20 °C and t_s = 0 °C.

6.3.5 Determination of the effective thermal capacity

6.3.5.1 General

The effective thermal capacity (C) and the time constant of a collector are important parameters which determine its transient performance. A collector can usually be considered as a combination of masses, each at a different temperature. 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.

The determination of c_5 (see Equation 32) requires a large enough variation in dt_m/dt. In the test, this can only be achieved by variations in irradiation level as the inlet temperature is fixed due to the requirement for compatibility with testing according to 6.1 and 6.2.

6.3.5.2 Procedure

The effective thermal capacitance, modelled as c_5 and equal to C/A, is a mandatory part of the collector model, Equation 32, and is identified simultaneously together with all other collector parameters.

It is essential to have large enough variability in solar radiation during the test so that the thermal capacitance effects will be significant. In all empirical data so far, partly cloudy conditions will induce enough variability in dt_m/dt for the determination of c_5. dt_m/dt should exceed ± 0,005 K/s during the partly cloudy day. If the unlikely case happens that this is not met during the test period, an extra test day, type 2, as described under 6.3.4.6.1 with partly cloudy conditions, shall be added to the data used for identification.

6.3.6 Collector incidence angle modifier

The Collector incidence angle modifiers (IAM), modelled as $K_{\theta b}(\theta)$ for direct radiation and as $K_{\theta d}$ for diffuse radiation (see also 6.3.4.8.3, Note 1), are mandatory parts of the collector model, Equation 32. These are identified simultaneously together with all other collector parameters.

The basic modelling of IAM-dependence of flat plate collectors shall be done with the equation

$$K_{\theta b}(\theta) = 1 - b_0((1/\cos\theta_i) - 1) \qquad (33)$$

as described in e.g. ASHRAE 93-77.

For those collectors (e.g. evacuated tube collectors and CPC collectors) for which the incidence angle effects are not symmetrical with direction of incidence, it is necessary to measure the incident angle effects from more than one direction to fully characterize the incident angle modifier.

The complex individual incident angle modifier can be estimated by considering it to be the product of the separate incident angle modifiers, $K_{\theta L}$ and $K_{\theta T}$, for two perpendicular symmetry planes (Equation 33.1).

$$K_{\theta b}(\theta) = K_{\theta L} \cdot K_{\theta T} \qquad (33.1)$$

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 θL and θT are the projections of the incidence angle θ onto the longitudinal and transversal planes, respectively.

For the correlation between θ, θL and θT, the following equation holds:

$$\tan^2\theta = \tan^2\theta L + \tan^2\theta T \qquad (33.2)$$

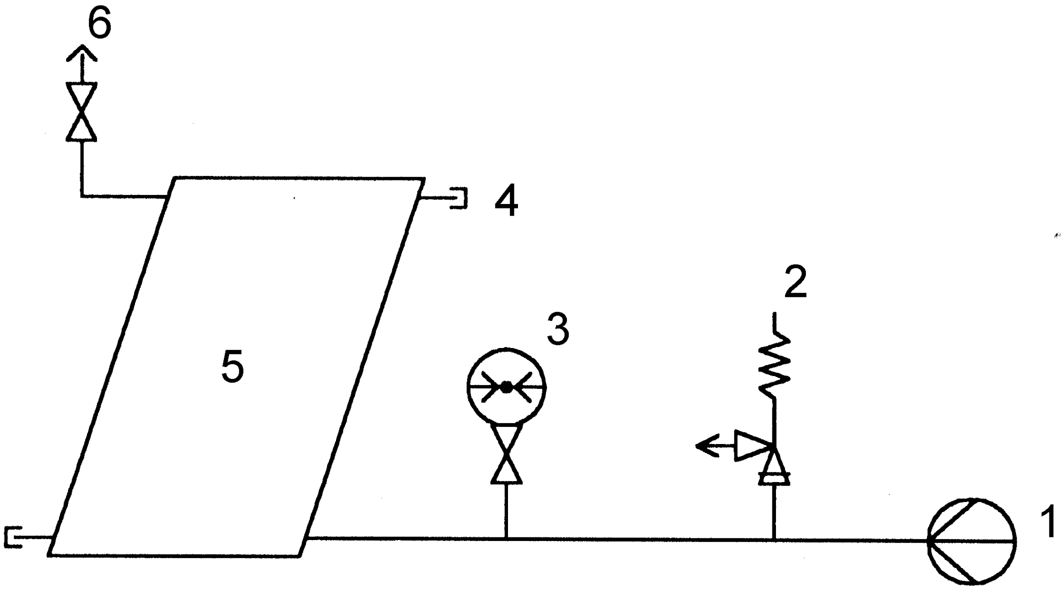
While measuring the incident angle modifier in one plane of an optical unsymmetrical collector the incident angle within the other plane should be kept to a value where the incident angle modifier does not differ more than 2 % from the one at normal incidence.

For collectors with special IAM-dependence, see also note under 6.3.4.8.1.

$K_{\theta d}$ shall be modelled as a collector constant.

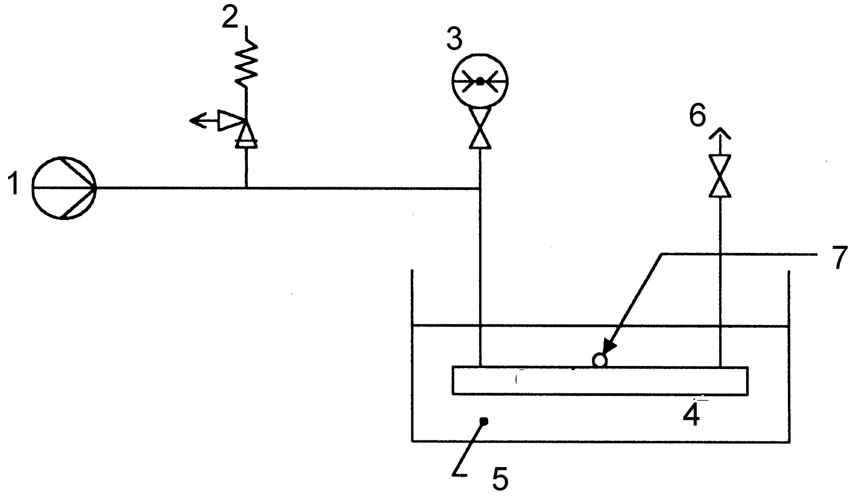
For general information, also refer to 6.1.7.

Annex A
(normative)
Schematics for durability and reliability tests



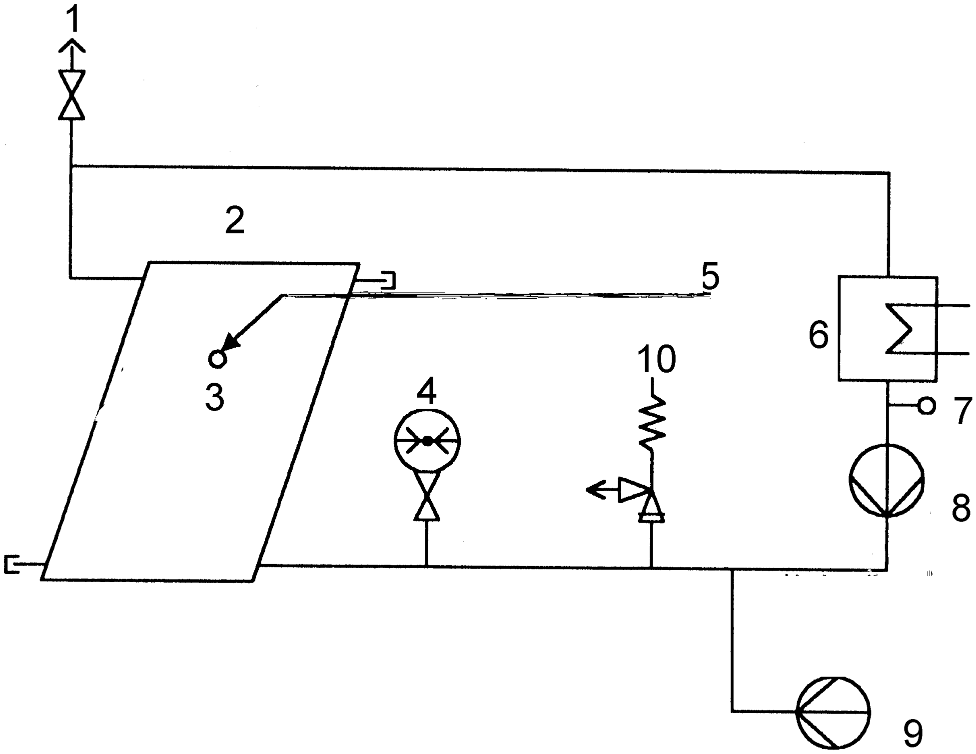
Key
1 Hydraulic pressure source
2 Safety valve
3 Pressure gauge
4 Fluid pipe sealed with cap nut
5 Collector with inorganic absorber
6 Air-bleed valve

Figure A.1 - Schematic for internal pressure test of inorganic absorbers



Key
1 Hydraulic or pneumatic pressure source
2 Safety valve
3 Pressure gauge
4 Organic absorber
5 Heated water bath
6 Air-bleed valve (for hydraulic absorber)
7 Temperature sensor attached to absorber

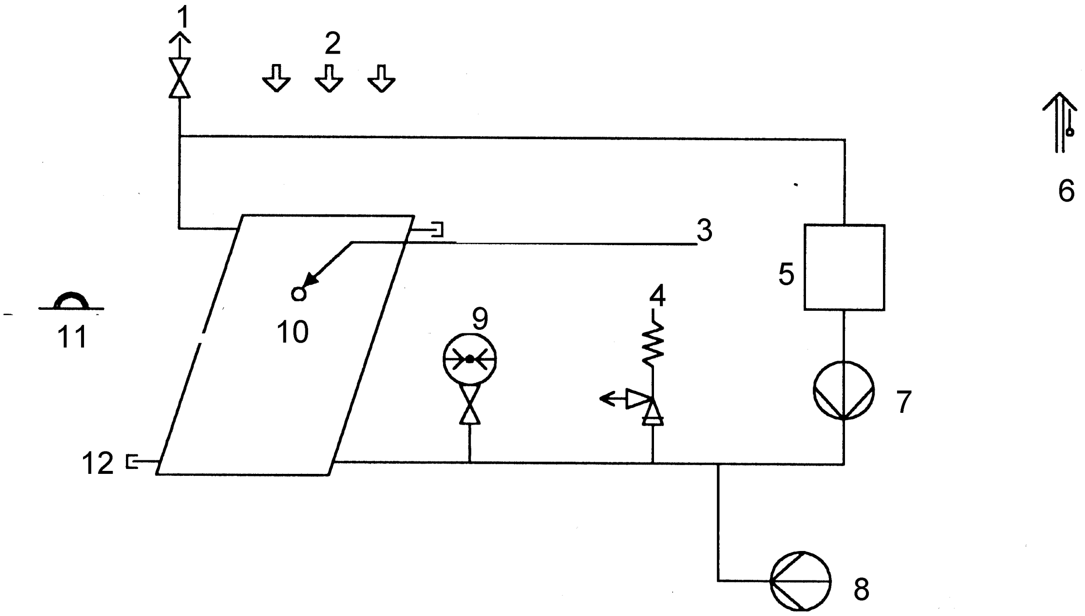
Figure A.2 - Schematic for internal pressure test of organic absorbers for use in unglazed collectors



Key

1 Air-bleed valve
2 Fluid pipe sealed with cap nut
3 Collector with organic absorber
4 Pressure gauge
5 Temperature sensor attached to absorber
6 Hot oil source
7 Temperature sensor
8 Circulating pump
9 Hydraulic pressure source
10 Safety valve

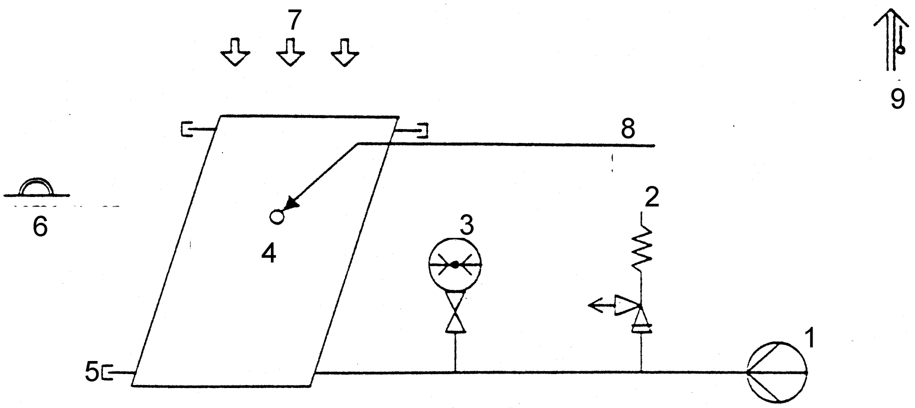
Figure A.3 - Schematic for internal pressure test of organic absorbers for use with oil-based fluids (hot oil source)



Key

1 Air-bleed valve
2 Natural or simulated solar radiation
3 Temperature sensor attached to absorber
4 Safety valve
5 Oil source
6 Ambient temperature sensor
7 Circulating pump
8 Hydraulic pressure source
9 Pressure gauge
10 Collector with organic absorber
11 Pyranometer on collector plane
12 Fluid pipe sealed with cap nut

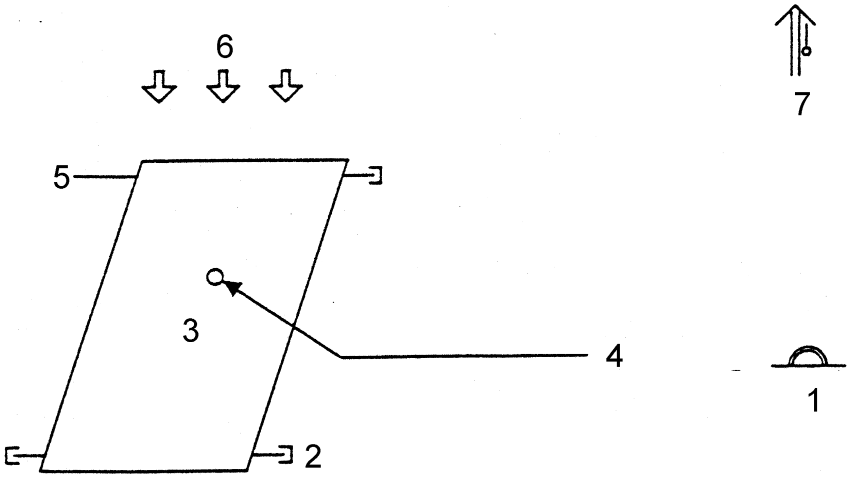
Figure A.4 - Schematic for internal pressure test of organic absorbers for use with oil-based fluids (test under solar irradiance)



Key

1 Pneumatic pressure source
2 Safety valve
3 Pressure gauge
4 Collector with organic absorber
5 Fluid pipe sealed with cap nut
6 Pyranometer on collector plane
7 Natural or simulated solar radiator
8 Temperature sensor attached to absorber
9 Ambient temperature sensor

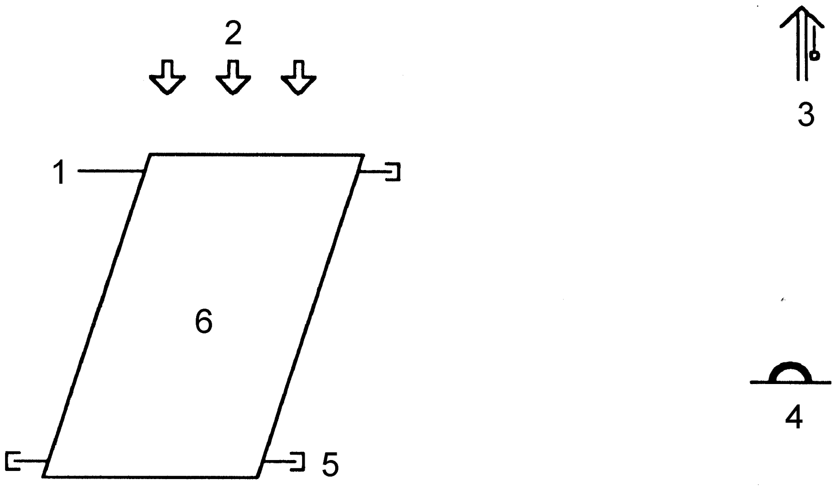
Figure A.5 - Schematic for internal pressure test of organic absorbers (pneumatic test under solar irradiance)



Key

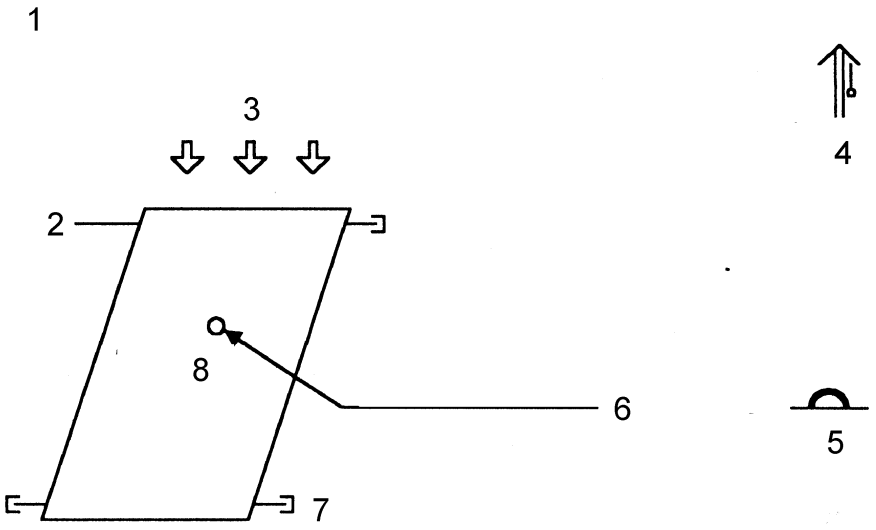
1 Pyranometer on collector plane
2 Fluid pipe sealed with cap nut
3 Collector
4 Temperature sensor attached to absorber
5 Fluid pipe left open
6 Natural or simulated solar radiation
7 Ambient temperature sensor

Figure A.6 - Schematic for high-temperature resistance test (outdoor or in simulator)



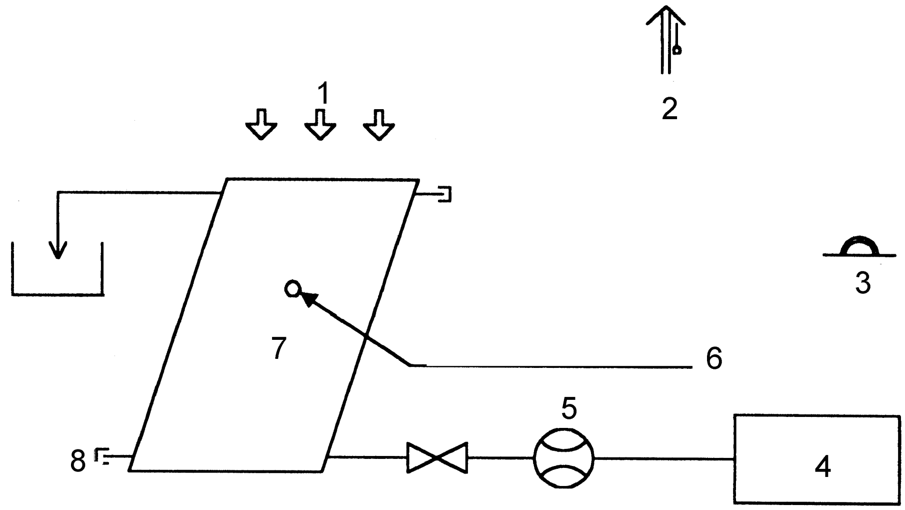
Key
1 Fluid pipe left open
2 Solar radiation
3 Ambient temperature sensor
4 Pyranometer on collector plane
5 Fluid pipe sealed with cap nut
6 Collector

Figure A.7 - Schematic for exposure test



Key
1 Water spray on all sides
2 Fluid pipe left open
3 Natural or simulated solar radiation
4 Ambient temperature sensor
5 Pyranometer on collector plane
6 Temperature sensor attached to absorber
7 Fluid pipe sealed with cap nut
8 Collector

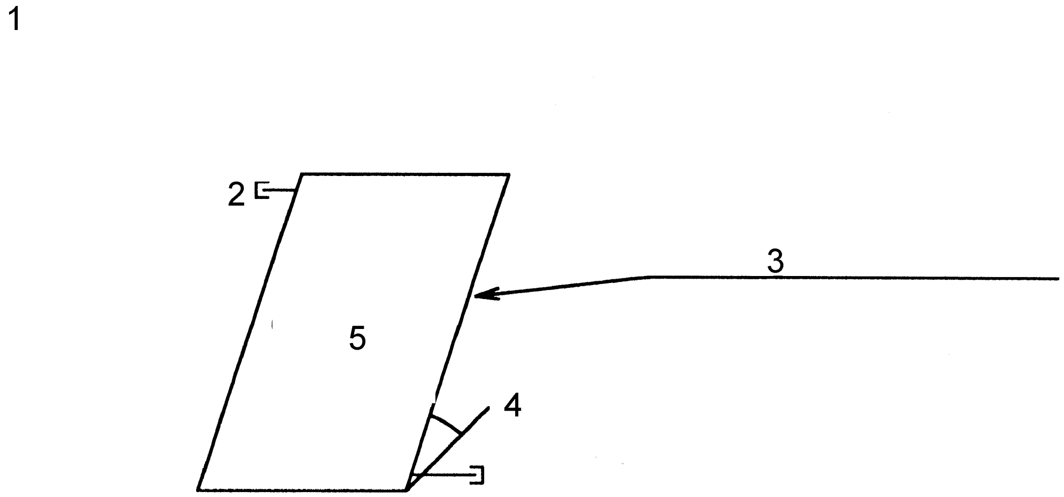
Figure A.8 - Schematic for external thermal shock test



Key

1 Natural or simulated solar radiation
2 Ambient temperature sensor
3 Pyranometer on collector plane
4 Heat transfer fluid source
5 Flowmeter
6 Temperature sensor attached to absorber
7 Collector
8 Fluid pipe sealed with cap nut

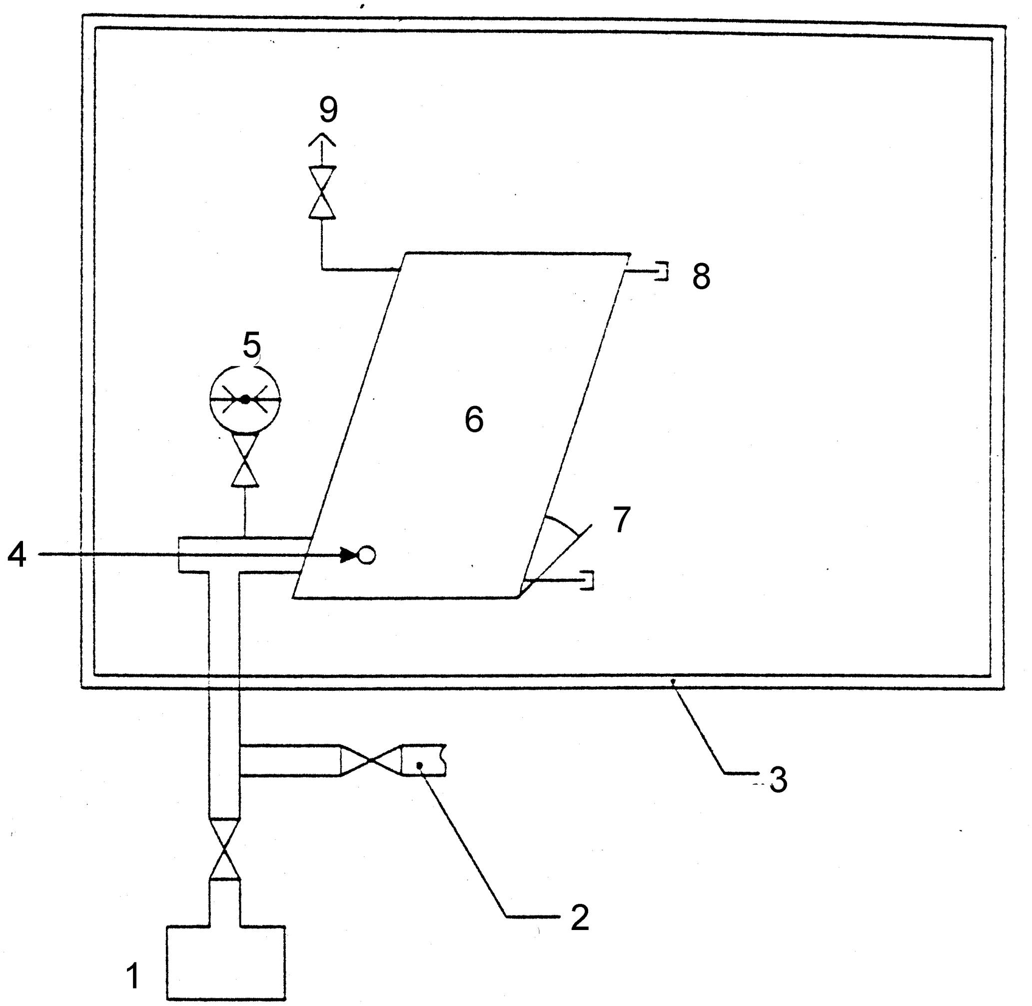
Figure A.9 - Schematic for internal thermal shock test



Key

1 Water spray on all sides
2 Fluid pipe sealed with cap nut
3 Collector underside to be protected for collectors which are designed to be integrated into roof structure
4 Tilt angle
5 Collector

Figure A.10 - Schematic for rain penetration test



Key

1 Water source

2 Drain line (for drain-down systems only)

3 Temperature cycling chamber

4 Temperature sensor

5 Pressure gauge

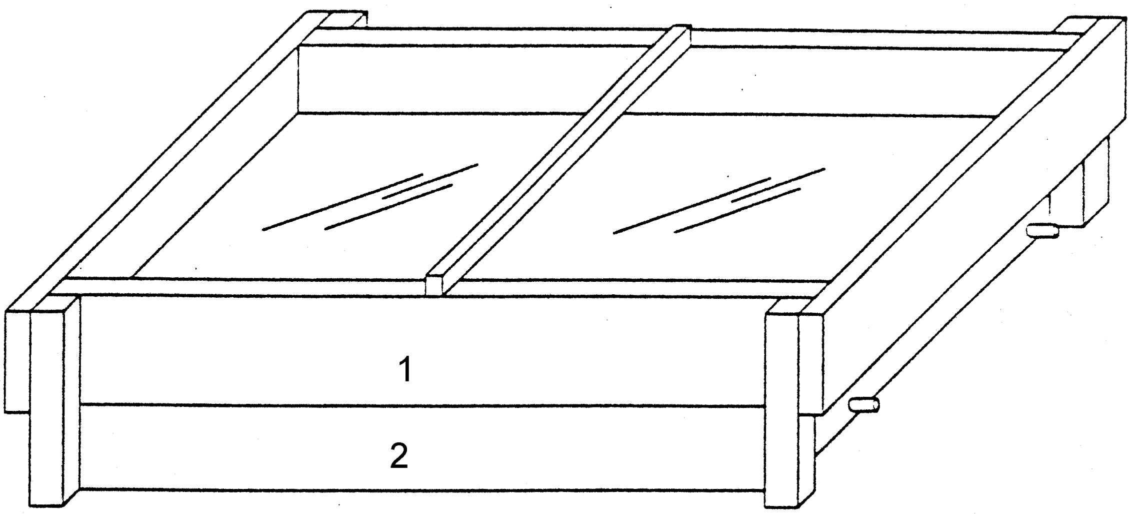
6 Collector

7 Tilt angle

8 Fluid pipe sealed with cap nut

9 Air bleed-valve

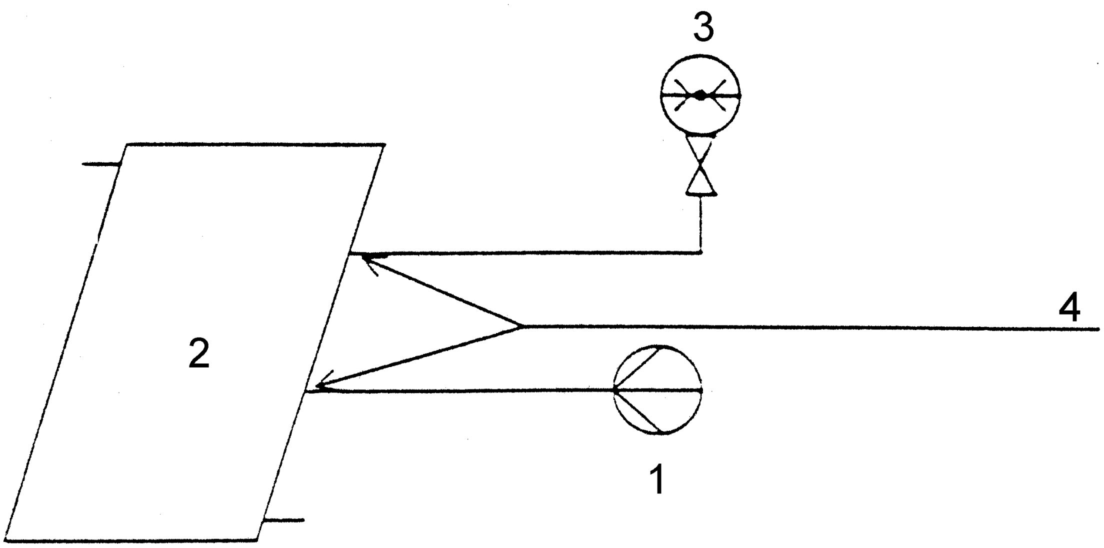
Figure A.11 - Schematic for freeze resistance test



Key

1 Wooden frame for gravel
2 Collector

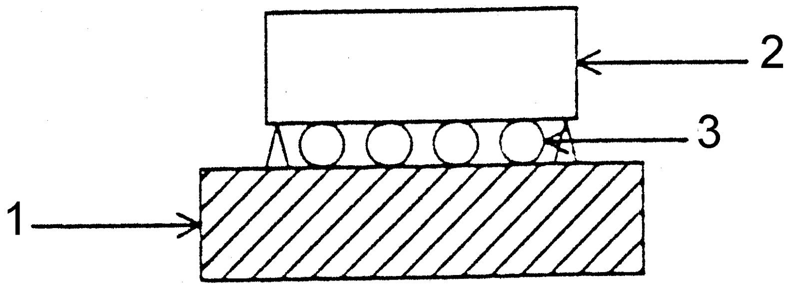
Figure A.12 - Schematic for mechanical test (positive pressure on the collector cover)



Key

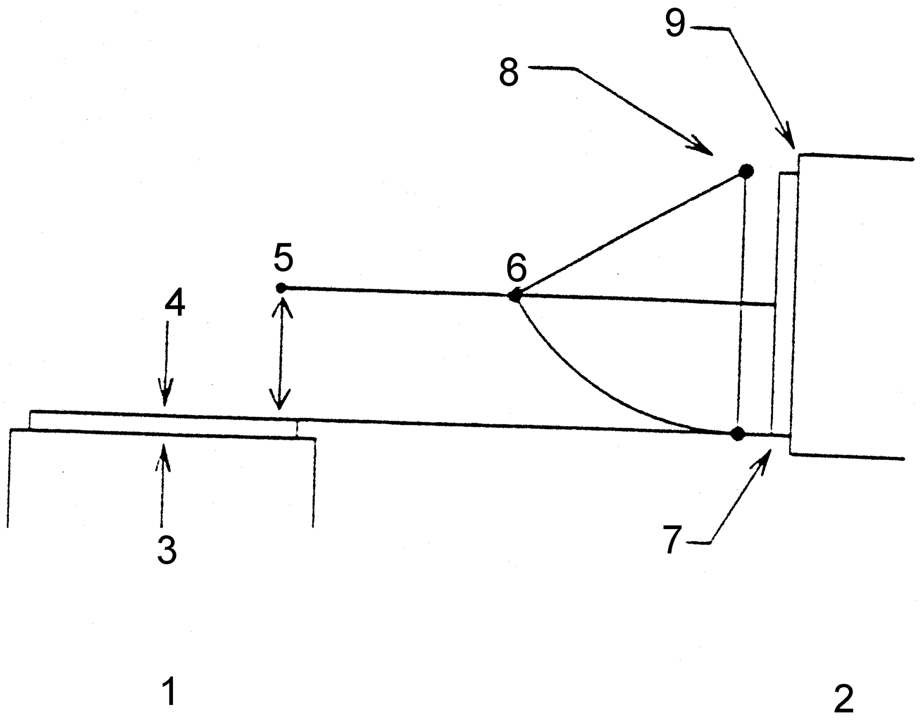
1 Pneumatic pressure source
2 Collector
3 Pressure gauge
4 Holes into airgap between the collector cover and absorber

Figure A.13 - Schematic for mechanical test (negative pressure on fixings between the cover and the collector box)



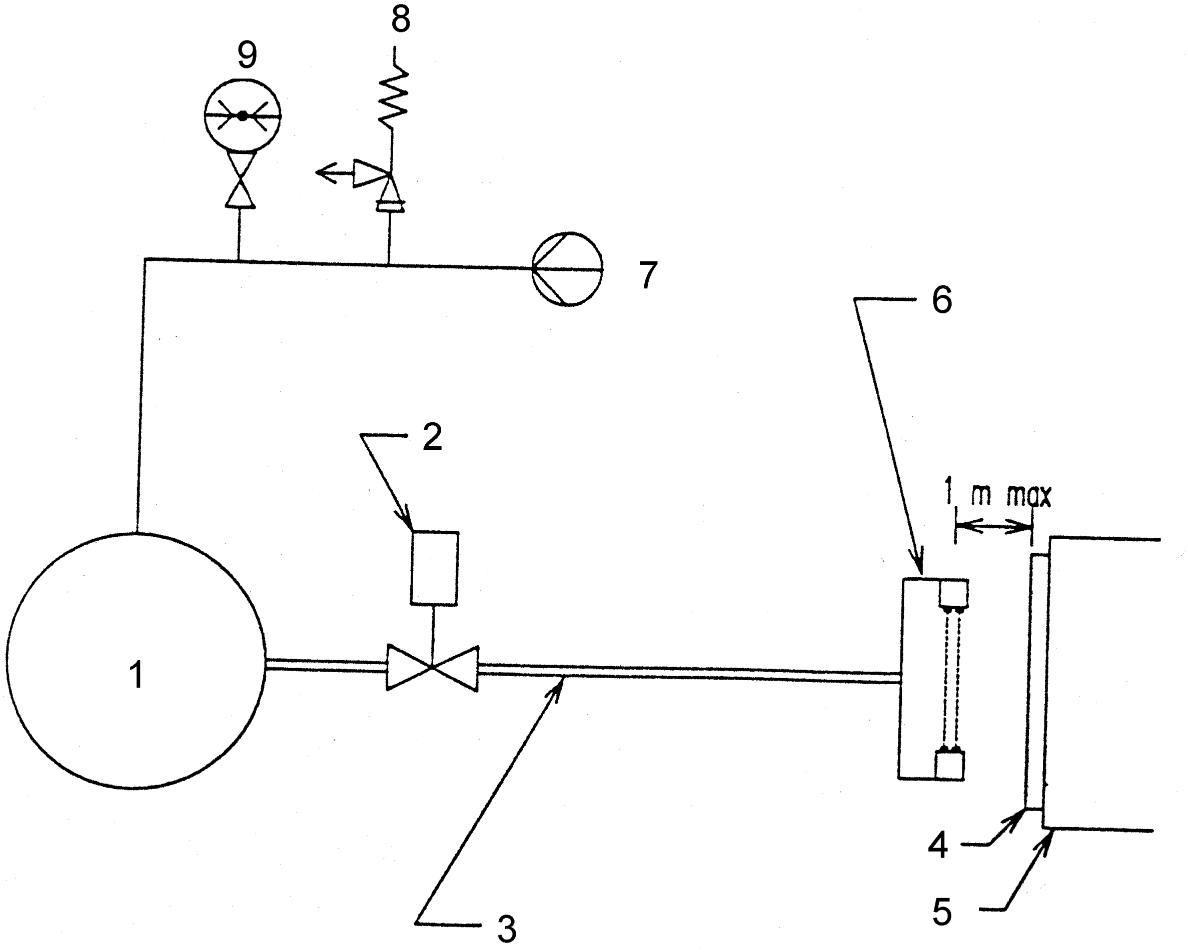
Key
1 Stiff support
2 Collector
3 Air cushions to apply pressure

Figure A.14 - Schematic for mechanical test (negative pressure on collector mounting)



Key
1 Alternative A (steel ball dropped vertically)
2 Alternative B (pendulum)
3 Rigid frame
4 Collector
5 Steel ball
6 Steel ball
7 Collector
8 Pendulum
9 Rigid frame

Figure A.15 - Schematic for impact resistance test using steel balls



Key

1 Reservoir
2 Solenoid valve large, fast opening
3 Barrel
4 Collector
5 Rigid frame
6 Photoelectric velocity measuring system
7 Pneumatic pressure source
8 Safety valve
9 Pressure gauge

Figure A.16 - Schematic for impact resistance test using ice balls

Annex B
(normative)
Durability and reliability test report sheets

Collector Identification

Manufacturer:
Brand Name:
Collector Type: Unglazed/Glazed/Evacuated
Year of Production:
Serial No:
Drawing Document No
Collector reference No.: ....

B.1 Record of test sequence and summary of main results

All significant damage to the collector, including rain penetration, should be summarised in Table B.1. Full details should be given in the individual test result sheets.

Table B.1

Test		**Date**		**Summary of main test results**
		Start	**End**	
Internal pressure				
High-temperature resistance				
Exposure				
External thermal shock	First			
	Second			
Internal thermal shock	First			
	Second			
Rain penetration				
Freeze resistance				
Mechanical load				
Thermal performance				
Impact resistance (optional)				
Final inspection				

Remarks: ....

....

Collector reference No.: ....

B.2 Internal pressure test for inorganic absorbers

NOTE See B.3 for internal pressure test for absorbers made of organic materials.

B.2.1 Technical details of collector

B.2.1.1 Collector type:

☐ Glazed

☐ Unglazed

B.2.1.2 ... Maximum collector operating pressure specified by manufacturer: kPa

B.2.2 Test conditions

Test temperature: .... °C

Test pressure: .... kPa

Test duration: ....min

B.2.3 Test results

Give details of any observed or measured leakage, swelling or distortion and any of the failures denoting “major failure”, defined in 5.3.1 of EN 12975-1:2006

....

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....

Collector reference No.: ....

B.3 Internal pressure test for absorbers made of organic materials

NOTE See B.2 for internal pressure test for absorbers made of inorganic materials.

B.3.1 Technical details of collector

B.3.1.1 Collector type:

☐ Glazed

☐ Unglazed

B.3.1.2 Maximum collector operating pressure specified by manufacturer **kPa**

B.3.1.3 Calculated collector stagnation temperature: **°C**

Provide details of calculation, showing input data used (attach separate page if necessary)

B.3.2 Test conditions

B.3.2.1 Fluid used to pressurize absorber:

☐ Oil

☐ Air

☐ Other (specify):

B.3.2.2 Method used to heat absorber:

☐ Water bath

☐ Heater in fluid loop

☐ Natural solar irradiance

☐ Simulated solar irradiance

B.3.2.3 Measured absorber test temperature: °C

B.3.2.4 Final test pressure: kPa

B.3.2.5 Duration of test at final test pressure: min

Collector reference No.: ....

B.3.2.6

Intermediate test pressures kPa	**Duration of test at each intermediate pressure** min

B.3.2.7 For absorber tested under irradiance

Collector tilt angle (degrees from horizontal): .... °

Average irradiance during test: .... W/m^2

Average ambient temperature during test: .... °C

Average wind speed during test: ....m/s

B.3.3 Test results

Details of any observed or measured leakage, swelling or distortion and the test pressure at which it occurred and any of the failures denoting “major failure”, defined in 5.3.1 of EN 12975-1:2006

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Collector reference No.: ....

B.4 High-temperature resistance test

B.4.1 Method used to heat collectors

☐ Outdoor testing

☐ In solar simulator

B.4.2 Test conditions

B.4.2.1 General

Collector tilt angle (degrees from horizontal): .... °

Average irradiance during test: ....W/m^2

Average surrounding air temperature: ....°C

Average surrounding air speed: m/s

Average absorber temperature: ....°C

Duration of test: ....min

B.4.2.2 Additional information required if an evacuated tubular collector was tested

The temperature of the collector was measured at the location shown below:

B.4.2.3 Additional information required if the absorber temperature was measured using a special fluid (as described in 5.3.2, note 2)

The absorber was partially filled with .... and the average pressure was .... Pa, which corresponds to the average absorber temperature given in B.4.2.

B.4.3 Test results

Give details of any observed or measured degradation, distortion, shrinkage or outgassing and any of the failures denoting “major failure”, defined in 5.3.1 of EN 12975-1:2006

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Collector reference No.:

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B.5 Exposure test

B.5.1 Test conditions

Collector tilt angle (degrees from horizontal):

In Tables B.2 and B.3 full details should be given of the climatic conditions for all days during the test, including:

- daily global irradiation, H (MJ/m^2);
- periods when the global irradiance G and the surrounding air temperature t_a have values greater than those specified in Table 4;
- surrounding air temperature, t_a (°C);
- rain (mm).

B.5.2 Test results

Inspection should be conducted according to B.5.5. A full description and evaluation should be given of any problems or failures observed, including any of the failures denoting "major failure", defined in 5.3.1 of EN 12975-1:2006, together with appropriate photographs.

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Collector reference No.:

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B.5.3 Climatic conditions for all days during the test

Table B.2

Date	H MJ/m^2	t_a °C	**Rain** mm	**Date**	H MJ/m^2	t_a °C	**Rain** mm

Total: .... days in which H > ………..MJ/m^2

Collector reference No.: ....

B.5.4 Time periods in which irradiance and surrounding air temperature have values greater than those specified in Table 4

Table B.3

Date	***G*** **W/m^2**	**t_a** **°C**	**Time periods** min
		Total:	

Collector reference No.: ....

B.5.5 Inspection results

Evaluate each potential problem according to the following scale:

0 - No problem

1 - Minor problem

2 - Severe problem

• - Inspection to establish the condition was not possible

	Collector component	Potential problem	Evaluation
a)	Collector box/fasteners	Cracking/warping/corrosion/rain penetration	....
b)	Mountings/structure	Strength/safety	....
c)	Seals/gaskets	Cracking/adhesion/elasticity	....
d)	Cover/reflector	Cracking/crazing/buckling/delamination/ warping/outgassing	....
e)	Absorber coating	Cracking/crazing/blistering	....
	Absorber tubes and headers	Deformation/corrosion/leakage/loss of bonding	....
	Absorber mountings	Deformation/corrosion	....
f)	Insulation	Water retention/outgassing/degradation .	....

Collector reference No.: ....

B.6 External thermal shock test:

B.6.1 Test conditions

B.6.1.1 General

Test performed:

☐ Outdoors ☐ In solar irradiance simulator

Test combined with exposure test:

☐ Yes ☐ No

Test combined with high-temperature resistance test:

☐ Yes ☐ No

Collector tilt angle (degrees from horizontal):..°

Average irradiance during test: .... W/m^2

Minimum irradiance during test: .... W/m^2

Average surrounding air temperature: .... °C

Minimum surrounding air temperature: .... °C

Period during which the required operating conditions were

maintained prior to external thermal shock: .... min

Flowrate of water spray:..kg/(s•m^2)

Temperature of water spray:... °C

Duration of water spray:.. min

Absorber temperature immediately prior to water spray:... °C

B.6.1.2 Additional information required if an evacuated tubular collector was tested

The temperature of the collector was measured at the location shown below:

B.6.1.3 Additional information required if the absorber temperature was measured using a special fluid (as described in 5.5.2, note 2)

The absorber was partially filled with .... and the average pressure was ....Pa, which corresponds to the absorber temperature given in B.6.1.1.

B.6.2 Test results

Give details of any cracking, distortion, condensation, water penetration or loss of vacuum found and any of the failures denoting “major failure”, defined in 5.3.1 of EN 12975-1:2006 when examining the collector after the test.

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Collector reference No.:

....

B.7 Internal thermal shock test:

B.7.1 Test conditions

B.7.1.1 General

Test performed:

☐ Outdoors ☐ In solar irradiance simulator

Test combined with exposure test:

☐ Yes ☐ No

Test combined with high-temperature resistance test:

☐ Yes ☐ No

Collector tilt angle (degrees from horizontal): .... °

Average irradiance during test: ....W/m^2

Minimum irradiance during test: ....W/m^2

Average surrounding air temperature during test: .... °C

Minimum surrounding air temperature: .... °C

Period during which the required operating conditions were maintained

prior to internal thermal shock: ....min

Flowrate of heat transfer fluid: .... kg/(s•m^2)

Temperature of heat transfer fluid: .... °C

Duration of heat transfer fluid flow: ....min

Absorber temperature immediately prior to heat transfer fluid flow: .... °C

B.7.1.2 Additional information required if an evacuated tubular collector was tested

The temperature of the collector was measured at the location shown below:

B.7.1.3 Additional information required if the absorber temperature was measured using a special fluid (as described in 5.6.2, note 2)

The absorber was partially filled with .... and the average pressure was ....Pa, which corresponds to the absorber temperature given in B.7.1.1.

B.7.2 Test results

Give details of any cracking, distortion, deformation, water penetration or loss of vacuum found and any of the failures denoting “major failure”, defined in 5.3.1 of EN 12975-1:2006 when examining the collector after the test**.**

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Collector reference No.:

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B.8 Rain penetration test

B.8.1 Test conditions

B.8.1.1 Collector mounting

Collector mounted on:

☐ Open frame

☐ Simulated roof

Collector tilt angle (degrees from horizontal): °

B.8.1.2 Method used to keep absorber warm:

☐ Hot water circulation

☐ Exposure of collector to solar radiation

B.8.1.3 Water spray

Water spray flowrate: kg/(s•m^2)

Duration of water spray: h

B.8.2 Test results

Area with visible sign of water penetration (expressed as a percentage of aperture area): %

Give details of water penetration, reporting the places where water penetrated and the time the sign of rain penetration took to vanish.

....

....

Give details of any of the failures denoting “major failure”, defined in 5.3.1 of

EN 12975-1:2006...

....

....

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Collector reference No.: ....

B.9 Freeze resistance test

B.9.1 Collector type

☐ Freeze-resistant when filled with water

☐ Drain-down

B.9.2 Test conditions

B.9.2.1 Tilt angle of collector during test (degrees from horizontal): °

B.9.2.2 Details of freeze-thaw cycles

No.of freeze-thaw cycles	Freeze conditions		Thaw conditions	
	Test temperature °C	Duration min	Test temperature[a] °C	Duration min
1				
2				
3				

[a] For freeze-resistant collectors, this is the temperature of the contents of the collector, e.g. water, ice.

For drain-down collectors, this is the temperature measured inside the absorber close to the inlet.

B.9.2.3 Rate of chamber cooling: K/h

B.9.2.4 Rate of chamber heating: K/h

B.9.3 Test results

Give details of leakage, breakages, distortion or deformation and any of the failures denoting “major failure”, defined in 5.3.1 of EN 12975-1:2006

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Collector reference No.:

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B.10 Mechanical load test

B.10.1 Positive pressure test of the collector cover

B.10.1.1 Method used to apply pressure:

☐ Loading with gravel or similar material

☐ Loading with water

☐ Suction cups

☐ Pressurisation of collector cover

B.10.1.2 Test conditions

Maximum pressure load:

B.10.1.3 Test results

Give details of any damage to the collector cover after the test, reporting the value of pressure load which caused the damage and any of the failures denoting "major failure", defined in 5.3.1 of EN 12975-1:2006

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B.10.2 Negative pressure test of fixings between the cover and the collector box

B.10.2.1 Method used to apply pressure:

☐ Suction cups ☐ Pressurisation of collector box

B.10.2.2 Test conditions

Maximum pressure load:

B.10.2.3 Test results

Give details of any damage to the collector cover or cover fixings after the test, reporting the value of pressure load which caused the damage and any of the failures denoting “major failure”, defined in 5.3.1 of EN 12975-1:2006

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Collector reference No.:

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B.10.3 Negative pressure test of collector mountings

B.10.3.1 Method used to apply pressure:

☐ Suction cups ☐ Air bags

B.10.3.2 Test conditions

Maximum pressure load: Pa

B.10.3.3 Test results

Give details of any damage to the collector mounting fixtures or fixing points after the test, reporting the value of pressure load which caused the damage and any of the failures denoting “major failure”, defined in 5.3.1 of EN 12975-1:2006

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Collector reference No.:

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B.11 Impact resistance test using steel balls

B.11.1 Test conditions

Diameter of ball: mm

Mass of ball: g

Test performed using:

☐ Vertical impact (dropping ball)

☐ Horizontal impact (pendulum)

B.11.2 Test procedure

Drop height m	**No. of drops**

B.11.3 Test results

Give details of any damage to the collector and any of the failures denoting “major failure”, defined in 5.3.1 of EN 12975-1:2006

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....

....

....

Collector reference No.:

....

B.12 Impact resistance test using ice balls

B.12.1 Test conditions

Diameter of ball: ....mm

Mass of ball: ....g

Velocity of ball: m/s

B.12.2 Test procedure

No. of impacts:

B.12.3 Test results

Give details of any damage to the collector and any of the failures denoting "major failure", defined in 5.3.1 of EN 12975-1:2006

....

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Collector reference No.:

....

B.13 Final inspection results

Evaluate each potential problem according to the following scale:

0 - No problem

1 - Requirement apart from testing not fulfilled

2 - Requirements for testing not fulfilled

• - Inspection to establish the condition was not possible

Collector component Potential problem Evaluation

a) Collector box/fasteners Cracking/warping/corrosion/rain penetration ....

b) Mountings/structure Strength/safety ....

c) Seals/gaskets Cracking/adhesion/elasticity ....

d) Cover/reflector Cracking/crazing/buckling/delamination/ ....
warping/outgassing

e) Absorber coating Cracking/crazing/blistering ....

Absorber tubes and headers Deformation/corrosion/leakage/loss of bonding ....

Absorber mountings Deformation/corrosion ....

f) Insulation Water retention/outgassing/degradation ....

Annex C
(normative)
Stagnation temperature of liquid heating collectors

C.1 General

This annex provides a method for calculating the 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 surrounding temperatures.

The stagnation temperature should be determined for a selected solar irradiance G_s and a selected ambient temperature t_as.

The calculated stagnation temperature is used for determining the test temperature for:

- internal pressure testing of collectors with organic absorbers (see 5.2.2);
- high-temperature resistance test using a hot fluid loop (see 5.3).

C.2 Determination of stagnation temperature

The stagnation temperature t_stg, for the selected values of solar irradiance G_s and ambient temperature t_as, is calculated by extrapolating from measured steady-state values of:

- solar irradiance G_m (natural or simulated) on the collector plane;
- surrounding air temperature t_am;
- absorber temperature t_sm.

while the collector is exposed to the available solar irradiance and ambient temperature (outdoors, or in a solar irradiance simulator) under steady-state conditions without heat extraction from the collector (stagnation conditions).

The expression for determining the stagnation temperature for the selected parameters (G_s and t_as) is:

$$t_{stg} = t_{as} + \frac{G_s}{G_m}(t_{sm} - t_{am}) \qquad \text{(C.1)}$$

It is based on the approximation that the ratio (t_{sm} - t_{am})/G_m remains constant under steady-state collector stagnation conditions.

This approximation is acceptable only if the irradiance level (G_m) used during the test is within 10 % of the irradiance specified for the stagnation conditions (G_s).

Annex D
(normative)
Performance test report for glazed solar collectors

D.1 General

Collector reference No:

Test performed by:

Address:

Date, Tel, Fax:

D.2 Solar collector description

Name of manufacturer:

Brand Name: Serial No:

Collector Type : Glazed/Evacuated Drawing Document No:

Year of Production:

Flow range: to kg/s

Operating pressure: kPa

Stagnation temperature at 1000 W/m^2

and 30 °C ambient temperature: °C

Collector mounting:

Collector:

Type name:

Flat plate / evacuated / subatmospheric:Gross area:

Aperture area:

Absorber area:

Dimensions of collector unit

Length:	mm	Absorber area:	m^2
Width :	mm	Aperture area:	m^2
Height:	mm	Gross Area:	m^2

Weight empty:

Fluid content:

Number of covers:

Cover materials:

Cover thickness:

Cover solar transmittance:

Absorber:

Material:

Fin width:

Fin thickness:

Solar absorptance α:

Hemispherical emittance ε:

Surface treatment:

Construction type:

Number of risers:

Riser diameter or dimensions:

Distance between risers:

Dimensions:

Thermal insulation and casing:

Thermal insulation thickness:

Insulation material:

Casing material:

Sealing material:

Limitations:
Maximum operation temperature:

Maximum operation pressure:

Other limitations:

Photograph of the collector

Comments on collector design

Schematic diagram of collector mounting

Schematic diagram of the test loop

Heat transfer medium: water / oil / other

Specifications (additives etc.):

Alternative acceptable heat transfer fluids:

D.3 Test results

Thermal performance has been tested based on test methods:

☐ 6.1 Outdoor - Steady State Method ☐ 6.1 Indoor - Steady State Method ☐ 6.3 Outdoor-Quasi-dynamic Method

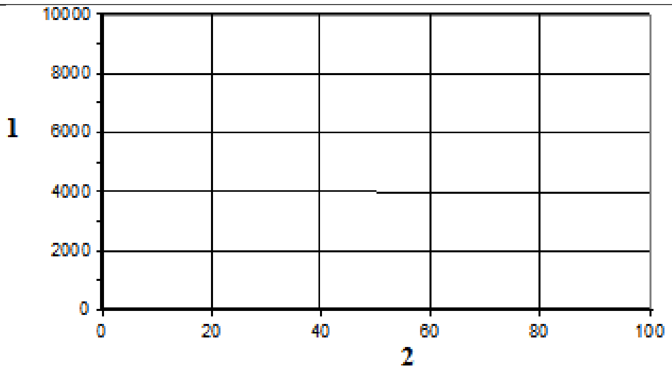
Outdoor	**indoor**
Latitude:	mean solar irradiance:
Longitude:	type of the lamps:
Collector azimuth:	shading of longwave radiation: yes no
Collector tilt:	

Orientation of absorber tubes during testing (horizontal or vertical):

Peak Power (G = 1000 W/m²) per collector unit:…………………………………W$_{peak}$

Power output per collector unit (W):

Irradiance			
T_m-T_a in K	400 W/m²	700 W/m²	1000 W/m²
10			
30			
50			
NOTE The reported values are for normal incidence.			



Key

1 Power output per collector unit [W]

2 (t_m-t_a) [K]

Figure D.1 - Power output per collector unit (for G = 1000 W/m²)

Instantaneous efficiency curve based on (absorber/aperture) area and mean temperature of heat transfer fluid.

Reference area: Absorber area A_A **Reference area: Aperture area A_a**

absorber area used for curve in m² : **aperture area** used for curve in m² :

The instantaneous efficiency is defined by:

$$\eta_A = \frac{\dot{Q}}{A_A G} \quad \text{(D.1)}$$

$$\eta_a = \frac{\dot{Q}}{A_a G} \quad \text{(D.2)}$$

Fluid flowrate used for the tests: kgs^{-1}

Gross collector area: m²

Second order fit to data:

$$\eta_A = \eta_{0A} - a_{1A}\left(\frac{t_m - t_a}{G}\right) - a_{2A} G\left(\frac{t_m - t_a}{G}\right)^2 \qquad (D.3)$$

$$\eta_a = \eta_{0a} - a_{1a}\left(\frac{t_m - t_a}{G}\right) - a_{2a} G\left(\frac{t_m - t_a}{G}\right)^2 \qquad (D.4)$$

<u>Based on Absorber Area</u>		**Std.Deviation**	**<u>Based on Aperture Area</u>**		**Std.Deviation**
η_{oA}			**η_{oa}**		
a_{1A}			**a_{1a}**		
a_{2A}			**a_{2a}**		
In case of 6.3, test results according to Annex J should be attached to this document					

Time constant

τ_C= s

Effective thermal capacity

C = JK^{-1}

Determination:

Calculation:

Indoors:

Outdoors:

Incident angle modifier

Angle:

K_θ:

Observed failures

Give details of any of the failures denoting “major failure”, defined in 5.3.1 of EN 12975-1:2006

Delivery of sample:

Start of test:

End of test:

Test Institute:…………………………….... Date: …………………

Annex E
(normative)
Performance test report for unglazed solar collectors

E.1 General

Collector reference No:

Test performed by:

Address:

Date, Tel, Fax:

E.2 Solar collector description

Name of manufacturer:

Brand Name: Serial No:

Collector Type : Drawing Document No:

Year of Production:

Flow range: to kg/s

Operating pressure: kPa

Stagnation temperature at 1000 W/m^2

and 30 °C ambient temperature: °C

Collector mounting:

Collector:

Type name:

Flat plate / evacuated / subatmospheric:

Gross area:

Aperture area:

Absorber area:

Dimensions of collector unit

Length:	mm	Absorber area:	m^2
Width :	mm	Aperture area:	m^2
Height:	mm	Gross Area:	m^2

Weight empty:

Fluid content:

Absorber:

Material:

Fin Width:

Fin thickness:

Solar absorptance α:

Hemispherical emittance ε:

Surface treatment:

Construction type:

Number of risers:

Riser diameter or dimensions:

Distance between risers:

Dimensions:

Limitations:
Maximum operation temperature:

Maximum operation pressure at 45 °C:

Maximum operating pressure at maximum temperature of operation:

Other limitations:

Photograph of the collector

Comments on collector design

Schematic diagram of collector mounting

Instantaneous efficiency

Heat transfer medium: water / oil / other

Specifications (additives etc.):

Alternative acceptable heat transfer fluids:

E.3 Test results

Thermal performance has been tested based on test methods:

☐ 6.1 Outdoor - Steady State Method ☐ 6.1 Indoor - Steady State Method ☐ 6.3 Outdoor-Quasi-dynamic Method

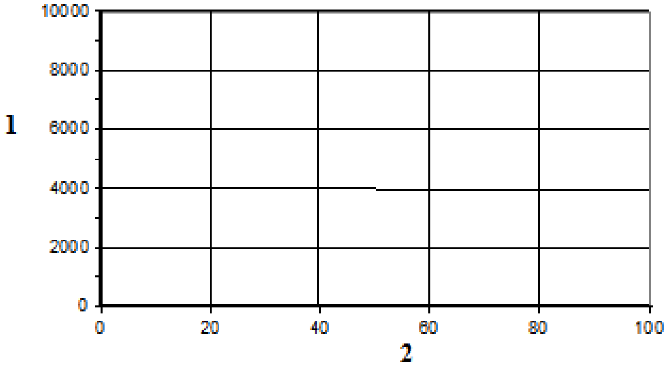
Outdoor	**indoor**
Latitude:	mean solar irradiance:
Longitude:	type of the lamps:
Collector tilt:	shading of longwave radiation: yes no
Collector azimuth:	

Peak Power (G = 1000 W/m²) per collector unit:…………………………………W_{peak}

Power Output per collector unit (W):

	Irradiance		
T_m-T_a = 2 K	400 W/m^2	700 W/m^2	1000 W/m^2
u < 1 m/s			
u = 1,5 ± 0,5 m/s			
u = 3 ± 0,5 m/s			

The power output per collector unit shall be presented graphically according to Figure E.1 for the following wind conditions: u<1 ms^{-1} , u=1,5 $\pm$ 0,5 ms^{-1} and u=3 $\pm$ 0,5 ms^{-1}



Key

1 Power output per collector unit [W]
2 (t_m-t_a) [K]

Figure E.1 - Power output per collector unit

Instantaneous efficiency curve based on collector area and mean temperature of heat transfer fluid.

The instantaneous efficiency is defined by: $\eta = \frac{\dot{Q}}{AG''}$ (E.1)

collector area used for curve: m^2

Fluid flowrate used for the tests: kgs^{-1}

$$\eta = \eta_o(1 - b_u u) - (b_1 + b_2 u)\frac{(t_m - t_a)}{G''} \qquad (E.2)$$

Based on Absorber Area		**Based on Aperture Area**	
η_{oA}		η_{oa}	
b_{uA}		b_{ua}	
b_{1A}		b_{1a}	
b_{2A}		b_{2a}	
In case of 6.3, test results according to Annex J should be attached to this document			

Time constant

τ_C= s

Effective thermal capacity

C= JK^{-1}

Determination:

Calculation:

Indoors:

Outdoors:

Incident angle modifier

Angle:

K_θ:

Observed failures

Give details of any of the failures denoting “major failure”, defined in 5.3.1 of EN 12975-1:2006

Delivery of sample:

Start of test:

End of test:

Test Institute:…………………………….... Date: …………………

Annex F
(normative)
Modelling of the coefficients c_1 to c_6 of the collector model of 6.3.

Coefficient c_1 is the Heat loss coefficient at $(t_m - t_a)=0$ [Wm^{-2}K^{-1}]

c_1 is modelled as $F' U_0$

Coefficient c_2 is the Temperature dependence of the heat loss coefficient [Wm^{-2}K^{-2}]

c_2 is equal to $F' U_1$

Coefficient c_3 is the Wind speed dependence of the heat loss coefficient [Jm^{-3}K^{-1}]

c_3 is equal to $F' U_u$

Coefficient c_4 is the Long wave irradiance dependence of the heat loss coefficient [-]

c_4 is equal to $F'\varepsilon$

NOTEThe modelling of the long wave irradiance dependence of the collector is made in the same principle way as described in the basic ISO 9806-3: 1995, 8.8, for testing of unglazed collectors. The Net long wave irradiance, is defined as $(E_L-\sigma T_a^4)$ and where E_L is the measured long wave thermal irradiance in the collector plane.

However, a purely mathematical difference exists between ISO 9806-3 and this standard that eliminates G'' and the use of the ε/α -coefficient in the equation. Physically, the long wave radiation corrections are the same. In this standard, the correction factor for long wave radiation is treated as a separate heat loss term and is not involved in an effective radiation term G'' as in ISO 9806-3. The main reason for this is that the collector equation is simplified by doing so, as this approach also takes into account incidence angle effects and diffuse radiation effects. In this case, α otherwise should be corrected for these effects. In ISO 9806-3, these factors are not taken into account and the equation is simplified by using G'' and the ε/α-factor.

Coefficient c_5 is the Effective thermal capacitance [Jm^{-2}K^{-1}]

c_5 is equal to C/A (definition of C, see under 6.1.6.2).

NOTE C is often denoted $(mC)_e$ in basic literature

Coefficient c_6 is the Wind speed dependence in the zero loss efficiency [sm^{-1}]

c_6 is modelled as a collector constant

$K_{\theta b}(\theta)$ is the Incidence angle modifier (IAM) for direct radiation [-]

The basic modelling of IAM-dependence is made with the equation

$$K_{\theta b}(\theta) = 1 - b_0((1/\cos\theta_i) - 1) \quad \text{(H.1)}$$

as described in e.g. ASHRAE 93-77.

For collectors with special IAM-dependence, see note 2 under 6.3.4.8.1.

$K_{\theta d}$ is the Incidence angle modifier for diffuse radiation [-]

$K_{\theta d}$ is modelled as a collector constant

Annex G
(normative)
Measurement of effective thermal capacity

G.1 Test installation

The collector is mounted in accordance with the recommendations of 6.1.1 and coupled to a test loop for thermal capacity measurement.

Effective thermal capacity measurements may be carried out indoors, where only heat loss is measured. They may also be made outdoors in steady-state clear sky conditions, or in a solar irradiance simulator.

G.2 Indoor test procedure

G.2.1 General

The heat fluid is circulated from the top to the bottom of the collector with a constant inlet temperature, using a flowrate similar to that defined for collector efficiency testing, until steady-state conditions are reached.

The inlet temperature of the fluid is raised rapidly by about 10 K, and measurements made continuously until steady-state conditions are achieved again. This process is performed four times and an arithmetic mean value of the effective thermal capacity calculated.

G.2.2 Measurements

The following quantities are measured:

a) heat transfer fluid mass flowrate;

b) temperature of the heat transfer fluid at the collector inlet;

c) temperature of the heat transfer fluid at the collector outlet;

d) surrounding air temperature.

NOTEWhen testing collectors having a low thermal capacity, the sampling frequency selected for measuring the fluid temperatures may need to be greater than the usually used for collector efficiency testing, in order to adequately follow the transient behaviour of the collector.

G.2.3 Calculation of the effective thermal capacity

The transient behaviour of the collector between the two indoor steady states 1 and 2 is represented by the following equation:

$$C\frac{dt_m}{dt} = -\dot{m}c_f \Delta T - AU(t_m - t_a) \qquad \text{(G.1)}$$

where

$$\Delta T = (t_{\mathrm{e}} - t_{\mathrm{in}})(\text{negative}) \qquad \text{(G.2)}$$

and t_{in} and t_{e} are the heat transfer fluid temperatures at the collector inlet and outlet (exit), respectively, under the new flow direction of the heat transfer fluid.

Integrating the equation over the period between the two steady-states gives

$$C(t_{\mathrm{m2}} - t_{\mathrm{m1}}) = -\int_{\mathrm{t1}}^{\mathrm{t2}} \dot{\mathrm{m}} c_{\mathrm{f}} \Delta T dt - AU \int_{\mathrm{t1}}^{\mathrm{t2}} (t_{\mathrm{m}} - t_{\mathrm{a}}) dt \qquad \text{(G.3)}$$

Since

$$t_{\mathrm{m}} = t_{\mathrm{in}} + \frac{\Delta T}{2} \qquad \text{(G.4)}$$

we may express (t_{m}-t_{a}) as

$$t_{\mathrm{m}} - t_{\mathrm{a}} = (t_{\mathrm{in}} - t_{\mathrm{a}}) + \frac{\Delta T}{2} \qquad \text{(G.5)}$$

Combining the above equations, and rearranging, gives the following equation for the collector thermal capacity.

$$C = \frac{-\dot{\mathrm{m}} c_{\mathrm{f}} \int_{\mathrm{t1}}^{\mathrm{t2}} \Delta T dt - AU \left[\int_{\mathrm{t1}}^{\mathrm{t2}} (t_{\mathrm{in}} - t_{\mathrm{a}}) dt + \frac{1}{2} \int_{\mathrm{t1}}^{\mathrm{t2}} \Delta T dt \right]}{t_{\mathrm{m2}} - t_{\mathrm{m1}}} \qquad \text{(G.6)}$$

G.2.4 Determination of effective thermal capacity from experimental data

From the test results, (t_{in} - t_{a}) and ΔT are plotted as a function of time. The areas under the curves, between the two steady states, are

$\int_{\mathrm{t1}}^{\mathrm{t2}} (t_{\mathrm{in}} - t_{\mathrm{a}}) dt$ and $\int_{\mathrm{t1}}^{\mathrm{t2}} \Delta T dt$

respectively.

The heat transfer coefficient U of the collector may already have been determined during indoor collector heat loss measurement. However, *AU* may be obtained directly from two steady states since in a steady state we have:

$$0 = -\dot{\mathrm{m}} c_{\mathrm{f}} \Delta T - AU(t_{\mathrm{m}} - t_{\mathrm{a}}) \qquad \text{(G.7)}$$

and hence

$$AU = -\frac{\dot{\mathrm{m}} c_{\mathrm{f}} \Delta T}{t_{\mathrm{m}} - t_{\mathrm{a}}} \qquad \text{(G.8)}$$

AU is evaluated for both steady states, and arithmetic mean value taken.

A value of the effective thermal capacity is determined by inserting these experimental values in Equation (G.6).

G.3 Outdoor or solar irradiance simulator test procedure

The fluid is circulated with a constant temperature, using a flowrate similar to that defined for collector efficiency testing, until steady-state conditions are reached. The aperture of the collector should be shielded from the solar radiation (natural or simulated) by means of a solar-reflecting cover.

The cover is removed and measurements are made continuously until steady-state conditions are achieved again. This process is performed four times and an arithmetic mean value of the effective thermal capacity deduced.

The measurements indicated in G.2.2 are made. In addition, the solar irradiance (natural or simulated) G is measured.

The transient behavior of the collector between two steady states 1 and 2 is represented by the following equation

$$C\frac{dt_m}{dt} = A\eta_0 G - \dot{m}\, c_f \Delta T - AU(t_m - t_a) \qquad \text{(G.9)}$$

where, as in G.2.3,

$$\Delta T = (t_e - t_{in}) \text{ (positive)}$$

Integrating the Equation (G.9) over the period between the two steady states gives the following equation for the collector thermal capacity:

$$C = \frac{A\eta_0 \int_{t1}^{t2} G dt - \dot{m}\, c_f \int_{t1}^{t2} \Delta T dt - AU\left[\int_{t1}^{t2} (t_{in} - t_a) dt + \frac{1}{2}\int_{t1}^{t2} \Delta T dt\right]}{t_{m2} - t_{m1}} \qquad \text{(G.10)}$$

From the test records, (t_{in} - t_a), ΔT and G are plotted as a function of time. The areas under the curves, between the two steady states, are:

$$\int_{t1}^{t2} (t_{in} - t_a) dt \;, \qquad \int_{t1}^{t2} \Delta T dt \quad \text{and} \quad \int_{t1}^{t2} G dt$$

respectively.

The y intercept η_0 and the slope U of the linear form of the instantaneous efficiency η are known from testing.

A value for the effective thermal capacity is determined by inserting these experimental values in Equation (G.10).

Annex H
(informative)
Comparison of the collector model of 6.1 to the collector model of 6.3

In a comparison, we start to describe the present stationary collector model used in 6.1. This model has been widely used both in testing (ISO 9806-1 and ASHRAE 93-77) and for simulation. The basic equation is a stationary model for near normal incidence angle operation and can be written as:

$$\dot{Q}/A = F'(\tau\alpha)_{en}\, G^* - c_1\,(t_m - t_a) - c_2\,(t_m - t_a)^2 \tag{H.1}$$

The irradiance is denoted G^* , but could instead be denoted G_b to point out that only high irradiance levels are accepted in the test sequence, and thus a low diffuse fraction. No correction for non stationary conditions is made, so very stable inlet and radiation conditions are needed for each test point.

Furthermore, it is assumed that the incidence angle is near normal, so that incidence angle effects can be neglected.

In 6.1, there are furthermore optional test procedures also for the determination of incidence angle dependence of the zero loss efficiency and the effective thermal capacitance of the collector. Therefore the full instantaneous equation from all the options in 6.1 can be written as:

$$\dot{Q}/A = F'(\tau\alpha)_{en}\, K_{\theta b}(\theta)\, G^* - c_1\,(t_m - t_a) - c_2\,(t_m - t_a)^2 - c_5\, dt_m/dt \tag{H.2}$$

As a first step in the approach of 6.3, the first term of the equation is divided into two parts, giving the sum of the zero loss efficiency for beam radiation and the diffuse radiation, or $F'(\tau\alpha)_{en}\, K_{\theta b}(\theta)\, G^*$ is divided into $F'(\tau\alpha)_{en}\, K_{\theta b}(\theta)\, G_b + F'(\tau\alpha)_{en}\, K_{\theta d}\, G_d$ while the rest of the equation is kept unchanged.

To make it possible to test a much wider range of solar collectors, but also to achieve a much more complete characterization of the collector from the same test and with the same method, just another correction is added to the collector model, namely the correction for the wind-dependence. In the 6.1-method, this is handled by limiting the test requirements for wind-speed to 2-4 m/s for glazed collectors during test. For unglazed, their sensitivity to wind-speed has resulted in the need for a test method (6.2) of their own, which prescribes that 3 different efficiency functions have to be measured for each collector at 3 given wind-speeds. A fact that makes testing of each collector expensive and time consuming. For test sites with varying climate, such tests can also be difficult to conduct outdoors.

In this approach, wind-dependence is modeled by 2 terms added to the basic equation. One gives the effect on the zero loss efficiency ($- c_6\, u\, G^*$) and the other the effect on the heat losses ($- c_3\, u\, (t_m - t_a)$). After a final addition of the Long-wave irradiance dependence of the heat losses ($+ c_4\, (E_L - \sigma T_a^4)$), modeled as done for unglazed collectors (see Annex F), the collector model is completed and is written as in Equation 7. Equation 7 gives the output power of the collector per square meter of the reference area used.

Annex I
(informative)
Properties of water (see DIN V 4757-4:1995-11)

I.1 Density of water (at 1 bar) in kg/m³

$$\rho(\vartheta) = a_0 + a_1\vartheta + a_2\vartheta^2 + a_3\vartheta^3 + a_4\vartheta^4$$

$$(0 \leq \vartheta \leq 99{,}5\ ^\circ C)$$

with

$a_0 = 999{,}85$

$a_1 = 6{,}187\ 10^{-2}$

$a_2 = -7{,}654\ 10^{-3}$

$a_3 = 3{,}974\ 10^{-5}$

$a_4 = -1{,}110\ 10^{-7}$

The deviation of the polynomial to the values published in tables is always smaller than 0,02 %. R² equals 0,99998

I.2 Specific heat capacity of water (at 1 bar) in kJ/(kg K)

$$c_p(\vartheta) = a_0 + a_1\vartheta + a_2\vartheta^2 + a_3\vartheta^3 + a_4\vartheta^4 + a_5\vartheta^5$$

$$(0 \leq \vartheta \leq 99{,}5\ ^\circ C)$$

with

$a_0 = 4{,}217$

$a_1 = -3{,}358\ 10^{-3}$

$a_2 = 1{,}089\ 10^{-4}$

$a_3 = -1{,}675\ 10^{-6}$

$a_4 = 1{,}309\ 10^{-8}$

$a_5 = -3{,}884\ 10^{-11}$

The deviation of the polynomial to the values published in tables is always smaller than 0,02%. R² equals 0,9994

Annex J

(informative)

Performance test report summary for quasi dynamic test method

Identification:

Manufacturer:

Brand Name:	Serial No.:
Collector Type:	Drawing document No.:

Dimensions of Collector unit:

Length:	mm	Absorber area:	m^2
Width:	mm	Aperture area:	m^2
Height:	mm	Gross area (casing):	m^2

General Specifications:

Weight:	kg
Heat transfer fluid:	
Flow range:	to l/h
Operating pressure:	bar

Stagnation Temperature at 1000Wm^{-2},

and 30 °C ambient temperature °C

Thermal performance based on:

Aperture Area: **Absorber Area:**

	Value	**Standard deviation**		**Value**	**Standard deviation**
$F'(\tau\alpha)_{en}$			$F'(\tau\alpha)_{en}$		
$K_{\theta d}$			$K_{\theta d}$		
b_0			b_0		
c_1			c_1		
c_2			c_2		
c_3			c_3		
c_4			c_4		
c_5			c_5		
c_6			c_6		

Table M.1 - Incidence angle modifier, $K_{\theta b}(\theta)$

θ	10	20	30	40	50	60	70	80
$K_{\theta b}(\theta)$								

This test report should be completed in conjunction with the test report according to Annex D or E.

Tested by:

Date:

Annex K
(informative)
General guidelines for the assessment of uncertainty in solar collector efficiency testing

K.1 Introduction

The aim of this annex is to provide a general guidance for the assessment of uncertainty in the result of solar collector testing performed according to the present standard. Testing laboratories are often invited to provide a statement of uncertainty in test results in quantitative tests, in the framework of their accreditation or of application of product certification schemes. It is not the aim of this annex to define whether and in which cases the calculation of uncertainty in test results is necessary.

This guidance concerns only in collector efficiency testing due to i) the great importance of the result of this testing for the user, and ii) the peculiarities of the calculations, since the final result of efficiency testing is not derived by a single measurement but by elaboration of a large number of primary measurements.

It is noted that the proposed methodology is one of the possible approaches for the assessment of uncertainty, and other approaches can be implemented. It is of the responsibility of each Laboratory to choose and to implement a scientifically valid approach for the determination of uncertainties, following the recommendations of the accreditation bodies, where appropriate. For a more detailed review of the different aspects of determination of uncertainties in solar collector testing see also (Mathioulakis *et al*., 1999; Sabatelli *et al*., 2002; Müller-Schöll and Frei, 2000).

K.2 Measurement uncertainties in solar collector efficiency testing

The basic target of solar collector efficiency testing is the determination of the collector efficiency by measurements under specific conditions. More specifically, it is assumed that the behavior of the collector can be described by a *M*-parameter single node, steady state or quasi-dynamic model:

$$\eta=c_1p_1+c_2p_2+\ldots+c_Mp_M \qquad \text{(K.1)}$$

where:

η is the collector instantaneous efficiency.

$p_1, p_2,\ldots,p_N$ are quantities, the values of which are determined experimentally through testing

$c_1, c_2,\ldots,c_M$ are characteristic constants of the collector that are determined through testing.

In the case of the steady state model, for example, $M=3$, $c_1=\eta_0$, $c_2=U_1$, $c_3=U_2$, $p_1=1$, $p_2=(T_m-T_a)/G$ and $p_3=(T_m-T_a)^2/G$.

During the experimental phase, the output, solar energy and the basic climatic quantities are measured in *J* steady-state or quasi-dynamic state points, depending the model used. From these primary measurements the values of parameters η, p_1, $p_2,\ldots,p_M$ are derived for each point of observation j, $j=1\ldots J$. Generally, the experimental procedure of the testing leads to a formation of a group of *J* observations which comprise, for each one of the *J* testing points, the values of η_j, $p_{1,j}$, $p_{2,j},\ldots,p_{M,j}$.

For the determination of uncertainties, it is essential to calculate the respective combined standard uncertainties $u(\eta_j)$, $u(p_{1,j})$, $\ldots u(p_{M,j})$ in each observations point. It should be noted that in practice the uncertainties $u(\eta_j)$, $u(p_{1,j})$, $\ldots u(p_{M,j})$ are almost never constant and the same for all points, but that each testing point has its own standard deviation.

For the calculation of the standard deviation (squared standard uncertainty) in each point *j*, the following general rules can be applied (ISO GUM:1995):

I. Standard uncertainties in experimental data are determined by taking into account Type A and Type B uncertainties. According to the recommendation of ISO GUM, the former are the uncertainties determined by statistical means while the latter are determined by other means.

II. The uncertainty $u(s)$ associated with a measurement s is the result of a combination of the Type B uncertainty $u_B(s)$, which is a characteristic feature of the calibration setup, and of the Type A uncertainty $u_A(s)$, which represents fluctuation during sampling of data. If there is more than one independent source of uncertainty (Type B or type A) u_k, the final uncertainty is calculated according to the general law of uncertainties combination:

$$u = \left(\sum_k u_k^2 \right)^{1/2} \qquad \text{(K.2)}$$

III. Type B uncertainty $u_B(s)$ derives from a combination of uncertainties over the whole measurement chain, taking into account all available data, such as sensor uncertainty, data logger uncertainty, uncertainty resulting from the possible differences between the measured values perceived by the measuring device. Relevant information should be obtained from calibration certificates or other technical data related to the devices used.

IV. By nature, Type A uncertainties depend on the specific conditions of measurement and they account for the fluctuations in the measured quantities during the measurement. Type A uncertainty $u_A(s)$ derives from the statistical analysis of experimental data. In some cases (for example in the case of the steady-state model), the best estimate of S is the arithmetic means s of the I repeated observations s_i ($i=1...I$) and its Type A uncertainty is the standard deviations of the mean:

$$s = \frac{\sum_{i=1}^{I} s_i}{I}, \text{ and } u_A(s) = \left(\frac{\sum_{i=1}^{I} (s_i - s)^2}{I(I-1)} \right)^{1/2} \qquad \text{(K.3)}$$

In some other cases (for example in the case of the quasi-dynamic model where no arithmetic mean of the repetitive measurements is used) uncertainty $u_A(s)$ can be equal to zero.

V. The term *combined standard uncertainty* means the standard uncertainty in a result when that result is obtained from the values of a number of other quantities. In most cases a measured Y is determined indirectly from P other directly measured quantities X_1, X_2, ...X_P through a functional relationship Y=f(X_1, X_2, ...X_P). The standard uncertainty in the estimate y is given by the *law of error propagation*:

$$u(y) = \left(\sum_{i=1}^{P} \left(\frac{\partial f}{\partial x_i} \right)^2 \left(u(x_i) \right)^2 + 2 \sum_{i=1}^{P-1} \sum_{j=i+1}^{P} \frac{\partial f}{\partial x_i} \frac{\partial f}{\partial x_j} \operatorname{cov}(x_i, x_j) \right)^{1/2} \qquad \text{(K.4)}$$

An example of such indirect determination in the case of solar collector efficiency testing is the determination of instantaneous efficiency η, which derives from the values of global solar irradiance in the collector level G, fluid mass flowrate m, temperate difference ΔT, collector area A and specific heat capacity c_f. Thus, in this case the standard uncertainty $u(\eta_j)$ in each value η_j of instantaneous efficiency is calculated by the combination of standard uncertainties in the values of the primary measured quantities, taking into account their relation to the derived quantity η.

K.3 Fitting and uncertainties in efficiency testing results

During analyzing the data a least square fitting of the model equation is performed, in order to determine the values of coefficients $c_1, c_2, \ldots, c_M$ for which the model of Equation (K.1) represents the series of J observations with the greatest accuracy.

Since in reality the typical deviation is almost never constant and the same for all observations, but each data point $(\eta_j, p_{1,j}, p_{2,j},\ldots,p_{M,j})$ has its own standard deviation σ_j, an interesting solution is the use of the ***weighted least square (WLS)*** method, which calculates, on the base of the measured values and their uncertainties, not only the model parameters but also their uncertainty. In the case of WLS, the maximum likelihood estimate of the model parameters is obtained by minimising the chi-square function:

$$\chi^2=\sum_{j=1}^{J}\frac{\left(\eta_j\text{-}(c_1p_{1,j}+c_2p_{2,j}+...c_Np_{M,j})\right)^2}{u_j^2} \qquad \text{(K.5)}$$

where u_j^2 is the variance of the difference $\eta_j\text{-}(c_1p_{1,j}+c_2p_{2,j}+...c_Np_{M,j})$:

$$u_j^2=Var\left(\eta_j\text{-}(c_1p_{1,j}+c_2p_{2,j}+...c_Np_{M,j})\right)=\left(\boldsymbol{u}(\boldsymbol{\eta_j})\right)^2+c_1^2\left(u(p_{1,j})\right)^2+...+c_M^2\left(u(p_{M,j})\right)^2 \qquad \text{(K.6)}$$

Finding coefficients $c_1, c_2,\ldots,c_M$ and their standard uncertainties by minimizing chi-square function is complicated, because of the non-linearity present in Equation (K.5). A strategy is therefore to find these uncertainties numerically. A method for the case of a *M*-parameter model is presented below (Press *et al.*, 1996).

Let *K* be a matrix whose *J*x*M* components $k_{j,m}$ are constructed from *M* basic functions evaluated at the *J* experimental values of $p_1,\ldots,p_M$ weighted by the uncertainty u_j :

$$\boldsymbol{k}_{\boldsymbol{j,m}}=\frac{\boldsymbol{p}_{\boldsymbol{m,j}}}{\boldsymbol{u}_{\boldsymbol{j}}}, \qquad \boldsymbol{K}=\begin{vmatrix} \frac{\boldsymbol{p}_{1,1}}{\boldsymbol{u}_1} & \cdot & \cdot & \frac{\boldsymbol{p}_{1,\boldsymbol{M}}}{\boldsymbol{u}_1} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \frac{p_{1,J}}{\boldsymbol{u}_{\boldsymbol{J}}} & \cdot & \cdot & \frac{p_{M,J}}{\boldsymbol{u}_{\boldsymbol{J}}} \end{vmatrix} \qquad \text{(K.7)}$$

Let also L be a vector of length *J* whose components l_j are constructed from values of η_j to be fitted, weighted by the uncertainty u_j:

$$l_j=\frac{\eta_j}{u_j}, \qquad \boldsymbol{L}=\begin{vmatrix} \eta_1/\boldsymbol{u}_1 \\ \cdot \\ \cdot \\ \cdot \\ \eta_{\boldsymbol{J}}/\boldsymbol{u}_{\boldsymbol{J}} \end{vmatrix} \qquad \text{(K.8)}$$

The *normal equation of the least square problem* can be written:

$$(K^T \bullet K) \bullet INV(C) = K^T \bullet L \qquad \text{(K.9)}$$

where C is a vector whose elements are the fitted coefficients.

Given the fact that for the calculation of variances u_j^2 the knowledge of coefficients $c_1, c_2,\ldots,c_M$ is needed, a possible solution is to use the values of coefficients calculated by standard least squares fitting as the initial values. These initial values can be used in Equation (K.6) for the calculation of u_j^2, $J=1\ldots J$ and the formation of matrix K and of vector L.

The solution of Equation (K.9) gives the new values of coefficients $c_1, c_2,\ldots,c_M$, which however are not expected to differ noticeably from those calculated by standard least squares fitting and used as initial values for the calculation of u_j^2.

Moreover, Z=INV(K^T•K) is a matrix whose diagonal elements $z_{k,k}$ are the squared uncertainties (variances) and the off-diagonal elements $z_{k,l}= z_{l,k}$, $k\neq l$ are the covariance between fitted coefficients:

$$u(c_m) = \sqrt{z_{m,m}}\text{ , } m=1,\ldots,M \tag{K.10}$$

$$Cov(c_k,c_l)= z_{k,l}= z_{l,k},\ k=1,\ldots,M \text{ and } l=1,\ldots,M \text{ and } k\neq l \tag{K.11}$$

It should be noted that the knowledge of covariance between the fitted coefficients is necessary if one wishes to calculate, in a next stage, the uncertainty $u(\eta)$ in the predicted values of η using Equations (K.1) and (K.4).

Equation (K.9) can be solved by a standard numerical method, for example, by Gauss-Jordan elimination. It is also possible to use matrix manipulation functions of commonly used spreadsheet software.

Annex L
(informative)
Determination of the pressure drop across a collector

L.1 General

The pressure drop across a collector may be of importance to designers of solar collector systems. The fluid used in the collector for the test shall be water or a mixture water:glycol (60:40), or a mixture recommended by the manufacturer.

The temperature of the fluid shall be (20 ± 2) °C.

L.2 Test installation

The collector shall be mounted in accordance with 6.1.1 and coupled to a test loop which conforms broadly with 6.1.3, although less instrumentation is required for pressure drop determination than for collector efficiency testing.

The heat transfer fluid shall flow from the bottom to the top of the collector, and particular attention shall be paid to the selection of appropriate pipe fittings at the collector entry and exit ports, as specified in 6.1.3.3. In the case of unglazed collectors the direction of the fluid flow may be recommended by the manufacturer.

L.3 Preconditioning of the collector

The fluid shall be inspected to ensure that it is clean.

The collector shall be vented of air by means of an air bleed valve or other suitable means, such as increasing the fluid flowrate for a short period to force air from the collector.

L.4 Test procedure

a) Glazed solar collectors

The pressure drop between the collector inlet and outlet connections shall be determined for flowrates which span the range likely to be used in real operation. In the absence of specific flowrate recommendations by the manufacturer, pressure drop measurements shall be made over the range of flowrates from 0,005 kgs^{-1} to 0,03 kgs^{-1} per square metre of collector area. The origin of the pressure drop diagram – the point (0,0) should be considered as well.

At least five measurements shall be made at values equally spaced over the flowrate range.

b) Unglazed solar collectors

The pressure drop between the collector inlet and outlet connections shall be determined with the collector and its fluid close to ambient air temperature, and for flowrates, which span the range likely to be used in the application for which the collector is intended.

Because the arrangement of the strips and the manifolds used in the test usually differs from typical installations, the pressure drop of a strip and of the manifolds shall be determined separately. This may be achieved by two consecutive pressure drop measurements of one short absorber strip including manifolds (at least 3 m) and one long absorber strip including manifolds (e.g. 15 m).

The difference of both pressure drop curves may then be divided by the difference of strip lengths between both absorbers. The resulting curve is the undisturbed pressure drop per meter strip.

The test should be carried out at a constant pressure which corresponds to the intended operating pressure.

In the absence of specific flowrate recommendations by the manufacturer, pressure drop measurements shall be made over the range of flowrates from 0,02 kgs^{-1} to 0,1 kgs^{-1} per square metre of collector area.

At least five measurements shall be made at values equally spaced over the flowrate range. The zero level shall be checked as well.

L.5 Measurements

The following data shall be measured in accordance with 6.1.2:

a) fluid temperature at the collector inlet;

b) fluid flowrate;

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.

L.6 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 fittings shall be used to correct the measured pressure drop of the collector.

L.7 Test conditions

The fluid flowrate shall be held constant to within ± 1 % of the nominal value during test measurements.

The inlet temperature of the heat transfer fluid shall be held constant to within ± 5 K (± 1 K for unglazed collectors) during test measurements. The test shall be carried out with the collector at a temperature which lies within ± 10 K of that of the surrounding air. Pressure drop tests at other temperatures may be important for oil-based heat transfer fluids.

L.8 Calculation and presentation of results

The pressure drop shall be presented graphically as a function of the fluid flowrate for each of the tests performed, using the format sheets given in Annex D (glazed collectors) or in Annex E (unglazed collectors).

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