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

Thermische Solaranlagen und ihre Bauteile - Kollektoren - Teil 2: Prüfverfahren (einschließlich Corrigendum EN 12975-2:2001/AC:2002)

Installations solaires thermiques et leurs composants - Capteurs - Partie 2: Méthodes d'essais

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

Installations solaires thermiques et leurs composants - Capteurs - Partie 2: Méthodes d'essais

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

This European Standard was approved by CEN on 19 January 2001.

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Although this (draft) European Standard has been developed in one language only in accordance with Resolution BT 74/1997 related to the one language experiment, it exists in accordance with the CEN/CENELEC Internal Regulations in the three official versions (English, French, German).

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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Foreword

This European Standard 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of an identical text or by endorsement, at the latest by December 2001, and conflicting national standards shall be withdrawn at the latest by December 2001.

The annexes A, B, C, D, E, F, G and H are normative. The annexes I, J, K, L, M, N and O are informative.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the 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-steady-state 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 is to check, 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 flow rate 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:

- A shorter and less expensive outdoor test, suitable for European climate conditions.
- A 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.
- The 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.
- The same test equipment can be used as for stationary testing with only minor changes, which also will 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 has Multiple Linear Regression (MLR) as an option.

An accurate long term prediction of the collector performance (not included in this standard) can be an integral part of this test method, as the same collector model and parameters can be used for both testing and prediction.

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 not basically not applicable to tracking concentrating collectors, however thermal performance testing as given in clause 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 have to 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 shall be at least $2m^2$.

2 References

This European Standard incorporates, by dated or undated reference, provisions from other publications. The normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

ISO 9060	Solar energy - Specification and classification of instruments for measuring hemispherical solar and direct solar radiation.
ISO 9806-1	Test methods for solar collectors – Part 1: Thermal performance of glazed liquid heating collectors including pressure drop.
ISO 9806-2	Test methods for solar collectors – Part 2: Qualification test procedures.
ISO 9806-3: 1995	Test methods for solar collectors - Part 3: Thermal performance of unglazed liquid heating collectors (sensible heat transfer only) including pressure drop.
ISO 9846	Solar energy - Calibration of a pyranometer using a pyrheliometer.
ISO 9847	Solar energy - Calibration of field pyranometers by comparison to a reference pyranometer.
ISO/TR 9901	Solar energy - Field pyranometers - Recommended practice for use.
EN ISO 9488	Solar Energy - Vocabulary (ISO 9488:1999)

EN 12975-1:2000	Thermal solar systems and components - Solar collectors - Part 1: General requirements

3 Terms and definitions

For the purpose of this standard, the Terms and definitions given in EN ISO 9488 apply.

4 Symbols and units

a_1	algebraic constant, reference to T^*_m	$Wm^{-2}K^{-1}$
a_2	algebraic constant, reference to T^*_m	$Wm^{-2}K^{-2}$
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_1	collector efficiency coefficient	$Wm^{-2}K^{-1}$
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 (λ >3µm)	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}
$G*$	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
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	K
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 uni-form 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_0	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 H)

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

5 Reliability testing of liquid heating collectors

5.1 General

The tests shall be carried out in the sequence shown in table 1. Changes in the test sequence, upon agreement of all parties involved or at discretion of the test laboratory, shall be reported with the test results and the reasons for deviation shall be given.

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.

NOTE This sequence has been determined with a view to minimise test costs while ensuring that the possible effects of each degrading influence are likely to be evaluated in a later test. (For example, rain penetration may result if a collector is distorted by exposure to high temperatures).

Table 1 - Test sequence

Sequence	Subclause	Test
1	5.2	Internal pressure
2	5.3	High-temperature resistance 1)
3	5.4	Exposure
4	5.5	External thermal shock 2)
5	5.6	Internal thermal shock 2)
6	5.7	Rain penetration 3)
7	5.8	Freeze resistance 4)
8	5.2	Internal pressure (retest)
9	5.9	Mechanical load
10	6.1-6.2-6.3	Thermal performance
11	5.10	Impact resistance
12	5.11	Final inspection

1) 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.

2) The two external and internal thermal shock tests may be combined with the exposure test or the high-temperature resistance test.

3) The rain penetration test shall be carried out only for glazed collectors.

4) The freeze resistance test shall be carried out only for collectors claimed to be freeze resistant.

5.2 Internal pressure tests for absorbers

5.2.1 Metallic 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 an accuracy better than 5%. The air-bleed valve shall be used to empty the absorber of air before pressurisation. The metallic 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

Metallic 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.

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.

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 an accuracy 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 an accuracy 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 an accuracy 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. One of its fluid pipes shall be sealed to prevent cooling by natural circulation of air, but the other shall be left open to permit free expansion of air in the absorber.

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 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 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 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 which 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. One of the fluid pipes shall be sealed to prevent cooling by natural circulation of air, while the other shall be left open to permit free expansion of air in the absorber.

The air temperature shall be recorded to an uncertainty of 1 K and the global irradiance on the plane of the collector recorded using a pyranometer of class I in accordance with ISO 9060. Irradiation and mean air temperature values shall be recorded every 30 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. 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. One of its fluid pipes shall be sealed to prevent cooling by natural circulation of air, while the other 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.