BS EN ISO 9806:2013

BSI Standards Publication

Solar energy — Solar thermal collectors — Test methods

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National foreword

This British Standard is the UK implementation of EN ISO 9806:2013. It supersedes BS EN 12975-2:2006 which is withdrawn.

Users should be aware that BS 5918:1989, Code of practice for solar heating systems for domestic hot water, is in the process of being revised. BS 5918 covers ad hoc assemblies out of scope of the BS EN 12976 series and the BS EN 12977 series of standards.

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

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

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Foreword

The text of ISO 9806:2013 has been prepared by Technical Committee ISO/TC 180 “Solar energy” of the International Organization for Standardization (ISO) and has been taken over as EN ISO 9806:2013 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of an identical text or by endorsement, at the latest by May 2014, and conflicting national standards shall be withdrawn at the latest by May 2014.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 12975-2:2006.

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

Endorsement notice

The text of ISO 9806:2013 has been approved by CEN as EN ISO 9806:2013 without any modification.

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Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 9806 was prepared by Technical Committee ISO/TC 180, *Solar energy*, and by Technical Committee CEN/TC 312, *Thermal solar systems and components* in collaboration.

This first edition cancels and replaces the first editions EN 12975-2:2006, ISO 9806-1:1994, ISO 9806-2:1995, and ISO 9806-3:1995, which have been technically revised.

Introduction

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

Collectors tested according to this International Standard represent a wide range of applications, e.g. tracking concentrating collectors for thermal power generation and process heat, glazed flat plate collectors and evacuated tube collectors for domestic water and space heating, unglazed collectors for heating swimming pools or other low temperature applications. Air heating collectors have been included in the scope of this International Standard. Similarly, collectors using external power sources for normal operation and/or safety purposes (overheating protection, environmental hazards, etc.) are also considered.

Solar energy — Solar thermal collectors — Test methods

1 Scope

This International Standard specifies test methods for assessing the durability, reliability and safety for fluid heating collectors.

This International Standard also includes test methods for the thermal performance characterization of fluid heating collectors, namely steady-state and quasi-dynamic thermal performance of glazed and unglazed liquid heating solar collectors and steady-state thermal performance of glazed and unglazed air heating solar collectors (open to ambient as well as closed loop).

This International Standard is also applicable to hybrid collectors generating heat and electric power. However it does not cover electrical safety or other specific properties related to electric power generation.

This International Standard is also applicable to collectors using external power sources for normal operation and/or safety purposes.

This International Standard 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.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

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

ISO 9488, *Solar energy — Vocabulary*

ASTM E330-02, *Standard Test method for Structural performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference*

EN 779, *Particulate air filters for general ventilation - Determination of the filtration performance*

EN 13142, *Ventilation for buildings - Components/products for residential ventilation - Required and optional performance characteristics*

EN 13779, *Ventilation for non-residential buildings - Performance requirements for ventilation and room-conditioning systems*

VDI 4670, *Thermodynamic properties of humid air and combustion gases*

3 Terms and definitions

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

3.1
longitudinal angle of incidence

angle between the normal to the plane of the collector and incident sun beam projected into the longitudinal plane

Note 1 to entry: Not applicable to point-focus collectors and central receivers.

3.2
longitudinal plane

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

3.3
maximum operating temperature

maximum temperature reached during collector or system normal operation, usually stated by the manufacturer

Note 1 to entry: Concentrating collector.

3.4
module

smallest unit that would function as a solar energy collection device

3.5
no-flow condition

condition that occurs when the heat transfer fluid does not flow through the collector array, due to shut-down or malfunction, and the collector is exposed to the same solar irradiance as under normal operating conditions

3.6
optical axis

symmetry line orthogonal to focal line and the plane of the collector in line-focus collectors

3.7
outgassing

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

3.8
peak efficiency

efficiency of the collector at a temperature difference (ϑ_m - ϑ_a = 0) based on normal incidence of solar radiation and either hemispherical or beam irradiance

3.9
peak power

power output of the collector at a temperature difference (ϑ_m - ϑ_a = 0) based on normal incidence of solar radiation and either hemispherical or specific combinations of beam and diffuse irradiance

3.10
passive

operating condition where no human or mechanical intervention is required for operation as intended

Note 1 to entry: Concentrating collector.

3.11
reflector or reflective surface

surface intended for the primary function of reflecting radiant energy

Note 1 to entry: Concentrating collector.

Note 2 to entry: It includes also the optional reconcentrator.

3.12
Simulated Roof
construction using materials of a quality typical to that used in roofs, from roof structure to roof coverings

3.13
transversal angle of incidence
angle between collector the normal to the plane of the collector and incident sun beam projected into the transversal plane

Note 1 to entry: Not applicable to point-focus collectors and central receivers.

3.14
transversal plane
plane defined by the normal to the plane of the collector and the line orthogonal to the concentrator axis, or the shortest symmetry line for flat biaxial geometries

3.15
trigger or safety activation temperature
temperature value at which the safety controls are activated for fail safe operating condition

Note 1 to entry: Concentrating collector.

4 Symbols and abbreviated terms

A_G	gross area of collector	m^2
AM	optical air mass	-
a_1	heat loss coefficient at $(\vartheta m - \vartheta a) = 0$	$W/(m^2 \cdot K)$
a_2	temperature dependence of the heat loss coefficient	$W/(m^2 \cdot K^2)$
B	“earth position” around the sun during the year 0-360 deg	degrees
b_u	collector efficiency coefficient (wind dependence)	s/m
b_0	constant for the calculation of the incident angle modifier	
b_1	heat loss coefficient at $(\vartheta m - \vartheta a) = 0$	$W/(m^2 \cdot K)$
b_2	wind dependence of the heat loss coefficient	$Ws/ (m^3 \cdot K)$
C	effective thermal capacity of collector	J/K
$\mathrm{C_R}$	Concentration ration	
c_1	heat loss coefficient at $(\vartheta m - \vartheta a) = 0$	$W/(m^2 \cdot K)$
c_2	temperature dependence of the heat loss coefficient	$W/(m^2 \cdot K^2)$
c_3	wind speed dependence of the heat loss coefficient	$J/(m^3 \cdot K)$
c_4	sky temperature dependence of the heat loss coefficient	-

c_5	effective thermal capacity	$J/(m^2 \cdot K)$
c_6	wind dependence in the zero loss efficiency	s/m
c_f	specific heat capacity of heat transfer fluid	$J/(kg \cdot K)$
$C_{f,I}$	specific heat capacity of heat transfer fluid at the collector inlet	$J/(kg \cdot K)$
$C_{f,e}$	specific heat capacity of heat transfer fluid at the collector outlet	$J/(kg \cdot K)$
$C_{f,a}$	specific heat capacity of the ambient air	$J/(kg \cdot K)$
D	date	YYMMDD
E	formula of time correcting for the eccentric path	minutes of the earth around the sun.
E_L	long wave irradiance ($\lambda > 3$ µm)	W/m^2
$E\beta$	long wave irradiance on an inclined surface outdoors	W/m^2
E_s	long wave irradiance	W/m^2
F	radiation view factor	
$F´$	collector efficiency factor	
G	hemispherical solar irradiance	W/m^2
G''	net irradiance	W/m^2
G_b	direct solar irradiance (beam irradiance)	W/m^2
G_d	diffuse solar irradiance	W/m^2
H	hemispherical irradiation on the collector plane	MJ/m^2
$h_{f,a}$	enthalpy of the air-water vapor mixture of the ambient air	J/kg
$h_{f,e}$	enthalpy of the air-water vapor mixture at the outlet of the air collector	J/kg
$h_{f,i}$	enthalpy of the air-water vapor mixture at the inlet of the air collector	J/kg
h_L	enthalpy of the leaking air-water vapor mixture	J/kg
$K_{\mathrm{hem}}(\theta_L,\theta_T)$	incidence angle modifier	-
$K_b(\theta_L,\theta_T)$	incidence angle modifier for direct radiation	-
$K_{\theta L,\, coll}$	incidence Angle Modifier along the coll. tubes or reflectors	-

$K_{\theta T,coll}$	incidence Angle Modifier perpendicular to collector tubes or reflectors	-
K_d	incidence angle modifier for diffuse radiation	-
m	thermally active mass of the collector	kg
$\dot{m}$	mass flow rate of heat transfer fluid	kg/s
$\dot{m}_\mathrm{min}$	minimum mass flow by the performance test	kg/h
$\dot{m}_\mathrm{max}$	maximum mass flow by the performance test	kg/h
$\dot{m}_{pe}$	downstream air mass flow rate	kg/s
$\dot{m}_{pi}$	upstream air mass flow rate	kg/s
$\dot{m}_{pl}$	leakage air mass flow rate	kg/s
$p_{f,e}$	static pressure of the heat transfer fluid (air) at the outlet to the solar collector	Pa
$p_{f,i}$	static pressure of the heat transfer fluid (air) at the inlet to the solar collector	Pa
P_{abs}	absolute pressure of the ambient air	Pa
$\dot{Q}$	useful power extracted from collector	W
$\dot{Q}_{peak}$	power output of the solar collector module for normal incidence, $G = 1000\ \mathrm{W/m^2}$ and ϑ_m-$\vartheta_\mathrm{a} = 0\ \mathrm{K}$	W
$\dot{Q}_t$	mean power output during one time step	W
$\dot{Q}\ /A_\mathrm{G}$	specific useful energy extracted from the collector	W/m^2
$\mathrm{Q_{module}}$	useful energy extracted from the collector, annual energy gain	kWh per module
$\dot{Q}_L$	power loss of collector	W
R_D	gas constant for water vapor	461,4 J/(kgK)
rH_{amb}	(relative)humidity of the ambient air	%

rH_e	(relative)humidity of the fluid (air) at the outlet of the solar collector	%
rH_i	(relative)humidity of the fluid (air) at the inlet of the solar collector	%
R_L	gas constant for air	287,1 J/(kgK)
T	absolute temperature	K
T^*_m	reduced temperature difference (= $(\vartheta_\mathrm{m} - \vartheta_\mathrm{a})/G$)	$\mathrm{m^2K/W}$
$\vartheta_\mathrm{m,max}$	maximum operating temperature as stated by the manufacturer	
T_s	atmospheric or equivalent sky radiation temperature	K
t	time	s
U	measured overall heat loss coefficient of collector with reference to T^*_m	$\mathrm{W/(m^2K)}$
U_L	overall heat loss coefficient of a collector with uniform absorber temperature ϑ_m	$\mathrm{W/(m^2K)}$
u	surrounding air speed	m/s
V_f	fluid capacity of the collector	$\mathrm{m^3}$
$\dot{V}_p$	volumetric flow	$\mathrm{m^3/s}$
$\dot{V}_{p,e}$	volumetric flow at the outlet of the solar collector	$\mathrm{m^3/s}$
$\dot{V}_{p,i}$	volumetric flow at the inlet of the solar collector	$\mathrm{m^3/s}$
$\dot{V}_{p,L}$	volumetric leakage flow rate	$\mathrm{m^3/s}$
$X_{W,a}$	water content of the ambient air	kg $\mathrm{H_2O}$/kg dry *air*
$X_{W,e}$	water content at the exit of the solar collector	kg $\mathrm{H_2O}$/kg dry air
$X_{W,i}$	water content at the inlet of the solar collector	kg $\mathrm{H_2O}$/kg dry air
α	solar absorptance	%
α_s	solar altitude angle	degrees
β	tilt angle of a plane with respect to horizontal	degrees
γ	collector azimuth angle (0 = south, east negative)	degrees

γ_s	solar azimuth angle (0 = south, east negative)	degrees
Δp	pressure difference between fluid inlet and outlet	Pa
Δt	time interval	s
ΔT	temperature difference between fluid outlet and inlet (ϑ_e - ϑ_{in})	K
δ	solar declination	degrees
ε	hemispherical emittance	%
η	collector efficiency, with reference to T^*_m	-
η_b	collector efficiency, with reference to T^*_m, based on beam irradiance G_b	-
η_{hem}	collector efficiency, with reference to T^*_m, based on hemispherical irradiance G	-
$\eta_{0,b}$	peak collector efficiency (η_b at T*m = 0), reference to T*m, based on beam irradiance Gb	-
$\eta_{0,hem}$	peak collector efficiency (η_{hem} at T*m = 0), reference to T*m, based on hemispherical irradiance G	-
$\eta_{\max,0m/s}$	maximum collector efficiency (at 0 m/s and one fixed mass flow rate)	-
η_m	collector efficiency, with reference to $\eta_{\max, 0\ m/s}$	-
θ	angle of incidence	degrees
$\theta_{T,def}$	reference angle in T-direction for determination of IAM. Normally = 0	degrees
$\theta_{L,def}$	reference angle in L-direction for determination of IAM. Normally = 0	degrees
θ_Z	solar zenith angle (= 90 - θH)	degrees
θ_{II} or θ_L	longitudinal angle of incidence	degrees
$\theta_\perp$ or θ_T	transversal angle of incidence	degrees
ϑ_a	ambient or surrounding air temperature	°C
ϑ_{dp}	atmospheric dew point temperature	°C
ϑ_e	collector outlet (exit) temperature	°C
ϑ_{in}	collector inlet temperature	°C

ϑ_{m}	mean temperature of heat transfer fluid	°C
ϑ_{max_op}	maximum operating temperature	°C
ϑ_{s}	atmospheric or sky temperature	°C
ϑ_{stg}	standard stagnation temperature	°C
$\vartheta_{trigger}$	trigger temperature for safety activation	°C
$\vartheta_{m,th}$	volume flow weighted mean temperature	°C
$\vartheta_{max,start}$	maximum starting temperature	°C
$\vartheta_{mp,e}$	fluid temperate at the downstream air mass flow meter	°C
$\vartheta_{mp,i}$	fluid temperate at the upstream air mass flow meter	°C
λ	wavelength	µm
ρ	density of heat transfer fluid	kg/m^3
ρ_l	density of air	kg/m^3
σ	Stefan-Boltzmann constant	$W/(m^2K^4)$
τ_{c}	collector time constant	s
τ	transmittance	
$(\tau\alpha)$	effective transmittance-absorptance product	-
Φ	latitude of collector and climate data location	degrees
ω	solar hour angle	degrees

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 Clause 26)

NOTE 3 For more information about thermal performance coefficients (parameters) c_1 to c_6, see B.1

NOTE 4 Collectors not intended for the generation of steam or super-heated water have maximum operating temperature $\vartheta_{\mathrm{m,max}} \leq 110$ °C.

5 General

5.1 Test overview - Sequence of the tests

For some qualification tests (Table 1), a part of the collector may have to be manipulated 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 rain tight collector.

Table 1 — Test list

Subclause	Test
6	Internal pressure test for fluid channels [f, g]
7	Leakage test [h]
8	Rupture and collapse test [h]
9	High-temperature resistance [a, b]
11	Exposure test [b]
12	External thermal shock test [c]
13	Internal thermal shock test [c]
14	Rain penetration test [d, h]
15	Freeze resistance test [e, h]
16	Mechanical load test [h]
17	Impact resistance test [i]
20	Thermal performance test [j]
28	Pressure drop measurement [h, l]
18	Final inspection [k]

a For organic absorbers, the high-temperature resistance test shall be performed before internal pressure test in order to determine the collector standard 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 Applicable only for liquid heating collectors.

g For fluid channels made of organic materials, a full exposure is required before the test, see Clause 11.

h Pre-exposure or full exposure is required before the test, see Clause 11.

i Pre-exposure or full exposure is required before the test if polymer cover, see Clause 11.

j Full exposure is required before the performance testing of heat pipe collectors.

k Every collector tested needs to undergo the final inspection.

l Mandatory only for air heating collectors.

5.2 Particular aspects of collectors using external power sources and active or passive measures for normal operation and self-protection

Collectors shall be tested in such a way that they shall be able to demonstrate suitable performance and ability to protect themselves from common failures due to conditions that can arise in standard operation.

The collector shall be assembled (if it is necessary) and its components shall operate according to manufacturer’s specifications. If the collector has active mechanisms which are intended to be functional during normal operation, those mechanisms shall be operational during testing. A tracking device, if it is present, shall be supplied by the collector manufacturer and shall be used during the tests. Concentrating collector designs which include a factory sealed container charged with refrigerant or other fluid used in the collection of heat shall be tested without the removal of this element.

The protection systems can be active, such as actuators, motors and other equipment, or passive, such as materials reacting to heat or other designs. The manufacturer shall clearly define the equipment protection features and shall specify whether or not the equipment requires an external energy source to operate.

The collector can present a combination of active and passive controls, and in that case the test sequence shall be selected to verify suitable operation of active and passive mechanisms during normal operating conditions.

6 Internal pressure tests for fluid channels

6.1 Inorganic fluid channels

6.1.1 Objective

The fluid channels shall be pressure-tested to assess the extent to which they can withstand the pressures which they might meet in service.

6.1.2 Apparatus and procedure

The apparatus 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 fluid channels of air before pressurization. The inorganic fluid channels shall be filled with water at room temperature and pressurized to the test pressure for the test period. This pressure shall be maintained while the fluid channels are inspected for swelling, distortion or ruptures.

6.1.3 Test conditions

Inorganic fluid channels shall be pressure-tested at ambient temperature within the range 5 °C to 40 °C, shielded from light. The test pressure shall be 1,5 times the maximum collector operating pressure specified by the manufacturer. The test pressure shall be maintained (±5 %) for 15 min.

6.2 Fluid channels made of organic materials (plastics or elastomers)

6.2.1 Objective

The fluid channels shall be pressure-tested 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 fluid channel may be adversely affected as its temperature is increased.

6.3 Apparatus and procedure

6.3.1 General

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

The test conditions specified in 6.3.4 shall be maintained for at least 30 min prior to the test and for the full duration of the test.

The pressure in the fluid channels shall be raised in stages as specified in 6.3.4. If possible the pressure should be maintained while the fluid channels are 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 6.3.2 and 6.3.3 shall be chosen.

6.3.2 Organic fluid channels - high temperature hydraulic pressure test

The fluid channels may be connected to a hot fluid circuit. The fluid channels and hot fluid circuit are then pressurized. Fluid channels may be heated by any of the following methods:

a) submerging the fluid channels in a heated water bath and pressure-tested. The pressurized 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 %.

b) connecting a heater in the liquid circuit (fluid needs to be in liquid phase);

c) heating the whole collector in a solar irradiance simulator;

d) heating the whole collector outdoors under natural solar irradiance.

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

6.3.3 Organic fluid channels - high temperature pneumatic pressure test

The fluid channels 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;

b) heating the whole collector outdoors under natural solar irradiance.

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

6.3.4 Test conditions

The test temperature shall be the maximum operation temperature specified by the manufacturer or the standard stagnation temperature whichever is greater, see Clause 10. The test pressure shall be 1,5 times the maximum collector operating pressure specified by the manufacturer. For fluid channels made of organic materials, the pressure shall be raised to the test pressure in equal steps (approximately five) and maintained at each intermediate pressure for 5 min. The test pressure shall be maintained for at least 1 h.

6.4 Results

The collector shall be inspected for leakage[1], swelling and distortion. Leakage can be assumed if pressure loss $\Delta P > 5\ \%$ of the test pressure or 17 kPa, whichever is greater. The results of this inspection shall be reported together with the values of pressure and temperature used and the duration of the test.

7 Leakage test (closed loop air heating collectors only)

7.1 Objective

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

7.2 Apparatus and procedure

The Leakage test can be realized with a volumetric flow meter, e.g. as shown in Figure 1 — Schematic of apparatus used for measuring air leakage in air collectors. Leakages resulting from other sources other than the test object shall be quantified and deducted from the collector test results.

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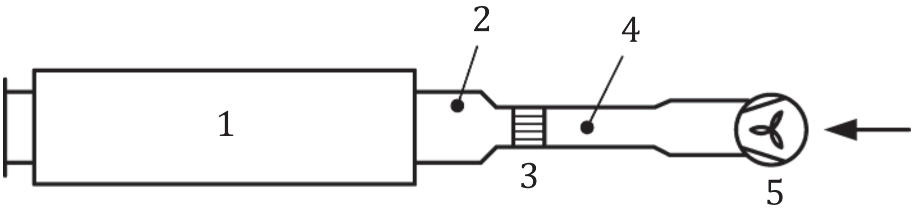
[1] In case of an air heating collector leakage is not defined as a problem. The leakage volumetric flow rate shall be determined according to Clause 7.



Key

1 Solar air heater
2 Pressure gauge
3 Flow meter
4 Temperature sensor
5 Fan

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

The collector shall be mounted with the air outlet sealed and the inlet connected to a volumetric air flow measurement as well as a variable speed fan. The pressure difference between inlet and ambient shall be measured with a differential pressure measurement device. The test consists of two parts, a positive and a negative leakage test. The test shall be performed with positive and negative pressure. The standard uncertainty shall be better than ± 2 % for volumetric air flow measurement and better than ± 10 Pa for the differential pressure measurement.

7.3 Test conditions

The test shall be done at ambient temperature without irradiance. Ambient temperature should not vary more than ± 5K during the test. At least four positive and four negative pressure values shall be realized. The maximum internal pressure shall be 1,5 times the maximum operating pressure specified by the manufacturer. The pressure shall be raised to the maximum test pressure in equal steps (approximately five). The test period for each step shall not be less than 10 min.

In the case of organic fluid channels it is recommended to repeat the test at maximum operation temperature specified by the manufacturer or standard stagnation temperature whichever is greater.

7.4 Results

The results shall be reported as in A.4.

8 Rupture or collapse test (air heating collectors only)

8.1 Objective

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

8.2 Apparatus and Procedure

8.2.1 General

The apparatus shall consist of a pneumatic pressure source, a means of measuring the pressure and a means of measuring the rate of air flow out of the collector. For collectors with organic materials (plastics or elastomers) in direct contact with the working fluid the tests shall be carried out at elevated temperatures and for this a means of heating the absorber to the required test temperature is also required.

The whole collector should then be heated using one of the following methods:

a) connecting a heater in the fluid circuit, and circulating hot air through the collector before the collector outlet is sealed

b) heating the whole collector in a solar irradiance simulator

c) heating the whole collector outdoors under natural solar irradiance

Appropriate safety measures shall be taken to protect personnel in the event of explosive failure during this test.

The basic apparatus can be similar or identical to that used for the air collector leakage test and the measurement accuracy shall fulfil the same requirements (see 7.2).

8.2.2 Closed-loop collectors

The collector shall be mounted the same as for the air collector leakage tests (see 7.2). The side wall aperture introduced for the purpose of the uniform load tests shall be sealed.

The procedure shall be as follows:

a) Seal the pressure gauge into the collector outlet port and connect the inlet port through the flow meter and pressure regulator to the air supply.

b) Ensure that the air supply is suitable for applying the appropriate positive or negative gauge pressure.

c) Set the pressure regulator to the ambient pressure and note the pressure gauge zero reading.

d) If the test is conducted at a temperature other than ambient temperature, then the collector shall be heated by one of the methods stated in 8.2.1.

e) Activate the air supply and open the regulator valve until a gauge pressure of 1,5 times the maximum (positive and/ or negative) collector operating pressure specified by the manufacturer is reached and maintain it for 10 min.

f) Inspect the collector and record any evidence of structural damage.

g) Note the flow rate meter indicator.

h) Allow the pressure to return to ambient.

i) Note the final reading of the pressure gauge.

8.2.3 Open to ambient collectors

The procedure shall be as follows:

a) Connect the outlet port of the collector to a suitable air extraction system. Provide a pressure tap at the outlet port of the collector to measure pressure at the collector outlet relative to atmospheric pressure. The outlet pressure tap shall be located as shown in Figure 8 Example of an open test loop of 23.2.3.

b) Ensure that the air supply is suitable for applying the required test flow rate.

c) If the test is conducted at a temperature other than ambient temperature, then the collector shall be heated by one of the methods stated in 8.2.1.

d) With no air flow through the collector, note the pressure gauge zero reading.

e) Activate the air supply and increase it until 1,5 times the maximum flow rate specified by the manufacturer is reached over a period of not less than 15 s. The collector will be tested in the normal use configuration, with air at atmospheric pressure being drawn into the collector.

f) The air flow shall be maintained for no less than 10 min. At the end of 10 min, while maintaining air flow rate, inspect the collector and record any evidence of distortion or collapse.

g) Allow the air flow to return to zero.

h) Note the final reading of the pressure gauge.

i) Inspect the collector for collapse, distortion, and permanent displacement of the collector components.

8.3 Test conditions

8.3.1 Temperature

Collectors with organic materials (plastics or elastomers) in direct contact with the working fluid shall be tested at the maximum temperature that the absorber reaches under the following conditions:

a) the solar collector manufacturer’s recommended minimum air flow rate;

b) 1 000 W/m^2; and

c) 30 °C ambient air temperature.

All other air heating solar collectors shall be tested at ambient temperature.

8.4 Results and reporting

The results shall be reported as required in A.5.

9 High-temperature resistance test

9.1 Objective

This test is intended to assess rapidly whether a collector can withstand high temperature and 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 or any other effect that possibly could lead to reduced performance, lifetime, safety or distorted visual appearance of the collector.

Direct heating solar air collectors should respect the requirements concerning components for ventilation in EN 13779 and EN 13142.

9.2 Apparatus and procedure

The collector shall be tested outdoors, or in a solar irradiance simulator.

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 fluid heating solar collectors.

The collector shall be mounted outdoors or in a solar simulator. Liquid heating collectors shall not be filled with fluid. In case of liquid heating collectors 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 in the hottest region of the absorber. The location shall be reported with the results. In case of liquid flat plate collectors the hottest region can be assumed 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.

In case of collectors using external power sources and active or passive measures for normal operation and self-protection, high temperature resistance test shall be carried out during the exposure test. If controls are present to manage both a no-flow and high temperature condition, the collector shall be filled with heat transfer fluid according to the procedure described in 28.3 and operated as intended. If the function is ok, it should not be able to reach stagnation conditions. In that case the controls shall be checked and the collector shall operate close to the maximum operating temperature defined by the manufacturer (below control system trigger temperature). In the test report specifications must be given for the flow rate, fluid temperature, and duration of flow.

When testing collectors, such as evacuated tubular collectors, for which it is not appropriate to measure the standard 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.

In some cases, such as evacuated collectors, it may be difficult to attach a temperature sensor to the absorber. In such cases, instead of attaching a temperature sensor to the absorber, the testing laboratory may partially fill the absorber with a suitable 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 vapor pressure/temperature relationship for the fluid. Alternatively the absorber temperature of a heat pipe tubular collector may reasonably be measured by affixing a temperature sensor to the condenser during assembly.

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

In case of a solar air heating collector, the mass flow rate for the measurement of the maximum starting temperature shall be same as the smallest one applied in the collector thermal efficiency test.

The test shall be performed for a minimum of 1 h after steady-state conditions have been established (steady-state conditions can be assumed for absorber temperatures changes of less than ± 5 K), and the collector shall be subsequently inspected for signs of damage as specified in Clause 18.

9.3 Test conditions

The set of reference conditions given in Table 2 or conditions resulting in the same or higher collector temperature than standard stagnation temperature according to Clause 10 shall be used for all climate classes (see Table 4).

Table 2 — Climate reference conditions for high-temperature resistance test

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

When testing unglazed collectors without backside insulation, the collector shall be mounted onto a dark surface ($\alpha > 80$ %) to rise maximum temperatures as worst case condition.

9.4 Results

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

The results of the inspection shall be recorded as in A.6 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 suitable fluid in the absorber, if that method is used) recorded during the test. Control functions which have been verified shall be described and reported with the test results.

For solar air heating collectors, the maximum start temperature at the collector outlet shall be measured and reported.

10 Standard stagnation temperature of liquid heating collectors

10.1 General

This Clause provides methods for determining the standard stagnation temperature of a collector, i.e. the temperature of the collector during periods of no useful heat removal from the collector with high solar radiation and ambient surrounding temperatures. These methods are used to check, that standard stagnation temperature at collector label and in installer instruction manual is higher than determined standard stagnation temperature.

Standard stagnation temperature given by the manufacturer should be given in an up-rounded 10° resolution

The standard stagnation temperature should be determined for a selected solar irradiance *G*s and a selected ambient temperature ϑas.

The determined standard stagnation temperature is used in the following tests:

- internal pressure testing of collectors with organic absorbers (see 6.2);
- high-temperature resistance test using a hot fluid loop (see 9.2).

For different kind of collectors different methods for determination of standard stagnation temperature are appropriate. Table 3 gives an overview:

Table 3 — Guide to standard stagnation temperature determination method

Collector type		10.2	10.3
Flat plate collector	Inorganic absorber	X	X
	Organic absorber	X	X
Evacuated tube collector	Heat pipe	X	X
	Direct flow	X	X

For collectors with organic absorbers the internal pressure test is done at standard stagnation temperature.

10.2 Measurement and extrapolation of standard stagnation temperature

The standard stagnation temperature ϑ_{stg}, for the selected values of solar irradiance G_S and ambient temperature ϑ_{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 ϑ_{am};
- absorber temperature ϑ_{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 standard stagnation temperature for the selected parameters (G_S and ϑ_{as}) is:

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

It is based on the approximation that the ratio $(\vartheta_{sm} - \vartheta_{am})/G_m$ 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).

For flat plate collectors the temperature 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.

For evacuated tubular collectors the temperature sensor should be placed at a suitable location in the collector i.e. where the highest temperature relevant to the heat transfer fluid is to be found.

10.3 Determining standard stagnation temperature using efficiency parameters

The thermal performance of the liquid heating collector is used in order to calculate its standard stagnation temperature. If the thermal performance of the collector is not known, it shall be determined by testing the collector accordingly.

The second-order formula for the instantaneous thermal efficiency of the collector should be used for determining the standard stagnation temperature:

$$\eta = \eta_0 - a_1 T_m^* - a_2 G \left(T_m^*\right)^2 \tag{2}$$

It should be noted that the reduced temperature difference $T_m{}^*$ is defined by the mean temperature of the heat transfer fluid (t_m). The instantaneous efficiency is based the gross area A. Two different sets of constants η_0, a_1 and a_2 may be available to express the instantaneous efficiency of the collector.

The standard stagnation temperature for the selected irradiance G_S and ambient temperature ϑ_{as} is calculated by the following formula:

$$\vartheta_{stg} = \vartheta_{as} + \frac{-a_1 + \left(a_1^2 + 4\,\eta_0\, a_2\, G_s\right)^{1/2}}{2\,a_2} + 20\,°\mathrm{C} \tag{3}$$

where any available set of constants η_0, a_1 and a_2 can be used.

This approach involves extrapolating the collector efficiency formula to the stagnation condition. Hence it is essential that the efficiency formula is valid up to η approximately 0. To ensure this, the collector efficiency formula evaluation should include test data at $T_m{}^*$ values approaching $T_m{}^*{}_{stagnation}$. If all the efficiency test data were evaluated at $T_m{}^*$ values less than $T_m{}^*{}_{stagnation}/2$, then 10.2 should be used to determine ϑ_{stg}.

NOTE Measurements of performance are done at higher wind speed than in stagnation conditions. 20 °C are added to compensate the higher wind speed.

10.4 Results

The results of the stagnation measurement shall be reported as required in A.6.4.

11 Exposure and pre-exposure test

11.1 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. For the latter purpose a pre-exposure test sequence with approximately half the duration of the full exposure test is defined. Which of these two sequences that shall or can be applied prior to a specific qualification test is explained in Table 1.

11.2 Apparatus and procedure

The collector shall be mounted outdoors, but not filled with fluid (in case of liquid heating collector), unless controls are used to manage both a no-flow and high temperature condition according to the manufacturer’s instructions. In that case, collectors shall be filled with the heat transfer fluid and such controls shall be verified. Collector designs which include a factory sealed container charged with refrigerants or other fluid used in the collection of heat shall be tested without heat transfer fluid flowing through them unless controls are used for over temperature protection. In case of liquid heating collectors all of the fluid pipes shall be sealed to prevent cooling by natural circulation of air. In case of solar air heaters all fluid pipes shall be sealed. One shall be left open to permit free expansion of air in the absorber. All components and subsystems, as they have been designed by the manufacturer and described in the operation manual, shall be validated to be functional during the exposure period. If the collector includes active systems to protect itself, these protections shall be active and operational during the exposure test.

The ambient 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. The collector shall be exposed until the test conditions have been met.

At least once a week, collectors shall be subjected to visual inspection and any signs of damage as specified in 11.4 or change in the physical appearance shall be registered and reported with the test results.

When testing unglazed collectors without backside insulation, the collector shall be mounted onto a dark surface ($\alpha > 80$ %) in order to rise maximum temperatures as during worst case conditions.

11.3 Test conditions

The set of reference conditions given in Table 4 shall be used. The class according to which the collector is to be tested is defined by the collector manufacturer.

The collector shall be exposed until at least 30 days (or 15 days for pre-exposure) have passed and the minimum irradiation H shown in Table 4 is reached. The irradiation is determined by recording irradiance measurements using a pyranometer.

The collector shall also be exposed for at least 30 h (15 h for pre-exposure) to the minimum irradiance level G given in Table 4 , as recorded by a pyranometer, when the ambient air temperature is greater than the value shown in Table 4 or conditions resulting in the same collector temperature according to Clause 10. These hours shall be made up of periods of at least 30 min.

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

Climate condition	**Value for climate class**		
	Class C **Temperate**	**Class B** **Sunny**	**Class A** **Very Sunny**
Hemispherical solar irradiance on collector plane during minimum 30 hours (or 15 hours in case of pre-exposure), G in W/m^2/minimum ambient temperature, ϑa in °C	800/10	900/15	1000/20
Irradiation on collector plane for exposure test during minimum 30 days, H in MJ/m^2	420	540	600
Irradiation on collector plane for pre-exposure sequence during minimum 15 days, H in MJ/m^2	210	270	300
Values given are minimum values for testing. The same class shall be applied for irradiance and for irradiation values respectively.			

Indoor exposure using a solar simulator may be applied to reach the 30 or 15 hours and/or the irradiation once the 30 or 15 outdoor days have been reached. It should not consist of cycles of more than 8 h. If a cycle takes more than 8 h, just 8 h are counted. A minimum of 4 h shall be passed in between each cycle to cool down the collector to close to ambient temperature.

11.3.1 Additional test conditions for active and passive controls

The manufacturer shall identify all active and passive controls which are present in the collector for protection purposes such as controls, motors, actuators or other elements. The manufacturer shall submit to the laboratories their control set points and parameters in order to verify their suitable operation during normal working conditions in which events as over temperature, wind, etc. can affect the collector lifetime and its performance.

The laboratory shall establish a test cycle in which all active and/or passive controls (if they are present) which are necessary to keep the collector in working order can be verified during the exposure period. Their operation shall be validated to be functional, in such a way that any failure can be detected. The test cycle shall include as events, the loss of electrical supply and the blockage of tracking mechanism (if it is present). The laboratory shall check the collector response and its ability to overcome (or not) such events.

In the test report specifications must be given for flow rate, fluid temperature, and duration of flow if a fluid flow is applied in the test.

11.4 Results

The resultsof the inspection shall be reported as required in A.7.

12 External thermal shock test

12.1 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.

12.2 Apparatus and procedure

The collector shall be mounted either outdoors or in a solar irradiance simulator. Liquid heating collectors shall not be filled with fluid. In case of liquid heating collectors all of the fluid pipes shall be sealed to prevent cooling by natural circulation of air. In case of solar air heaters all fluid pipes shall be sealed. One shall be left open to permit free expansion of air in the absorber. In case of an air heating collector the inlet and outlet shall resist water penetration.

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

The collector shall be exposed to climatic conditions as described in Table 4 (class specified by the manufacturer) for a period of 1 h before the water spray. It is then cooled by the water spray for 15 min before being inspected.

The collector shall be subjected to two external thermal shocks.

12.3 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 ϑa greater than the value shown in Table 4 .

Or conditions resulting in the same collector temperature according to Clause 10.

The water spray shall have a temperature of less than 25 °C and a flow rate in the range 0,03 kg/s to 0,05 kg/s per square meter of collector gross area.

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.

12.4 Results

The results shall be reported as required in A.8.

13 Internal thermal shock test

13.1 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.

13.2 Apparatus and procedure

The collector shall be mounted either outdoors or in a solar irradiance simulator. Liquid heating collectors shall not be filled with fluid. 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.

The collector shall be exposed to climatic conditions as described in Table 4 (class specified by the manufacturer) for a period of 1 h before it is cooled by supplying it with heat transfer fluid for at least 5 min.

The collector shall be subjected to two internal thermal shocks.

This test is not applicable to those parts of the collector which are factory sealed. It is not applicable to those collectors in which heat transfer fluid is continuously flowing for protection purposes. In that case control(s) used to manage a no-flow condition shall be validated to be functional in such a way that any failure can be detected.

13.3 Test conditions

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 - ambient air temperature ϑ_a greater than the value shown in Table 4 .

or conditions resulting in the same collector temperature according to Clause 10.

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

13.4 Results

The results shall be reported as required in A.9.

14 Rain penetration test

14.1 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.

When testing a concentrating collector a procedure comparable to this should be followed.

14.2 Apparatus and procedure

The collector shall be installed 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 (see Figure 2 — Positioning of collector and spray nozzles for rain penetration test). 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 with water at a temperature lower than 30 °C. The duration of the spraying process shall be at least 4 h. During the spraying process the absorber shall be kept warm. This shall be done by circulating hot fluid at 55 °C (±5 K) through the absorber.

If the detection of ingress of water by final inspection is chosen (Clause 18), the collector shall be left at the test rig for rain penetration for at least 4 h after the end of spraying, without heating the absorber. After that the collector shall be stored in such a way that the results are not influenced until the detection of ingress of water has been carried out. The detection of ingress of water by final inspection shall be done within at least 4 h and at most 48 h after the end of spraying. If the weighing method is chosen, the collector shall be weighted between 4 – 5 h after the spraying process. Unnecessary transportation of the collector should be avoided.

In case of rain penetration test outdoor the collector should be shaded to keep temperature of absorber at about 55 °C.

The penetration of water into the collector shall be determined by final inspection or by weighing the collector.

If the weighing method results in failure judgment, the final inspection shall be done for final assessment of the result.

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 three weights shall not vary by more than ± 5 g/m^2 collector gross area. After the spraying process the collector shall be weighted again on three consecutive occasions. Again the three weights shall not vary by more than ± 5 g/m^2 collector gross area. The determined water quantity shall be less than 30 g/m^2 collector gross area. The standard uncertainty of the scale shall be better than 5 g/m^2 collector gross area.

During final inspection (according to Clause 18) the collector shall be inspected with focus on the following criteria:

- Water inside the casing
- Wet insulation (more than 10 ml coming out by squeezing insulation)
- Visible trace of water drops running down (cover, absorber, casing)

When testing evacuated tubular collectors the fixing devices of evacuated tubes should be checked if they are designed for draining of water.

For the weighing method it is essential to dry and clean the outside of the collector before and after the spraying process. If a compressor is used this should be done in a way not to move water into or out of collector casing.

14.3 Test conditions

The water pressure shall be maintained at 300 kPa (±50 kPa). The spray heads required are specified as followed:

- full cone spray nozzles
- mass flow of 2 kg/min (±0,5 kg/min) per nozzle,
- spray angle of 60° ± 5°.

If drop size is defined in data sheets of spray nozzle it should be at least 150 µm.

The positioning of the spray nozzles shall be done according to Figure 2 — Positioning of collector and spray nozzles for rain penetration test, i.e.:

—- every corner of the casing shall be sprayed directly

— every area shown in Figure 3 — Spraying areas of flat plate collectors (including middle bar) and Figure 4 — Spraying areas of evacuated tube collectors and should be sprayed.

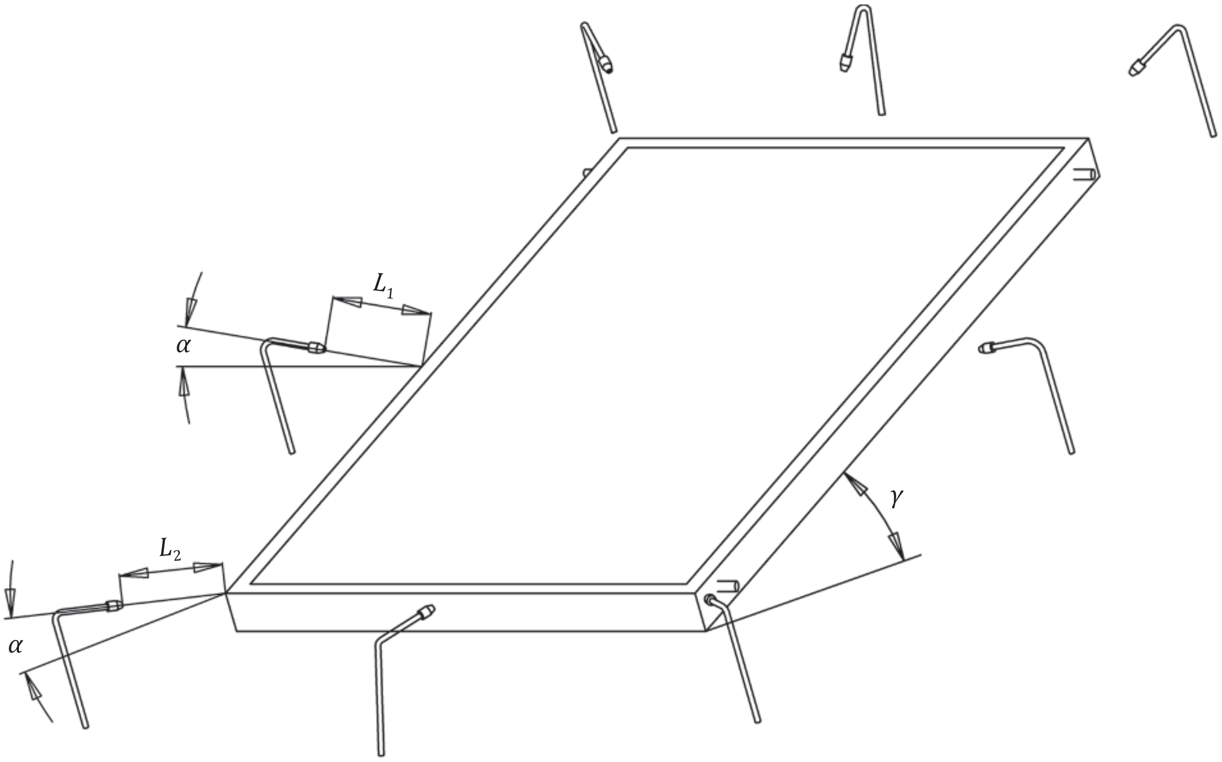
— spray heads shall also be positioned at the side of the collector if the corner nozzles are further apart than the maximum distance of 150 cm.

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

— the spray heads shall be located at a distance of 250 mm (±50 mm) from the corners and 250 – 400 mm from the sides of the collector (see Figure 2 — Positioning of collector and spray nozzles for rain penetration test).

— the maximum distance between two spraying nozzles shall be 150 cm

Middle bars should be sprayed from spraying heads above with a distance of 400 to 600 mm, the angle of 30° is not required.



Key

- L_1 250 – 400 mm
- L_2 250 mm
- α 30° angle of spray nozzle with respect to the collector surface
- γ smallest tilt angle to the horizontal recommended by the manufacturer, if this angle is not specified use 30°

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

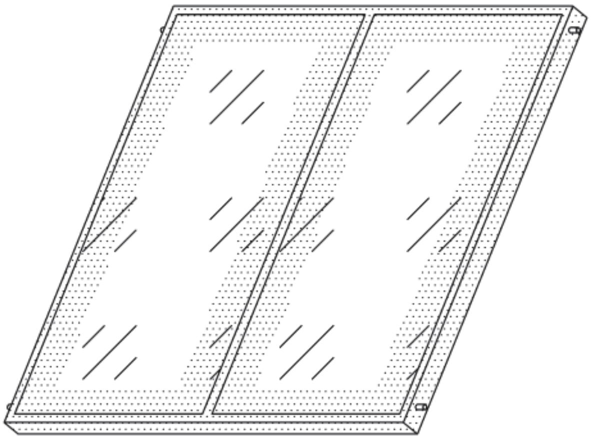


Figure 3 — Spraying areas of flat plate collectors (including middle bar)

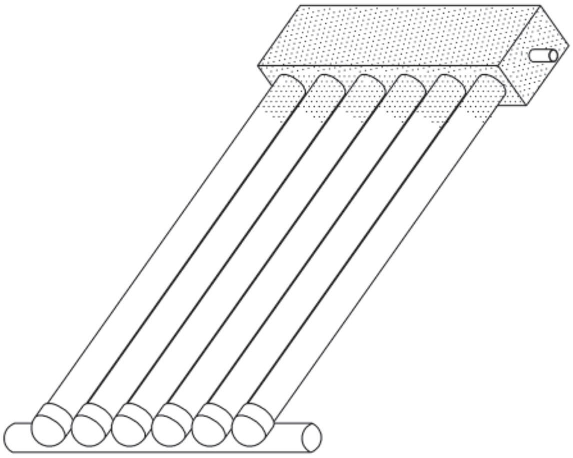


Figure 4 — Spraying areas of evacuated tube collectors

14.4 Results

The results shall be reported as required in A.10.

15 Freeze resistance test

15.1 Objective

This test is not applicable to collectors for which it is clearly stated in the installation manual that they may only be used with an antifreeze fluid or air. Neither is it to be used where special means are used to prevent water in a permanently filled collector loop from freezing e.g. by antifreeze algorithm unless additional liquids with the risk of freezing are used as e.g. in many heat pipes.

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.

15.2 Apparatus and procedure

15.2.1 General

The collector shall be mounted in a cold chamber. The collector shall be fitted correctly, shut completely and inclined at the smallest tilt angle to the horizontal recommended by the manufacturer. If no angle is specified by the manufacturer, 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.

15.2.2 Freeze-resistant collectors

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.

15.2.3 Collectors with drain-down protection

The collector shall be 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, no test in cold chamber is required. 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.

15.3 Test conditions

The water contents of the absorber or the heat pipe 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.

15.4 Results

The results shall be reported as required in A.11.

16 Mechanical load test with positive or negative pressure

16.1 Objectives

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

The mechanical load test with negative pressure is intended to assess the deformation and the extent to which the collector box and the fixings between the collector cover, collector box and collector mounting are able to resist uplift forces caused by the wind.

16.2 Apparatus and procedure

16.2.1 Mechanical load test with positive pressure

For the mechanical load test with positive pressure the collector shall be fixed on a stiff even ground using the manufacturers original equipment for mounting. Different methodologies may be used to apply load to the collector. If weight of material is used the collector shall be placed horizontally.

NOTE The collector mounting comprises the equipment to connect the collector fixings with the supporting framework (e.g. roof anchor, roof hook). The collector fixing comprises the equipment to connect the collector box/frame with the collector mounting equipment (e.g. clamps, bolts).

- Using a foil and gravel or water:

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. 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.

- Using suction cups:

The test can also be carried out using suction cups. The suction cups shall be distributed as even as possible on the collectors surface. The suction cups shall not hinder the movement of the collector cover caused by the mechanical load.

- Using air pressure on the collector cover:

If sealing towards the ambient is necessary, the sealing shall not hinder the movement induced by the load in any way.

16.2.2 Mechanical load test with negative pressure

For the mechanical load test with negative pressure the collector can be placed horizontally and the manufacturers' original equipment for mounting shall be used. Different methodologies may be used to apply load to the collector.

A lifting force which is equivalent to the specified negative pressure load shall be applied evenly over the cover or the tubes. If the cover has not been loosened, or any other failure which could be defined as major, 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 stabilize.

- Method (a): The load may be applied to the collector cover by means of a uniformly distributed set of suction cups.
- 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. Two holes are made through the collector box into the air gap between the collector cover and absorber, and an air source and pressure gauge are connected to the collector air gap through these holes. A negative pressure on the cover is created by pressurizing 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.
- Method (c): For evacuated tubular collectors ropes, belts or other appropriate equipment to distribute the forces along the tubes can be used.
- Method (d): For evacuated tubular and flat plate collectors the method according to ASTM E330-02 using air pressure can be applied.

Where flashings or sealing kits that are an integral part of the collector provide any uplift resistance, they should be included in the test.

16.2.3 Particular specifications for concentrating collectors

As concentrating collectors have different geometries, the laboratory may design specific and suitable procedures to test resistance against mechanical load. This circumstance and the procedure carried out shall be clearly described with the test results. When according to the manufacturer's instructions, controls are present to protect the collectors against wind or snow load, the control functions shall be checked, if it is possible, and they shall demonstrate resistance to failures associated with normal collector operation.

16.3 Test conditions

The test pressure shall be 2400 Pa (positive and negative) or as specified by the manufacturer. The reference area to be used is the gross area of the collector.

A permanent deformation should be assigned to a load value, while it is completely relieved after every load increment and the distortion is measured compared to the beginning of the test sequence.

16.4 Results

The results shall be reported as required in A.12.

17 Impact resistance test

17.1 Objective

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

17.2 Test procedure

Two test methods are available. The first one uses ice balls, the second one steel balls. The test method to be applied shall be chosen by the manufacturer.

The test procedure consists in a succession of shot series on the collector. Each shot series consists in 4 shots of the same impact strength. For ice balls the impact strength of a shot is determined by the ball diameter and velocity according to Table 5. For steel balls the impact strength of the shot is determined by the height of drop according to 17.5.

Balls of increasing impact strength shall be used in the successive shot series.

For the first shot series the smallest ice ball diameter specified by the manufacturer or the lowest height of drop specified by the manufacturer for the steel ball shall be used.

The last shot series shall be the one with the ice ball diameter or the steel ball height of drop specified by the manufacturer, unless the collector has to be considered as destroyed before this shot series could be performed.

Impact locations shall be selected according to 17.3. For each impact location the point of impact shall be moved by a few millimetres from all previous points of impact, while maintaining the shot direction normal to the collector surface at this location.

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

17.3 Impact location

a) Glazed flat plate collectors:

The points of impact shall be located 75 mm from each of two intersecting edges of the glazing, or absorber surface, as appropriate. For each shot of one specific ice ball diameter or test height a different corner shall be chosen.

b) Unglazed flat plate collectors:

For the selection of the points of impact the same rules as for glazed flat plate collectors applies. Unglazed collectors shall be filled with a fluid at atmospheric pressure.

c) Evacuated tube collectors:

For each ice ball diameter or height of drop, one randomly chosen tube of the collector shall be tested. The points of impact shall be located at 75 mm from each end and the shot direction shall be normal to the tube axis. The tube shall be hit twice at the upper end and twice at the lower end.

d) Collectors that cannot be clearly classified into the category a), b) or c):

Two representative impact locations shall be defined by the testing laboratory. Both impact locations shall be shot twice. The coordinates of the points of impact shall be defined before the shots.

17.4 Method 1: Impact resistance test using ice balls

17.4.1 Apparatus

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

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

c) A balance to determine the mass of an ice ball to a standard uncertainty of ± 2 %.

d) A launcher capable of propelling an ice ball as defined in 17.4.2.

e) An instrument for measuring the velocity of the ice ball to a standard uncertainty of ± 2 m/s. The distance of the velocity sensor to the collector surface shall be at maximum 1 m.

17.4.2 Ice balls

The ice balls shall be made of demineralized water without any additive. They shall consist in clear ice entirely free of air bubbles and shall not have any crack visible to an unaided eye. The ball diameter shall be one of those listed in Table 5. The ice balls used for the shots shall have a temperature of −4 °C ± 2 °C.

Table 5 — Ice ball masses and test velocities

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

17.4.3 Specific aspects of the test procedure using ice balls

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

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

c) Fire a number of trial shots at a simulated target in accordance with step e) 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 relevant hailstone test velocity given in Table 5 .

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

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

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

17.5 Method 2: Impact resistance test using steel balls

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

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

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

17.6 Results

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

18 Final inspection (related to Clauses 5 to 17)

When the tests have been completed, and the same collector is not going to be used for the performance test, the collector used for the test shall be dismantled and inspected. All abnormalities shall be documented and accompanied by photographs. The collector and all of its components shall be described and should be photographed (glazing, absorber, absorber coating, insulation, housing, inlet and outlet ports, glazing supports and retainers, seals, gaskets, back sheet, etc.).

Specific assessment criteria for each of the tests listed in Table 1 of 5.1 are listed in the respective test paragraphs. The term "no major failure", denotes that none of the following occurs:

- Fluid channel leakage (in case of liquid heating collectors only) or such deformation that permanent contact between absorber and cover is established;
- Breaking or permanent deformation of cover or cover fixing;
- Breaking or permanent deformation of collector fixing points or collector box;
- Vacuum loss, such that vacuum or sub atmospheric collectors shall be classified according to the definition in ISO 9488 (only applicable for vacuum and sub atmospheric collectors);
- Accumulation of humidity in form of condensate on the inside of the transparent cover of the collector exceeding 10 % of the visible transparent cover area. In case of an open loop air heating collector for limited periods of time this criterion maybe exceeded.
- Any other abnormality resulting in a significant reduction of performance or service life time.

The evaluation of accumulation of humidity for application of the pass criteria should be applied only on the following test:

- External Thermal Shock
- Rain Penetration Test

19 Test report (related to Clauses 5 to 18)

The format sheets given in Annex A shall be completed for each test, together with the introductory format sheet A.2 reporting a summary of main results, including the test methods.

20 Performance testing of fluid heating collectors

20.1 General

Performance testing includes the assessment of the heat power delivered by the collector under various operating conditions as well as the assessment of additional collector parameters (pressure drop, incident angle modifier, heat capacity, time constant) required for the calculation of the collector heat output.

For hybrid collectors generating heat and electric power, the operation mode of the electricity generator (MPP tracked, open or short circuit) could have a major influence on the thermal performance and need to be mentioned within the report. If the absorber of the hybrid collector is close connected to the electricity generator and if there is no extra glazing in front, this collector shall be treated as unglazed. During thermal performance testing, the electricity generator shall be maintained within 15 % of the module's maximum power point (MPP) if operated in MPP mode.

20.2 Steady-state efficiency test using a solar irradiance simulator

20.2.1 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 gross area.

20.2.2 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 gross area of at least 700 W/m^2. Values in the range 300 W/m^2 to 1000 W/m^2 may also be used for specialized tests, provided that the accuracy requirements given in Table 9 can be achieved and the irradiance values are noted in the test report.

At any time the irradiance at a point on the collector gross area shall not differ from the mean irradiance over the gross area 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 (τα) product for the collector. If the effective values of (τα) 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.

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

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

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 22.2).

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

The 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 1 Additional requirements concerning collimation apply to measurement of the incident angle modifier (see 27.1.2)

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.

20.2.3 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.

21 Collector mounting and location

21.1 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 21.2 to 21.8.

Tracking concentrating collectors shall be tested using the tracking device specified by the manufacturer.

21.2 Collector frame

21.2.1 General

The collector shall be mounted in the manner specified by the manufacturer. The collector mounting frame shall in no way obstruct irradiance on 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.

21.2.2 Air heating collectors/unglazed collectors

21.2.2.1 General

Collectors designed to be mounted directly on standard roofing or wall material may be mounted over a simulated roof or wall section. In case of building envelope integrated collectors, a model consisting of a small scale collector placed on an artificial roof/ wall 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 W/(m^2·K) ± 0,3 W/(m^2·K) 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 performance of some forms of solar air heating collectors and unglazed collectors is a function of module size. If the collector is supplied in fixed units of area smaller than 1 m^2 then a sufficient number of modules should be linked together to give a test system gross area of at least 3 m^2. The biggest possible test sample size should be chosen.

21.2.2.2 Unglazed collectors

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.

NOTE 1 In general the collectors are put together on-site, connecting absorber strips with manifolds. Real absorber areas are mostly between 10 to one hundred square meters.

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

NOTE 2 For linear tracking collectors like parabolic trough collectors this can be easily achieved with an east–west orientation which enables testing of the incidence angle modifier for all angles within one day.

21.3 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. Air collectors may be tested at tilt angles, as recommended by manufacturers or specified for actual installations. Otherwise the collector shall be tested at tilt angles such that the incidence angle modifier varies by less than 2 % from its value at normal incidence.

NOTE 1 For single glazed flat plate collectors, this condition will usually be satisfied if the angle of incidence of direct solar radiation at the collector area is less than 20°.

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 2 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.

NOTE 3 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.

21.4 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. Tracking concentrating collectors shall be mounted in a way that enables performance testing up to incidence angles of 60°.

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 area. Larger deviations from south may be acceptable, but will lead to a non-symmetrical angular distribution of beam radiation in Figure 10. 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 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.

The thermal performance could be influenced by the tilt angle. This should be taken into account during testing.

21.5 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.

21.6 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 dark (low reflectance) paint. The solar reflectance of the background used during the performance test of collectors being non-opaque from the back shall not exceed 20 %. The solar reflectance of the background used shall be reported in the test report.

21.7 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 W/m^2 (typically −100 W/m^2 for outdoor conditions).

21.8 Surrounding air speed

21.8.1 General

The performance of many collectors is sensitive to surrounding 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 front side, shall be between the limits specified in 24.4. Where necessary, artificial wind generators shall be used to achieve these air speeds. Collectors designed for integration into a building envelope may have their backs protected from the wind; if so, this shall be reported with the test results.

21.8.2 Air heating collector

In cases where the heat transfer fluid is in contact with the transparent cover sheet variable surrounding air speed shall be used for testing. Orientation can be taken from 24.5.4, Table 7.

21.8.3 Unglazed collectors

The average surrounding air speed at a distance of 100 mm above and parallel to the collector front side shall cover the range 0 m/s to 3,5 m/s 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 linearized hot wire anemometer or other appropriate equipment having a frequency response of at least 100 Hz. The turbulence level is defined as the standard deviation of air velocity divided by the average air velocity.

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.

If a wind generator is used the performance of an unglazed collector should be cross checked with artificial generated wind and with natural wind. This cross check shall be done whenever changes are made related to the wind generator. The use of artificial generated wind shall be reported with the collector test results.

22 Instrumentation

22.1 Solar radiation measurement

22.1.1 Pyranometer

22.1.1.1 General

Class I or better, as specified in ISO 9060, pyranometer(s) shall be used to measure the hemispherical solar radiation. The recommended practice for use given in ISO/TR 9901 should be observed. Before each test the pyranometer(s) should be checked for dust, soiling etc. on the outer dome and it should be cleaned if necessary. Class I or better pyranometer(s) equipped with a shading ring or alternatively a pyrheliometer together with a pyranometer shall be used to measure the diffuse short-wave radiation.

In case of concentrating collectors the direct normal irradiance (DNI) shall be measured with a pyrheliometer on its own tracking system. Beam and diffuse irradiance shall be calculated by:

$$G_b = DNI \cdot \cos \theta$$

$$G_d = G - G_b$$

NOTE The method of using the combination of pyrheliometer and pyranometer to determine the diffuse radiation delivers more precise results.

22.1.1.2 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.

22.1.1.3 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.

22.1.1.4 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.

22.1.1.5 Mounting of pyranometers outdoors

The pyranometers shall be mounted such that its sensor is coplanar, within a tolerance of 1° with the collector plane. It shall not cast a shadow onto the collector area at any time during the test period.

The pyranometers 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.

The body of the pyranometers 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 pyranometers.

22.1.1.6 Use of pyranometers in solar irradiance simulators

Pyranometers may be used to measure the distribution of simulated solar irradiance over the collector plane and the variation in simulated irradiance with time. 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 shall be mounted such that its sensor is coplanar, within a tolerance of ± 1° with the plane of the collector. It shall not cast a shadow onto the collector area at any time during the test period. The pyranometer(s) shall be mounted so as to receive the same levels of direct, 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 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 mid height of the collector as described for outdoor testing, will not be adequate. This is particularly the case when the lamp array is powered from unstabilized mains power supply 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.

22.1.1.7 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.

22.2 Thermal radiation measurement

22.2.1 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 and to one side at midheight, to determine the thermal irradiance at the plane of the collector.

22.2.2 Calculation of thermal irradiance from dew point temperature

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 ϑ_{dp}.

$$\varepsilon_s = 0{,}711 + 0{,}56\frac{\vartheta_{dp}}{100} + 0{,}73\left(\frac{\vartheta_{dp}}{100}\right)^2 \tag{5}$$

Where the dew point temperature ϑ_{dp} shall be measured to a standard uncertainty of < 0,5 K. The long wave irradiance is calculated by the expression:

$$E_s = \varepsilon_s \cdot \sigma \cdot T_a^4 \tag{6}$$

If the collector is inclined there will be thermal radiation exchange with both the sky and ground. The relative long wave irradiance $E\beta$ on a collector inclined at an angle β is given by:

$$E_\beta = \varepsilon_s \cdot \sigma \cdot T_a^4 \frac{1+\cos\beta}{2} + \varepsilon_g \cdot \sigma \cdot T_a^4 \frac{1-\cos\beta}{2} \tag{7}$$

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 $\beta = 45°$. In this case, Formula 7 can be written as:

$$E_\beta = \varepsilon_s \cdot \sigma \cdot T_a^4 \frac{1+\cos\beta}{2} \tag{8}$$

Thus, in Formula 23 the long wave irradiance E_L in the collector plane is equal to E_β when the collector is located outdoors

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

When calculating E_S Formula 6 should be used.

22.2.3 Calculation of long wave irradiance from sky temperature

For tests using an artificial sky (in solar irradiance simulators) the long wave radiation can be calculated from the emittance ε_S of the artificial sky and the mean sky temperature T_S determined by a set of contact sensors on the surface facing the collector of the artificial sky. The sensors shall be radiation shielded and thermally insulated. The formula is analogous to Formula 9 ($\beta = 0°$ as the collector is facing the artificial sky):

$$E_s = \varepsilon_s \cdot \sigma \cdot T_s^4 \tag{9}$$

Thus, in Formula 23 the long wave irradiance E_L in the collector plane is equal to E_S.

22.2.4 Determination of thermal irradiance indoors

22.2.4.1 Measurement

The thermal irradiance may be measured using a pyrgeometer as indicated in 22.2.1 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 W/m^2.

The global hemispherical long wave radiation may be measured using a pyrgeometer mounted in the plane of the collector. 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. 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. The influence of short wave solar heating effects should be minimized.

22.2.4.2 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 plane of the collector may be calculated using temperature measurements, surface emittance measurements and radiation view factors. The thermal irradiance E_L incident on a collector surface (designated 1), from a hotter surface (designated 2) is given by:

$$E_L = \sigma \cdot \varepsilon_2 \cdot \mathrm{F}_{12} \cdot \mathrm{T}_2^4 \tag{10}$$

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:

$$E_L = \sigma \cdot \mathrm{F}_{12} \cdot \varepsilon_2 \left(\mathrm{T}_2^4 - \mathrm{T}_\mathrm{a}^4 \right) \tag{11}$$

Radiation view factors are given in textbooks on radiation heat transfer. The thermal irradiance at the plane of the collector 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.

For unglazed collector a device shall be used to determine the global hemispherical long wave radiation in the plane of the collector.

22.3 Temperature measurements

22.3.1 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.

22.3.2 Measurement of heat transfer fluid (liquid) inlet temperature (ϑ_{in})

22.3.2.1 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.

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.

22.3.2.2 Mounting of sensors

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

22.3.2.3 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. Delta-T sensors shall be calibrated in the relevant temperature range.

22.3.3 Objective Velocity weighted mean temperature (Air heating collectors)

22.3.3.1 General

The velocity weighted mean temperature describes the volume flow, heat capacity and density weighted temperature which represents the real mean temperature in an air duct.

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

$$\vartheta_{m,th} = \frac{\iint \vartheta(x,y)v(x,y)\rho(x,y)c(x,y)dxdy}{\iint v(x,y)\rho(x,y)c(x,y)dxdy} \tag{12}$$

Due to the small influence of density and heat capacity, Formula 12 can be reduced

$$\vartheta_{m,th} = \frac{1}{Av_m}\iint \vartheta(x,y)v(x,y)dxdy \tag{13}$$

Since the flow distribution is not known, it shall be homogenized constructively over the channel cross-section. The temperature measurement shall be designed in a way that temperature gradients are balanced over the channel cross-section. For example the flow distribution can be homogenized by introducing fine-mesh nets in the ventilation channel. Using an averaging, evenly distributed (Archimedean spiral) temperature sensor in the channel, the thermal average temperature can be determined.

22.3.3.2 Required accuracy

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

22.3.3.3 Mounting of sensors

The thermal mean temperature shall be determined taking into account the factors described in 22.3.3. The sensor for temperature measurement shall be mounted at no more than 200 mm from the collector inlet/outlet, and insulation shall be placed around the ducts both upstream and downstream of the sensor. If it is necessary to position the sensor more than 200 mm away from the collector, then a test shall be made to verify that the measurement of fluid temperature is not affected; this can be done by a recalculation of the inlet and outlet temperature difference.

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

22.3.3.4 Determination of heat transfer fluid temperature difference (ΔT)

The difference between the collector outlet and inlet temperature (ΔT) shall be determined to a standard uncertainty of < 0,1 K. Delta-T sensors shall be calibrated in the relevant flow range and temperature range, using air.

NOTE Achieving this standard uncertainty it is possible to measure heat transfer fluid temperature differences of 5 K with a reasonable accuracy.

22.3.4 Measurement of surrounding air temperature (ϑ_a)

22.3.4.1 Required accuracy

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

22.3.4.2 Mounting of sensors

For outdoor measurements the sensor shall be shaded from direct and reflected solar radiation by means of a white-painted, well-ventilated shelter, preferably with forced ventilation. The shelter itself shall be shaded and placed at the mid height of the collector but at least 1 m above the local ground surface to ensure that it is removed from the influence of ground heating.

The shelter shall be positioned 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.

22.4 Flow rate measurement

22.4.1 Measurement of collector fluid (liquid) flow rate

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

The temperature of the fluid in volumetric flow meters should be known with sufficient accuracy to ensure that mass flow rates can be determined with the accuracy given above.

22.4.2 Measurement of collector fluid flow rate (air heating collectors)

The standard uncertainty of the mass flow rate measurement shall be within ± 2 % of the measured value, in mass per unit time. Through the determination of pressure and temperature, the volumetric flow rate can be converted to mass flow rate. Staying within the limits of the uncertainties for temperature, pressure and volume flow rate given in

Table 6 — Maximum allowed measurement uncertainties

Formula	Measurement Value	Measurement Uncertainty
V_p	Volumetric flow	± 1 %
ϑ_{mp}	Temperature of airflow at the volumetric flow rate measurement unit	± 1 K
P_{abs}	Absolute pressure of the ambient air	± 50 Pa
m_p	Mass flow rate	± 2 %

Each of the sensors should be calibrated in the full range of application.

The mass flow rate can be determined by the formula:

$$m_p = V_p \cdot \rho_I \tag{14}$$

The determination of the density shall be calculated following [84]:

$$\rho_I = \frac{1 + \frac{X_W}{1000}}{R_L + \frac{X_W}{1000} \cdot R_D} \cdot \frac{\left(P_{abs} + p_f\right)}{\left(\vartheta_{mp} + 273{,}15\right)} \tag{15}$$

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

22.5 Surrounding air speed measurement

22.5.1 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.

22.5.2 Required accuracy

The speed of the surrounding air over the front surface of the collector shall be measured to a standard uncertainty of < 0,5 m/s (0,25 m/s unglazed collectors) 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.

It should be taken into consideration that anemometers have starting limits which lie between 0,5 m/s and 1 m/s. Therefore, considerable errors may occur for air velocities less than 1 m/s.

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

22.5.2.1.1 General

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 plane of the collector, 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 area.

When testing outdoors in locations where the mean wind speed is below 2 m/s, an artificial wind generator shall be used, and anemometer measurements shall be fitted for the continuous measurement of air velocity.

Permanently installed anemometer(s) shall be placed at the edge of the collector in order to supervise the operation of the wind generator. These anemometers shall be mounted on a board so that there is a continuous surface pointing towards the wind generator from the collector to 0.3 m behind the anemometer. If the wind generator is mounted along the short edge of the collector, two anemometers shall be used. The anemometers shall be mounted one at 1/3 of one side of the collector, the other one at 2/3 of the other side of the height of the collector. If the wind generator is mounted along the long edge of the collector, at least one anemometer shall be used. The anemometer(s) shall be mounted in the air flow of the wind generator either at the end(s) of the collector, at 1/2 the width of the collector or along the edge of the collector on the side opposite the wind generator at 1/3 and 2/3 of the length of the collector. If the wind generator is located away from the collector, an anemometer shall be mounted to measure the wind speed across the face of the collector. The uniformity of air speed in the field of collector area shall be checked as the air speed may vary from one end of the collector to the other. 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 plane of the collector.

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 than the air speed above the plane of the collector.

In case of concentrating collectors the following rules apply:

a) Concentrating collectors without transparent cover and a concentration ration of $C_R < 10$ should be treated as unglazed collectors.

b) Concentrating collectors with transparent cover and with a concentration ratio of $C_R < 3$ should be treated as non-concentrating collectors.

c) For concentrating collectors with a transparent cover and a concentration ratio of $C_R > 3$ wind speed dependency can be neglected.

d) For evacuated concentrating collectors wind speed dependency can be neglected independent of the concentration ratio C_R.

22.5.2.1.2 Unglazed collectors

Two permanently installed anemometers shall be placed at the sides of the collector in order to supervise the operation of the wind generator. These anemometers shall be mounted on a board so that there is a continuous surface pointing towards the wind generator from the collector to 0,3 m behind the anemometer. The anemometers should be mounted one at 1/3 of one side of the collector, the other one at 2/3 of the other side of the height of the collector.

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.

If a wind generator is used a series of measurements of the turbulence level shall be taken at nine equally spaced positions over the collector area. The turbulence level shall be in the range of 20 % to 40 %.

During the test the turbulence level shall be checked as written in 22.5.2.1

22.6 Elapsed time measurement

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

22.7 Pressure measurement

The pressure measurement is used for determining different information about the collector:

- Pressure drop
- Pressure level during efficiency test

- Leakage rate (caused by pressure difference)

The equipment is described in Clause 7.

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 meter run of strip.

22.8 Humidity measurement

When air is used as the heat transfer fluid, its moisture content is needed for the correct determination of the specific heat capacity of air. The humidity ratio X_W shall be measured (see Figure 5 and Figure 6) to an accuracy of ± 0,001 (kg water/kg dry air) at 25 °C fluid temperature.

22.9 Collector gross area

The collector gross area 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.

22.10 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.

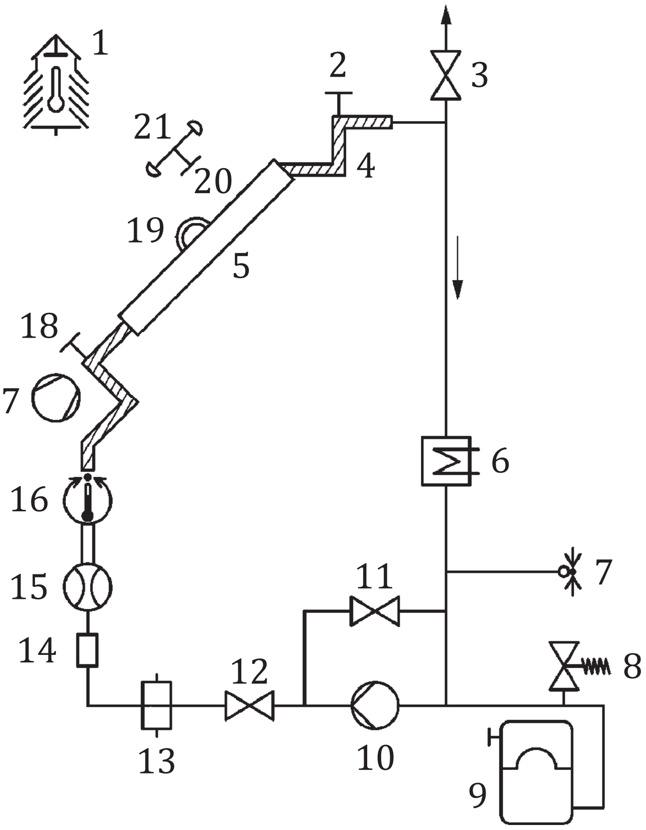
As an alternative, a determination by calculation, which is based on the geometrical circumstances, can be given.

23 Test installation

23.1 Liquid heating collectors

23.1.1 General

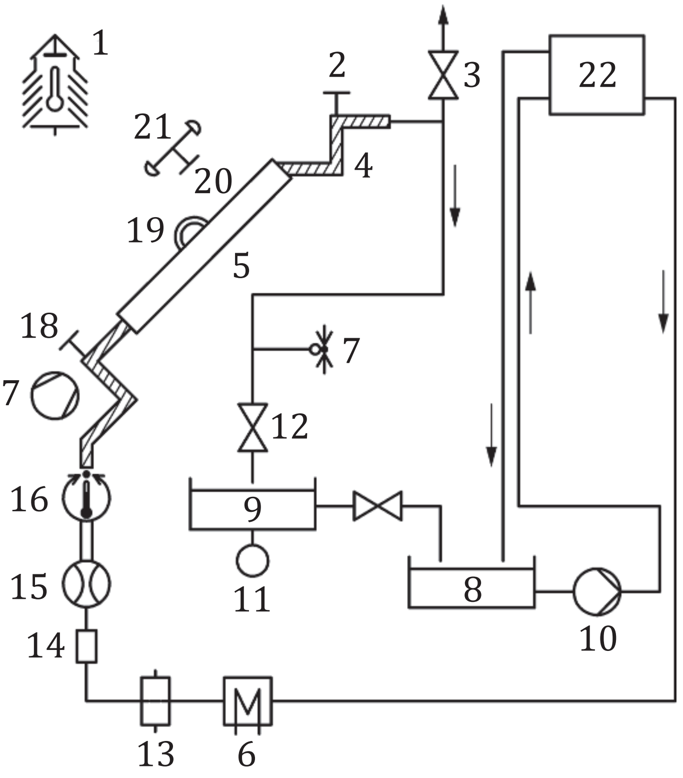
Examples of test configurations for testing solar collectors employing liquid as the heat transfer fluid are shown in Figure 5 and Figure 6. These are schematic only, and are not drawn to scale.



Key

1	Ambient temperature sensor	12	Flow control valve
2	Temperature sensor (ϑ_e)	13	Filter (200 µm)
3	Air vent	14	Sight glass
4	Insulated pipe	15	Flow meter
5	Solar collector	16	Secondary temperature regulator
6	Heater/cooler for primary temperature control	17	Artificial wind generator
7	Pressure gauge	18	Temperature sensor (ϑ_{in})
8	Safety valve	19	Pyrgeometer
9	Expansion tank	20	Pyranometer
10	Pump	21	Anemometer
11	Bypass valve		

Figure 5 — Example of a closed test loop



Key

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

Figure 6 — Example of an open test loop

23.1.2 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 shall be known to within ± 1 % over the range of fluid temperatures used during the tests. These values are given for water in Annex C.

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

The mass flow rate of the heat transfer fluid shall be the same (± 10 %) throughout the test sequence used to determine the power curve, time constant and incident angle modifiers for a given collector.

23.1.3 Pipe work and fittings

If non-aqueous 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 W/K, and shall be protected by a reflective weather proof coating. Pipe work between the temperature sensing points and the collector (inlet and outlet) shall be protected with insulation and reflective (for outdoor measurements also weather proof) 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 22.3).

A 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 flow meter is convenient for this purpose, as it simultaneously gives an independent visual indication of the flow rate. 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.

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).

23.1.4 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 flow rate.

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

23.1.5 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.

Test loops may contain two stages of fluid inlet temperature control, as shown in Figure 5 and Figure 6. The primary temperature controller should be placed upstream of the flow meter 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.

A 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 flow rate through the heaters will allow PID controlling with fast I and D action, while any flow rate through the collector can be chosen.

23.2 Air heating collectors

23.2.1 General

There are basically two types of air collectors.

A) Solar air heating collectors working in a closed air circuit (closed loop)

B) Solar air heating collectors sucking ambient air (open to ambient)

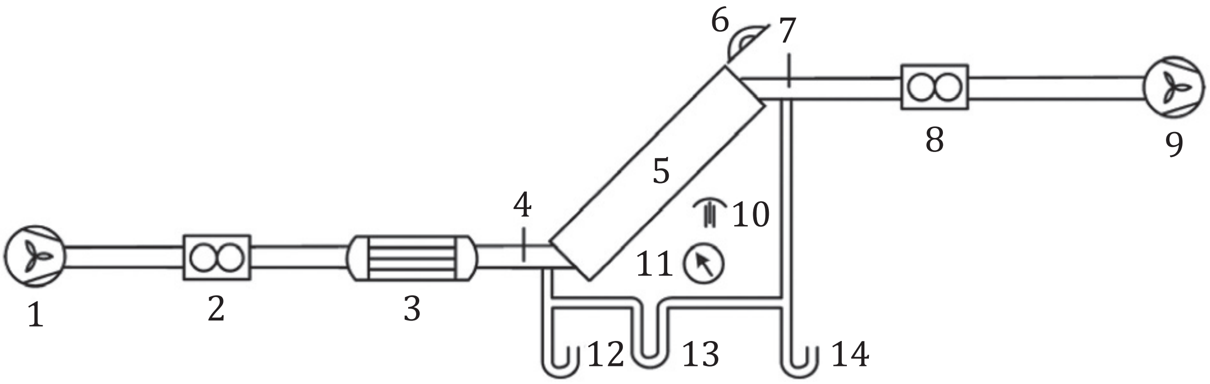
NOTE Type b) can be sub-divided into two different technological versions:

1) Open loop collectors, called transpired collectors. These are collectors, where the ambient air is sucked through the absorber material, or through the perforated glazed collector cover.

2) Open loop collectors. There are collectors where the ambient air is sucked in at a defined inlet duct or through the perforated glazed collector cover.

23.2.2 Closed loop

If collectors are measured in a closed air circulation with a speed controlled (RPM regulated) fan, a flow meter shall be used at the inlet and outlet. This type of collector shall be measured at ambient pressure, which can be realized by using two fans. Between the two fans, an area where the air can be conditioned can be installed. Figure 7 — Example of a closed test loop



Key

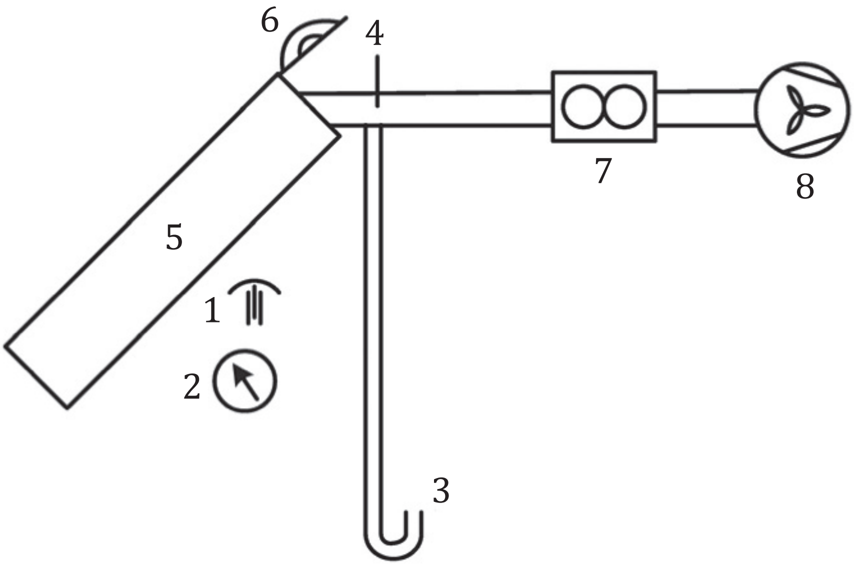
1 Fan
2 Flow meter $(\dot{m}_i = f(\dot{V}_i, \vartheta_{mp,i}, rH_i, P_i))$
3 Electric air heater
4 Temperature Sensor (ϑ_{in})
5 Solar air heater
6 Pyranometer (G)
7 Temperature Sensor (ϑ_e)
8 Flow meter $(\dot{m}_e = f(\dot{V}_e, \vartheta_{mp,e}, rH_e, P_e))$
9 Fan
10 Ambient temperature sensor (ϑ_a)
11 Pressure gauge for surrounding air (P_{abs})
12 Pressure gauge ($P_{f,i}$)
13 Differential pressure ($\Delta P = P_{f,i} - P_{f,e}$)
14 Pressure gauge ($P_{f,e}$)

Figure 7 — Example of a closed test loop

23.2.3 Open test circuit for open to ambient solar air heating collectors

When open to ambient solar air heating collectors shall be measured, the mass flow can only be determined at the collector outlet. The collector inlet temperature corresponds to the ambient temperature.

An example of a test configuration for testing open to ambient solar air heating collectors is shown in Figure 8 Example of an open test loop



Key

1 Ambient temperature sensor (ϑ_a)
2 Pressure gauge for surrounding air (P_{abs})
3 Pressure gauge ($P_{f,e}$)
4 Temperature sensor (ϑ_e)
5 Solar air heater
6 Pyranometer (G)
7 Flow meter $(\dot{m}_e = f(\dot{V}_e, \vartheta_{mp,e}, rH_e, P_e))$
8 Fan

Figure 8 — Example of an open test loop

23.2.4 Heat transfer fluid

The heat transfer fluid for air heating collectors is air. To determine the specific heat capacity of the air at each measurement point, the temperature and humidity are needed. This can be calculated with the fluid temperature as given in 25.2. The density shall be calculated as described in 22.4.2.

23.2.5 Test ducts

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

To reach an even air flow pattern throughout the collector, regular distribution ducts provided by the manufacturer at the inlet and outlet should be used for each collector tested. By means of boxes with perforated metal sheets at inlet and outlet, a well distributed air flow can be achieved, which means that an even air flow from the centre-line of the collector to the edges from entrance to outlet exists. The section between the inlet and outlet temperature sensor unit and the collector inlet and outlet shall be insulated to limit the heat losses to ± 0,2 W/K. For outdoor tests, the insulation shall be protected by a weather proof coating.

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

Every single pipe, duct connection, and measurement instrument shall be tested for leakage. The same method shall be used, as described in Clause 7. No component should have a higher leakage rate than 2 m^3/h at 250 Pa. Before the performance measurement the collector outlet and the collector inlet shall be tested for leaks and the leakage rate shall be mentioned in the test report.

23.2.6 Fan and flow control devices

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

23.2.7 Air Preconditioning apparatus

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

Its heating and cooling capacity shall be selected so that the dry-bulb temperature of the air entering the preconditioned apparatus may be raised or lowered to the required amount to meet the applicable test conditions in 24.5.3.

23.2.8 Humidity Ratio

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

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

24 Performance test procedures

24.1 General

The thermal performance of the solar collectors preferably should be tested according to one of the methods described in the following. For PVT collectors, the operation mode of the PV-module (MPP tracked, open or short circuit) could have a major influence on the thermal performance and it needs to be mentioned within the report. If the absorber of PVT's is close connected to the PV-Module and if there is no extra cover in front of the PV-Module, these PVT's will be treated as unglazed.

The thermal performance of concentrating collectors shall be tested according the quasi-dynamic test method.

The steady-state method may be used if a distinction between beam and diffuse irradiance is taken into account. However, in this case the requirements for quasi-dynamic testing related to concentrating collectors (including Formula 27) shall be followed.

24.2 Test installation

The heat transfer fluid (e.g. flow pattern, mass flow rate) shall flow as recommended by the manufacturer.

24.3 Preconditioning of the collector

The collector shall be exposed to irradiation for 5 h at the level of more than 700 W/m^2. If the collector is equipped with means to prevent stagnation, the collector must pass a preconditioning phase of 5 h at the level of more than 700 W/m^2 while operating with an inlet temperature equal to the maximum operating temperature defined by the manufacturer minus 10 K.

The collector shall be visually inspected and any damage recorded. The collector area 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 pipe work shall be vented of trapped air by means of an air valve or by circulating the fluid at a high flow rate, as necessary. The fluid shall be inspected for entrained air or particles, by means of the transparent tube built into the fluid loop pipe work. Any contaminants shall be removed.

In case the collector has been subject to the pre-exposure or exposure test before, preconditioning is not needed.

24.4 Test conditions

24.4.1 General

In some collectors the recommended fluid flow rate 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 flow rate, but this shall be clearly stated with the test results. Measurements of negative fluid temperature difference shall not be included in the test results.

In the transition regime, the flow rate should first be set high (turbulent) and then reduced to the set point value. This will prevent transition from laminar to turbulent during the measurements.

24.4.2 Steady-state

24.4.2.1 General

The angle of incidence of direct solar radiation at the plane of the collector shall be in the range in which the incident angle modifier for the collector varies by no more than ± 2 % from its value at normal incidence. For single glazed flat plate collectors, this condition will usually be satisfied if the angle of incidence of direct solar radiation at the plane of the collector 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 Clause 27).

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 %.

24.4.2.2 Liquid heating collectors glazed

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

If the manufacturer has limitations on operation with respect to maximum irradiance but not less than 800 W/m^2, this can be requested with the test. That maximum value should be clearly reported.

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

Unless otherwise specified, the fluid flow rate shall be set at approximately 0,02 kg/s per square meter of collector gross area. It shall be held stable to within ± 2 % 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.

24.4.2.3 Air heating collectors

At the time of test, the total solar irradiance at the plane of the collector shall be greater than 650 W/m^2.

In the case of glazed air-heating collectors, the average value of air speed parallel to the plane of the collector, taking into account spatial variations over the collector and temporal variations during the test period, shall be 3 m/s ± 1 m/s. In the case of unglazed air-heating collectors, surrounding wind speed parallel to the plan of the collector shall be in accordance with 24.5.4, Table 7.

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

NOTE In the case of open to ambient collector only one operation point need to be measured. This operation point is equal to the ambient temperature.

Unless the range of fluid flow rate is specified by the manufacturer, the fluid flow rate should be set to three values equally distributed between 30 to 300 kg/(h·m^2) gross area. If the manufacturer has guidelines for the airflow, the fluid flow rate should be set at the maximum, the minimum and at the medium flow rate.

Fluid flow rate shall be held stable to within ± 2 % of the set value during each test period, and shall not vary by more than ± 5 % of the set value from one test period to another.

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

The solar air heating collector should be measured under ambient pressure (|inlet pressure| = |outlet pressure|, inlet mass flow = outlet mass flow) to minimize the volumetric leakage flow rate.

24.4.2.4 Liquid heating collectors unglazed

At the time of the test, the net irradiance at the plane of the collector shall be greater than 650 W/m^2.

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

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 21.8.3.

Unless otherwise specified, the fluid flow rate shall be set at approximately 0,02 kg/s per square meter of collector gross area. It shall be held stable to within ± 2 % 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.

24.4.3 Quasi dynamic test

The average value of the surrounding air speed, taking into account spatial variations over the collector and temporal variations during the test period, shall be greater than 1 m/s and less than 4 m/s. Wind generators may be used if necessary to achieve sufficient wind speeds.

NOTE For concentrating collectors, follow rules as given in 22.5.1.

Unless otherwise specified, the fluid flow rate shall be set at approximately 0,02 kg/s per square meter of collector gross area (A_G). 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 flow rates can be accommodated by adhering to manufacturer's specification.

24.5 Test procedure

24.5.1 General

The collector should be tested up to the temperature specified by the manufacturer in order to determine its performance characteristic. If possible, one inlet temperature shall be selected such that the mean inlet temperature is within ± 3 K of the ambient air temperature, in order to obtain an accurate determination of η_0.

If possible the collector should be tested over the complete range of operating temperatures given by the manufacturer manual.

In some absorber designs local boiling may occur as a result of uneven flow distribution when testing at the highest temperature level. If this is anticipated, the highest temperature should be limited to a safe level.

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.

During a test, measurements shall be made as specified in 24.6.

When testing collectors using heat pipes, performance testing shall be done after the exposure test according to Clause 11.

24.5.2 Steady-state glazed liquid heating collector

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.

At least four independent data points shall be obtained for each fluid inlet temperature (two for indoor testing), 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.

24.5.3 Air heating collectors

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

24.5.4 Unglazed collectors

Data points which satisfy the requirements given below shall be obtained according to Table 7.

Under consideration 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 $\vartheta m = \vartheta a \pm 3$ 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**	**Tm (mean temperature)**	**Air Speed parallel to Collector**
	W/m^2	K	m/s
1	>650	$\vartheta_m = \vartheta_a \pm 3$ K	< 1
2	>650	$\vartheta_m = \vartheta_a \pm 3$ K	1,5 ± 0,5
3	>650	$\vartheta_m = \vartheta_a \pm 3$ K	3 ± 0,5
4	>650	$\vartheta_m = \vartheta_a + 0{,}5\,(\Delta T_{max}) \pm 3$ K	< 1
5	>650	$\vartheta_m = \vartheta_a + 0{,}5\,(\Delta T_{max}) \pm 3$ K	1,5 ± 0,5
6	>650	$\vartheta_m = \vartheta_a + 0{,}5\,(\Delta T_{max}) \pm 3$ K	3 ± 0,5
7	>650	$\vartheta_m = \vartheta_a + \Delta T_{max} \pm 3$ K	< 1
8	>650	$\vartheta_m = \vartheta_a + \Delta T_{max} \pm 3$ K	1,5 ± 0,5
9	>650	$\vartheta_m = \vartheta_a + \Delta T_{max} \pm 3$ K	3 ± 0,5

ΔTmax is the expected maximum temperature difference between absorber mean temperature and ambient temperature in real operation.

NOTE 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.

24.5.5 Quasi dynamic testing

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.

Weather conditions shall be as described in 24.7.2, 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 24.7.2, sequence type 3.

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.

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.

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 characterization 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.

24.6 Measurements

24.6.1 General

Depending on the test method chosen the quantities in Table 8 should be measured.

Table 8 — Measured quantities during testing

	Steady state liquid heating	Steady state air heating	Unglazed collectors	Quasi dynamic testing
gross collector area A_G	X	X	X	X
fluid capacity	X		X	X
hemispherical solar irradiance at the plane of the collector	X	X	X	X
diffuse solar irradiance at the plane of the collector (only outdoors)	X	X	X	X
angle of incidence of direct solar radiation (only outdoors) (alternatively, this angle may be determined by calculation)	X	X	X	X
air speed parallel to the plane of the collector	X	X	X	X
temperature of the heat transfer fluid at the collector inlet	X	X	X	X
temperature of the heat transfer fluid at the collector outlet	X	X	X	X
flow rate of the heat transfer fluid	X	-	X	X
the dew point temperature of the surrounding air	-	X	-	-
(relative) Humidity of the fluid at the collector inlet %	-	X	-	-
(relative) Humidity of the fluid at the collector outlet %	-	X	-	-
the mass flow rate of the heat transfer fluid at the collector inlet (only closed loop)	-	X	-	-
the mass flow rate of the heat transfer fluid at the collector outlet	-	X	-	-
static pressure of the heat transfer fluid at the outlet of the solar collector	-	X	-	-
static pressure of the heat transfer fluid at the inlet of the solar collector	-	X	-	-
absolute pressure of the ambient air	-	X	-	-
long wave thermal irradiance in the collector plane (or dew point temperature tdp.)	-	-	X	-
azimuth and tilt angle of the plan of the collector (standard uncertainty better than ± 1°)	-	-	-	X

24.6.2 Additional measurements during tests in solar irradiance simulators

24.6.2.1 Measurement of simulated solar irradiance

Pyranometers may be used to measure the irradiance of simulated solar radiation in accordance with 22.1. Alternatively, other types of radiation detectors 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 plane of the collector shall be measured using a grid of maximum spacing 150 mm, and the spatial mean deduced by simple averaging.

NOTE Simulated solar irradiance usually varies spatially over the plane of the collector as well as varying with time during a test. It is therefore essential to employ a procedure for integrating the irradiance over the plane of the collector. 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.

24.6.2.2 Measurement of thermal irradiance in simulators

The thermal irradiance in a solar simulator is likely to be higher than that which typically occurs outdoors. It shall therefore be measured to ensure that it does not exceed the limit given in 22.2.4.

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.

24.6.2.3 Ambient air temperature in simulators

The ambient air temperature ϑ_a in simulators shall be measured, taking the mean of several values if necessary. Sensors shall be shielded 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.

24.6.3 Data acquisition requirements for quasi dynamic testing

Sampling rate: 1 s to 10 s. In case the data are averaged, the time of average shall be given in the report. 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).

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

- useful output power of the collector or $\dot{Q}$
- time derivative of ϑ_m in the collector, i.e. $d\vartheta_\mathrm{m}/dt$ as (ϑ_m new - ϑ_m old) / (sampling interval for ϑ_in and ϑ_e)

The calculation of time derivative $d\vartheta_\mathrm{m}/dt$ should be performed online 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.

24.7 Test period

24.7.1 Steady-state

24.7.1.1 General

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 9. 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.

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 this Clause.

Table 9 — Permitted deviation of measured parameters during a measurement period

Parameter	Permitted deviation from the mean value		
	Glazed collector	Air heating collector	Unglazed collector
(Global)Test solar irradiance	± 50 W/m2	± 50 W/m2	± 50 W/m2
Total short wave solar irradiance	-	-	± 50 W/m2
Thermal irradiance	-	-	± 20 W/m2
Surrounding air temperature	± 1,5 K	± 1,5 K	± 1,5 K
Fluid mass flow rate	± 1 %	± 2 %	± 1 %
Fluid temperature at the collector inlet	± 0,1 K	± 1,5 K	± 0,1 K
Fluid temperature at the collector outlet	± 0,5 K	± 1.5 K	± 0,5 K
Surrounding air speed	-	-	± 0,5 m/s but ± 1,0 m/s for up to 10 % of the measurement period

24.7.2 Quasi dynamic testing

24.7.2.1 General

The test period consists of 4-5 sequences (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 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 24.7.2.4.

NOTE Enough variability is usually given if the standard deviation of the parameter is smaller than 10 % of the parameter.

24.7.2.2 Description of test sequences

The minimum length of a test sequence according to the requirements of 24.4.3 shall be 3 h. The 3 h do not need to be consecutive (the test sequence can consist out of several non-consecutive parts).

Day type 1

The test sequence under η_0 - conditions as specified in 24.5.5 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.

Day type 2

At least one test sequence shall be conducted under partly cloudy conditions, including broken cloud as well as clear sky conditions. This can be a test sequence under elevated operating temperature or under η_0 - conditions as specified in 24.5.5.

Day type 3 (1 or 2 days)

Measurements under mean operating temperature conditions as specified in 24.5.5, including broken cloud as well as clear sky conditions.

Day type 4

Measurements under high operating temperature conditions as specified in 24.5.5, including broken cloud as well as clear sky conditions.

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

24.7.2.3 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 to determine the dependency of the heat loss parameter c_1 on the tilt angle.

NOTE Extended MLR, see note 2 under 25.1.4.1.

24.7.2.4 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:

- ϑ_{out}-ϑ_{in} > 0 K
- ϑ_{in} stable within ± 1 K
- Flow rate stable within ± 2 % of the set value during test day or test sequence and 10 % from one sequence to another

During evaluation of the test data a 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 outliers that cannot be explained shall not be excluded from the data set.

For clearness reasons, most requirements are given in the form of idealized 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 9 — ϑ_m-ϑ_a versus G shows $\vartheta_m - \vartheta_a$ 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 $\eta_{0,b}$ and the collector heat losses.

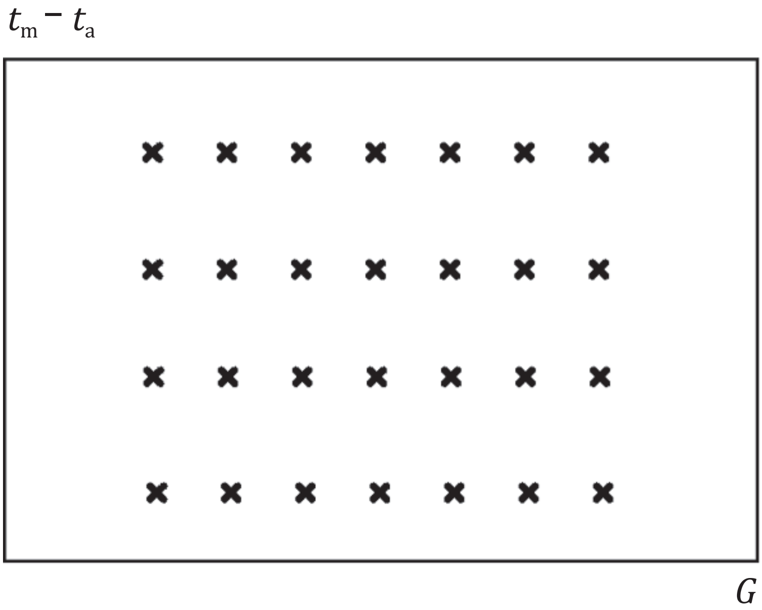


Figure 9 — ϑ_m-ϑ_a versus G

Figure 9 and Figure 10 shows 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_d.

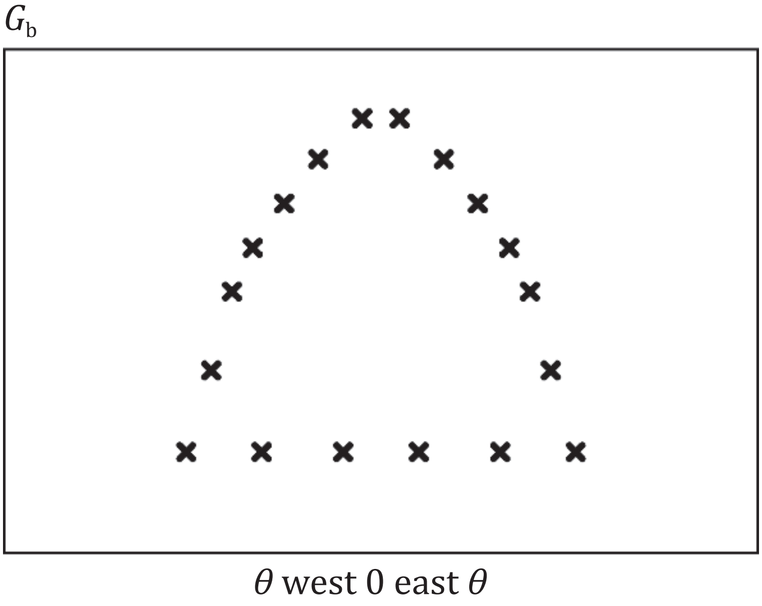


Figure 10 — Gb versus θ

NOTE Measurement data with higher Gb-values (upper curve), will give $K\theta_b(\theta)$.

The lower values will give K_d.

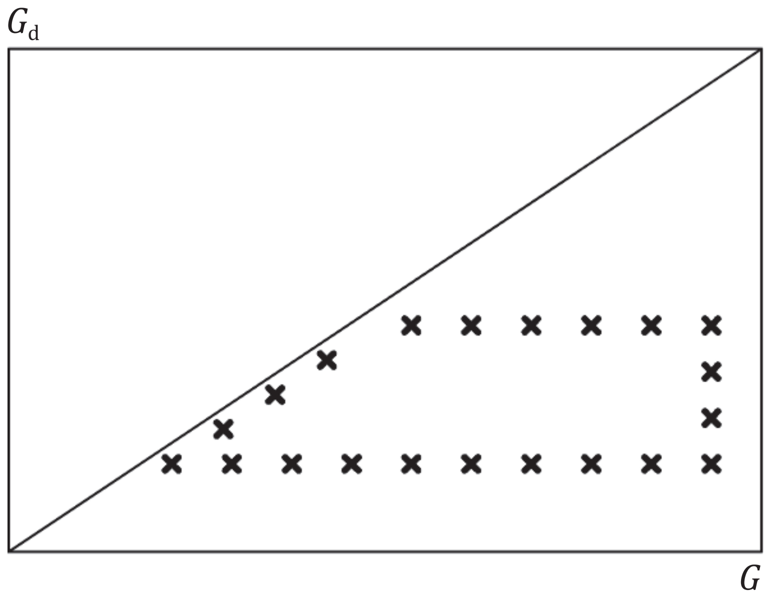


Figure 11 — G_d versus G

If wind speed dependence of the collector was considered Figure 11 shall be included. Figure 12 shows the ideal distribution of the relationship of wind speed versus G. The wind speeds as described in 24.4.3 should be considered.

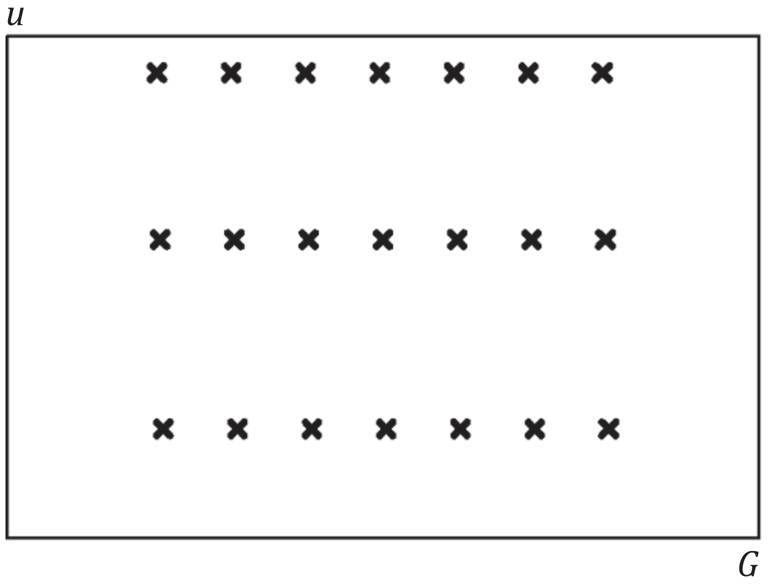


Figure 12 — Wind speed versus G

24.8 Presentation of results

24.8.1 General

Presentation of the results shall only be given up to the max. temperature difference between mean fluid and ambient plus a maximum of 30 K for which the collector was tested.

24.8.2 Steady-state

The measurements shall be collated to produce a set of data points which meet the required test conditions (see 24.4.2), including those for steady-state operation. These shall be presented using the data format sheets given in A.16.

24.8.3 Quasi dynamic testing

The test results shall be presented in a report using the data format sheets, given in A.16.7 and with the text and content adjusted in accordance with what is given by 24.7.2.4. 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 A.16.7 the measurement data used for collector parameter identification shall be presented in four diagrams, 1 to 4 as described under 24.7.2.4, Figure 9 to Figure 12. 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 The incidence angle modifier (IAM), $K_{\theta b}(\theta)$, shall be presented in a diagram 6 as indicated in Figure 14 — Typical incidence angle modifiers or Figure 15 — Typical incidence angle modifier.

In addition to the collector performance coefficients as requested by A.16.7, the full set of quasi dynamic performance coefficients as identified by Formula 27, should be included in the test report.

25 Computation of the collector parameters

25.1 Liquid heating collectors

25.1.1 General

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

$$\dot{Q} = \dot{m} \cdot c_f \cdot \Delta T \qquad (16)$$

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

The solar energy intercepted is A_G·G. "A_G" represents the gross area of the collector. Introducing the collector efficiency η_{hem}, the actual useful power extracted $\dot{Q}$ can also be written as:

$$\dot{Q} = A_G \cdot G \cdot \eta_{\mathrm{hem}} \tag{17}$$

When the mean temperature of the heat transfer fluid ϑ_{m} is used,

$$\vartheta_m = \vartheta_{in} + \frac{\Delta T}{2} \tag{18}$$

where the reduced temperature difference is calculated as:

$$T_m^* = \frac{\vartheta_m - \vartheta_a}{G} \tag{19}$$

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

For some collector types it has been shown that a separation between direct and diffuse irradiance is needed in the collector model in order to accurately predict their performance. As steady-state testing does not offer this feature a method has been developed to estimate $\eta_{0,\mathrm{b}}$ and $K\theta_{,\mathrm{d}}$ based on steady-state test data, basically $\eta_{\mathrm{o,hem}}$ and $K_{\mathrm{hem}}(\theta_L, \theta_T)$. This "Steady state to QDT conversion" shall be applied to steady-state parameters from Formula 20 or Formula 24, and from Formula 44 and Formula 45. The calculations are described in B.2.

25.1.2 Steady-state glazed liquid heating collectors

25.1.2.1 Modelling of instantaneous efficiency

The instantaneous efficiency η_{hem} shall be calculated by statistical curve fitting, using the least squares method, to obtain an instantaneous efficiency curve of the form:

$$\eta_{\mathrm{hem}} = \eta_{0,\mathrm{hem}} - a_1 \frac{\vartheta_m - \vartheta_a}{G} - a_2 \cdot G \left(\frac{\vartheta_m - \vartheta_a}{G} \right)^2 \tag{20}$$

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 or has no statistical significance (i.e. if T-ratio (parameter value/standard deviation of parameter value) is greater than 3. The test conditions shall be recorded on the data format sheets given in A.16.3

25.1.2.2 Modelling of collector output

Using Formula 17 and Formula 20 the collector output per module can be written as:

$$\dot{Q} = A_G \cdot G \cdot \left(\eta_{0,\mathrm{hem}} - a_1 \frac{\vartheta_m - \vartheta_a}{G} - a_2 \cdot G \left(\frac{\vartheta_m - \vartheta_a}{G} \right)^2 \right) \tag{21}$$

Where the area A_G is the collector gross area. The collector output per module shall be presented graphically as a function of the temperature difference between mean fluid and ambient temperature (ϑ_m – ϑ_a) using G = 1000 W/m^2. The product A_G·G·$\eta_{0,\mathrm{hem}}$ shall be referred to as peak power, $\dot{Q}_{peak}$.

25.1.3 Steady-state unglazed liquid heating collectors

25.1.3.1 Modelling of instantaneous efficiency

The solar energy intercepted is A·G” and so in this case

$$\eta_{\mathrm{hem}} = \frac{\dot{Q}}{A_G \cdot G''} \tag{22}$$

G” is the net irradiance determined by the formula:

$$G'' = G + \frac{\varepsilon}{\alpha}\left(E_L - \sigma T_a^4\right) \tag{23}$$

The value (ε/α) shall be taken 0,85 unless the manufacturer can supply a measured value. E_L is the measured long wave irradiance in the collector plane. Specification given in 25.1.1 applies, by replacing G by G”.

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

$$\eta_{\mathrm{hem}} = \eta_{0,\mathrm{hem}}\left(1 - b_u u\right) - \left(b_1 + b_2 u\right)\frac{\vartheta_m - \vartheta_a}{G''} \tag{24}$$

$\eta_{0,\mathrm{hem}}$, b_u, b_1, and b_2 are coefficients to be determined by curve fitting.

The test conditions shall be recorded on the data format sheet given in A.16.4

25.1.3.2 Modelling of the collector output

Using Formula 22 and Formula 24 the collector output per collector unit can be written as:

$$\dot{Q} = A_G \cdot G''\left(\eta_{0,\mathrm{hem}}\left(1 - b_u u\right) - \left(b_1 + b_2 u\right)\frac{\vartheta_m - \vartheta_a}{G''}\right) \tag{25}$$

25.1.4 Quasi dynamic liquid heating collectors

25.1.4.1 Collector parameter identification tool

Multiple Linear Regression (MLR) is a non-iterative very fast matrix method that is available in most standard program packages with statistical functions, such as spread sheets or more specialized statistical programs like MINITAB or SISS. Linear, in this instance means that the model is written as a sum of terms with the parameters pn as a multiplier in front of the terms. For example:

$$\mathrm{Yout} = \mathrm{p0} + \mathrm{p1}\cdot f(\mathrm{x1},\mathrm{x2}) + \mathrm{p2}\cdot g(\mathrm{x1},\mathrm{x3},\mathrm{x4}) + \mathrm{p3}\cdot h(\mathrm{x2},\mathrm{x5}) \tag{26}$$

The sub models f(x..), g(x..) and h(x..) in each term can be highly nonlinear. 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 $G > 700$ W/m^2, dϑ_m/dt < 0,002 K/s, u > 2 m/s and ϑ_a-ϑ_s > 10 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.

Other nonlinear 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.

25.1.4.2 Modelling of instantaneous collector output

This model is basically the same as the steady-state model, 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 B.

$$\frac{\dot{Q}}{A_G}=\eta_{0,b}\cdot K_b\left(\theta_L,\theta_T\right)\cdot G_b+\eta_{0,b}\cdot K_d\cdot G_d-c_6\cdot u\cdot G-c_1\cdot\left(\vartheta_m-\vartheta_a\right)-c_2\cdot\left(\vartheta_m-\vartheta_a\right)^2$$
$$-c_3\cdot u\cdot\left(\vartheta_m-\vartheta_a\right)+c_4\cdot\left(E_L-\sigma\cdot T_a^4\right)-c_5\cdot\frac{d\vartheta_m}{dt} \qquad (27)$$

where the area A_G is the gross area of the collector (see A.16.7).

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

25.1.4.3 Use of the Collector Model for different collector types

The collector model as described in 25.1.4.2, 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 $\eta_{0,b}$, $K_\theta(\theta_L, \theta_L)$, K_d, and the coefficients c_1, c_2, and c_5 are mandatory and they should be identified. In the exceptional case that coefficient c_2 comes out negative or has no statistical significance (i.e. if T-ratio (parameter value/standard deviation of parameter value) is smaller than 3, the parameter identification should be repeated without c_2 included in the model.

NOTE For sun tracking, high concentrating collectors the inclusion of K_d may not always be significant and should therefore be determined by the T-ratio of the parameter identification as given below. If not used, $K_d = 0$ should be used in Formula 27 and the parameter identification should be repeated.

If the coefficients c_3, c_4, and c_6 shall be included in the collector model, can be determined by the T-ratio (parameter value / standard deviation of parameter value) of the parameter identification. The T-ratio should be greater than 3 for those parameters presented in the test results. If the T-ratio is less than 3, (enough variability in the input data are assumed), the coefficient shall be set to zero and the parameter identification should be repeated with the adjusted collector model.

For concentrating collectors (taking into consideration 22.5.2.1.1) and for glazed collectors tested with artificial wind source at a speed between 2 m/s and 4 m/s the coefficients c_3, c_4 and c_6 can be neglected right from the beginning. For unglazed collectors, the use of the full collector model is mandatory.

25.1.4.4 Graphical presentation of test results

To conform with the presentation of test results, when testing in accordance with steady-state method, 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 ($\vartheta_m - \vartheta_a$). It shall be calculated from the power function, Formula 27, using the value of G = 1000 W/m^2 and a diffuse fraction of 15 %, i.e. G_d = 150 W/m^2. The parameter $d\vartheta_m/dt$ is set to zero ($d\vartheta_m/dt = 0$).

θ is set to 0° for all collector types.

$K_b(\theta)$ is set to 1 for all collector types.

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 25.1.4.3, the wind speed u = 3 m/s should be used in the formula. If sky temperature dependence of the heat loss coefficient is used in the collector model ($c_4 > 0$), then (E_L-$\sigma \cdot T_a^4$) = - 100 W/m^2 should be used in the formula.

$$\dot{Q} = A_G\Big(G\big(\eta_{0,b} \cdot K_b(\theta) \cdot 0.85 + \eta_{0,b} \cdot K_d \cdot 0.15 - c_6(3\,m/s)\big) - c_1(\vartheta_m - \vartheta_a) - c_2(\vartheta_m - \vartheta_a)^2 \\ - c_3(3\,m/s)(\vartheta_m - \vartheta_a) + c_4 \cdot \left(-100\,W/m^2\right)\Big) \qquad (28)$$

The product ($A_G \cdot G$)($\eta_{0,b} \cdot K_b(\theta) \cdot 0{,}85 + \eta_{0,b} \cdot K_d \cdot 0{,}15$) shall be referred to as peak power, $\dot{Q}_{peak}$.

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

25.2 Steady-state air heating collectors

25.2.1 General

The instantaneous efficiency of a solar collector, operating under steady-state conditions, is defined as the ratio of the actual useful extracted power to the solar energy intercepted by the collector. The actual useful power extracted, $\dot{Q}$, is calculated from:

$$\dot{Q} = (\dot{m}_{p\dot{e}} c_{f,e} \cdot \vartheta_e) - (\dot{m}_{pi} \cdot c_{f,i} \cdot \vartheta_i) - ((\dot{m}_{pe} - \dot{m}_{pi}) \cdot c_{f,amb} \cdot \vartheta_a) \qquad (29)$$

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

NOTE Formula 29 has an uncertainty if the measurement is done under positive gauge pressure because the exact temperature of the volumetric leakage flow rate is not known. Under positive pressure the temperature of the volumetric leakage flow rate differs depending on whether it occurs at the beginning or at the end of the collector.

Provided that the angle of incidence is less than 20°, the use of an incident angle modifier, as described in Clause 27 is not required for single glazed flat plate collectors.

The solar energy intercepted is AG where A_G is the gross area of the collector, and the collector efficiency is:

$$\eta_{\text{hem}} = \frac{\dot{Q}}{A_G \cdot G} = \frac{\left(\dot{m}_{pe} \cdot c_{f,e} \cdot \vartheta_e\right) - \left(\dot{m}_{\dot{p}} \cdot c_{f,i} \cdot \vartheta_i\right) - \left(\left(\dot{m}_{pe} - \dot{m}p_i\right) \cdot c_{f,a} \cdot \vartheta_a\right)}{A_G \cdot G} \qquad (30)$$

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

$$\vartheta_{\text{m}} = \vartheta_{\text{in}} + \frac{\Delta T}{2} \qquad (31)$$

The instantaneous efficiency η_{hem} shall be calculated according to 25.1.2.1.

Open to ambient collectors having a measurable wind speed dependency can be modelled with:

$$\frac{\dot{Q}_m}{A_G \cdot G''} = \eta_{\max,0m/s} - b_u \cdot u \qquad (32)$$

Collector efficiency shall be represented graphically as a function of wind speed (at constant mass flow rate).

25.2.2 Modelling of the collector output

The collector output per module shall be calculated according to 25.1.2.2.

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

26.1 Measurement of the effective thermal capacity (separate measurement)

26.1.1 Test installation

The collector is mounted in accordance with the recommendations of Clause 21 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.

26.1.2 Indoor test procedure

26.1.2.1 General

The heat transfer fluid is circulated from the top to the bottom of the collector with a constant inlet temperature, using a flow rate 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.

26.1.2.2 Measurements

The following quantities are measured:

a) heat transfer fluid mass flow rate;

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.

NOTE When 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.

26.1.2.3 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 formula:

$$C\frac{d\vartheta_m}{dt} = -\dot{m}\cdot c_f\cdot\Delta T - A_G\cdot U\left(\vartheta_m - \vartheta_a\right) \tag{33}$$

Where

$$\Delta T = \left(\vartheta_e - \vartheta_{in}\right)\left(negative\right) \tag{34}$$

and ϑ_{in} and ϑ_{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 formula over the period between the two steady-states gives:

$$C\left(\vartheta_{m2}-\vartheta_{m1}\right)=\int_{t1}^{t2}\dot{m}\cdot c_f\cdot\Delta T dt-A_G\cdot U\int_{t1}^{t2}\left(\vartheta_m-\vartheta_a\right)dt \tag{35}$$

Since

$$\vartheta_m=\vartheta_{in}+\frac{\Delta T}{2} \tag{36}$$

we may express (ϑ_m-ϑ_a) as:

$$\vartheta_m-\vartheta_a=\left(\vartheta_{in}-\vartheta_a\right)+\frac{\Delta T}{2} \tag{37}$$

Combining the above formulae, and rearranging, gives the following formula for the collector thermal capacity.

$$C=\frac{-\dot{m}c_f\int_{t1}^{t2}\Delta T dt-A_G\cdot U\left[\int_{t1}^{t2}\left(\vartheta_{in}-\vartheta_a\right)dt+\frac{1}{2}\int_{t1}^{t2}\Delta T dt\right]}{\vartheta_{m2}-\vartheta_{m1}} \tag{38}$$

26.1.2.4 Determination of effective thermal capacity from experimental data

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

$$\int_{t1}^{t2}\left(\vartheta_{in}-\vartheta_a\right)dt \quad \text{and} \quad \int_{t1}^{t2}\Delta T dt$$

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:

$$0=-\dot{m}\cdot c_f\cdot\Delta T-A_G\cdot U\left(\vartheta_m-\vartheta_a\right) \tag{39}$$

and hence

$$A_G\cdot U=-\frac{\dot{m}\cdot c_f\cdot\Delta T}{\left(\vartheta_m-\vartheta_a\right)} \tag{40}$$

A·U 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 Formula 38.

26.1.3 Outdoor or solar irradiance simulator test procedure

The fluid is circulated with a constant temperature, using a flow rate similar to that defined for collector efficiency testing, until steady-state conditions are reached. The collector area 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 26.1.2.2 are made. In addition, the solar irradiance (natural or simulated) G is measured.

The transient behaviour of the collector between two steady-states 1 and 2 is represented by the following formula

$$C\frac{d\vartheta_m}{dt} = A\cdot\eta_{0,hem}\cdot G - \dot{m}\cdot c_f\cdot\Delta T - A_G\cdot U\left(\vartheta_m - \vartheta_a\right) \tag{41}$$

where, as in 26.1.2.3,

$\Delta T = (\vartheta_e - \vartheta_{in})$ (positive)

Integrating Formula 41 over the period between the two steady-states gives the following formula for the collector thermal capacity:

$$C = \frac{A\cdot\eta_{0,hem}\int_{t1}^{t2} G dt - \dot{m}c_f\int_{t1}^{t2}\Delta T dt - A_G\cdot U\left[\int_{t1}^{t2}\left(\vartheta_{in} - \vartheta_a\right)dt + \frac{1}{2}\int_{t1}^{t2}\Delta T dt\right]}{\vartheta_{m2} - \vartheta_{m1}} \tag{42}$$

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

$$\int_{t1}^{t2}\left(\vartheta_{in} - \vartheta_a\right)dt\ ,\ \int_{t1}^{t2}\Delta T dt\ \text{ and }\ \int_{t1}^{t2} G dt$$

respectively.

The y intercept $\eta_{0,\mathrm{hem}}$ and the slope U of the linear form of the instantaneous efficiency η_{hem} are known from testing. A value for the effective thermal capacity is determined by inserting these experimental values in Formula 42.

26.2 Measurement of the effective thermal capacity (quasi dynamic method)

The effective thermal capacitance, modelled as c_5 and equal to C/A, is a mandatory part of the collector model, Formula 27, 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 $d\vartheta_\mathrm{m}/dt$ for the determination of c_5. $d\vartheta_\mathrm{m}/dt$ 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 24.7.2 with partly cloudy conditions, shall be added to the data used for identification.

26.3 Calculation method

26.3.1 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 flow rate. Other collector components respond with different times to give an effective overall time constant, which depends on the operating conditions.

26.3.2 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 mi (expressed in kilograms), its specific heat ci (expressed as joules per kilogram Kelvin) and a weighting factor p_i:

$$C = \sum_i p_i \cdot m_i \cdot c_i \qquad (43)$$

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 10.

Table 10 — Values of weighting factors

Elements	p_i
Absorber	1
Insulation	0,5
Heat transfer liquid	1
External glazing	0,01
Second glazing	0,2
Third glazing	0,35
Perforated glazing and glazing of front-pass collector (if present)	1
Solid glazing on back-pass collector (if present)	0.2

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.

26.3.3 Calculation for solar air heating collectors

The collector fluid capacity shall be calculated as described in VDI 4670. All parts of the collector which are in direct contact with the air flux shall be weighted by 1.

26.4 Determination of collector time constant (optional)

26.4.1 Test procedure for collector time constant

Testing shall be performed either outdoors or in a solar irradiance simulator. In either case, the solar irradiance on the plane of the collector shall be greater than 700 W/m^2. The heat transfer fluid shall be circulated through the collector using the lowest flow rate used in the thermal efficiency tests.

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 0,5 K per minute.

Alternatively a method that provides equivalent results in a solar simulator is to measure the time constant during a cool down period rather than a heat up period. To accomplish this, first achieve steady-state conditions with a steady inlet temperature and irradiance, and then turn off the irradiance while monitoring the quantities listed below. The time constant of the collector is then the elapsed time between turning off the irradiance and the point where the collector temperature rise drops to 63,2 % of its steady-state value, since the final steady-state value will be a temperature rise of zero.

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

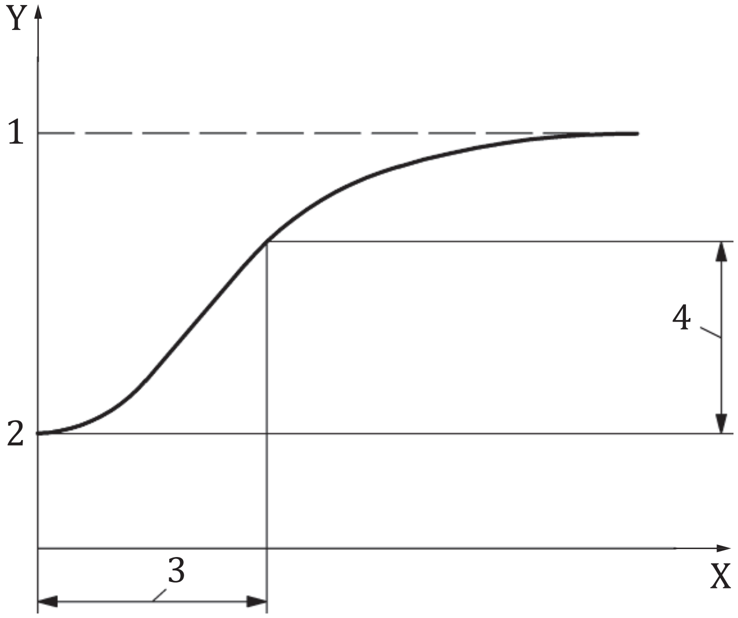
— Collector fluid inlet temperature (ϑ_{in});

— Collector fluid outlet temperature (ϑ_e);

— Surrounding air temperature (ϑ_a).

26.4.2 Calculation of collector time constant

The difference between the temperature of the fluid at the collector outlet and that of the surrounding air (ϑ_e - ϑ_a) shall be plotted against time, beginning with the initial steady-state condition (ϑ_e - ϑ_a)$_0$ and continuing until the second steady-state has been achieved at a higher temperature (ϑ_e - ϑ_a)$_2$ (see Figure 13 — Collector time constant).



Key

X Time

Y $\vartheta_e - \vartheta_a$

1 $(\vartheta_e - \vartheta_a)_2$

2 $(\vartheta_e - \vartheta_a)_0$

3 τ_c

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

Figure 13 — 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 (ϑ_e - ϑ_a)$_0$ to (ϑ_e - ϑ_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.

27 Determination of incident angle modifier

27.1 Modelling

27.1.1 General

The incidence angle modifier is defined as the ratio of the peak efficiency at a given angle of incidence and the peak efficiency at a defined reference angle of incidence according to Formula 44 and Formula 45 respectively.

$$K_b(\theta_L,\theta_T)=\frac{\eta_{0,b}(\theta_L,\theta_T)}{\eta_{0,b}\left(\theta_{L,def},\theta_{T,def}\right)} \tag{44}$$

$$K_{hem}(\theta_L,\theta_T)=\frac{\eta_{0,hem}(\theta_L,\theta_T)}{\eta_{0,hem}\left(\theta_{L,def},\theta_{T,def}\right)} \tag{45}$$

Normal incidence (equal to zero) is normally used as the defined angles of incidence $\theta_{\mathrm{L,def}}$ and $\theta_{\mathrm{T,def}}$, however other values can be chosen if appropriate, e.g. in case the thermal performance cannot be determined under normal incidence.

27.1.2 Steady-state glazed collectors and air heating collectors

Using Formula 45 and Formula 20 the incidence angle modifier, K_{hem} (θ_L, θ_T), is introduced in Formula 46.

$$\eta_{\mathrm{hem}}=\eta_{0,\mathrm{hem}}\cdot K_{hem}(\theta_L,\theta_T)-a_1\cdot\frac{\vartheta_m-\vartheta_a}{G}-a_2\cdot G\cdot\left(\frac{\vartheta_m-\vartheta_a}{G}\right)^2 \tag{46}$$

Figure 14 shows the variation of $K_{hem}(\theta_L, \theta_T)$ 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.

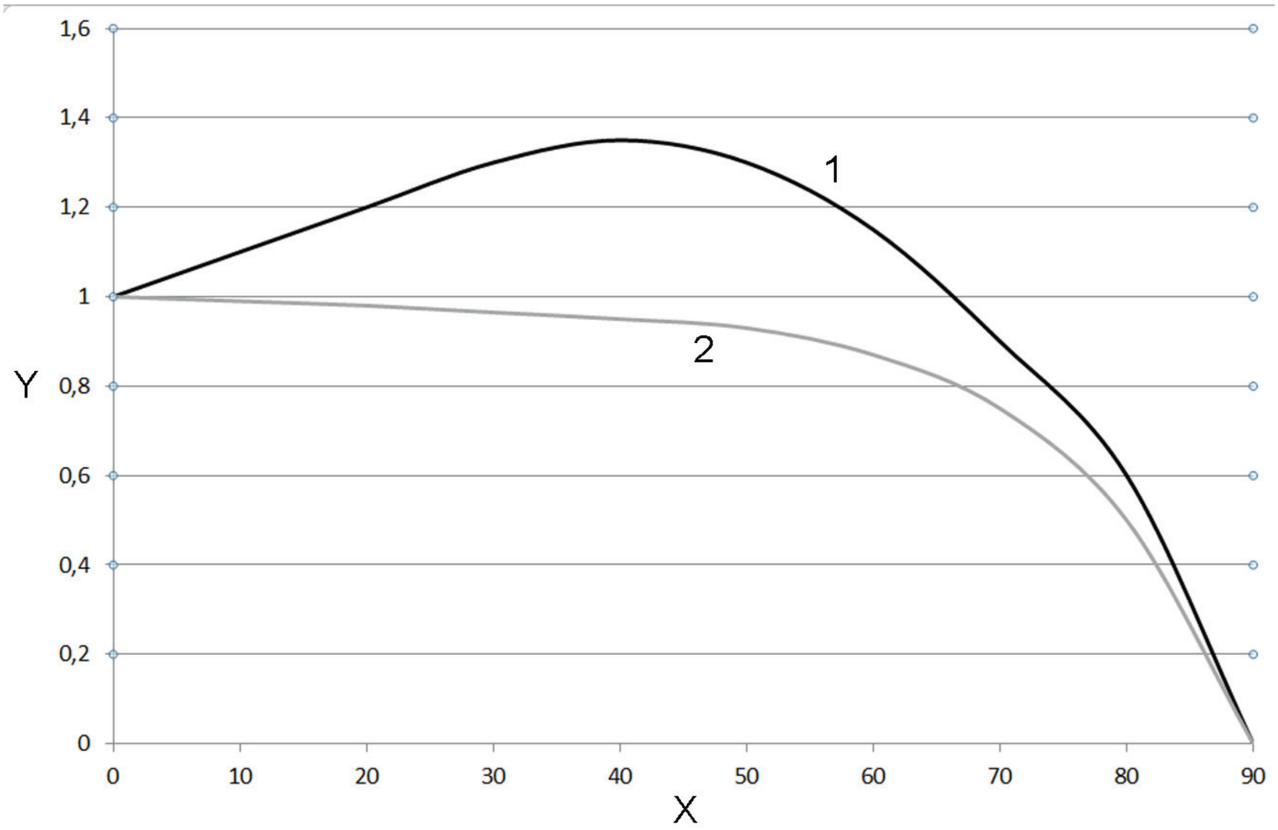
The complex individual incident angle modifier can be estimated by considering it to be the product of the separate incident angle modifiers, $K_{\theta\mathrm{L}}$ and $K_{\theta\mathrm{T}}$, for two perpendicular symmetry planes, Formula 47.

$$K_{hem}(\theta_L,\theta_T)=K_{hem}(\theta_L,0)\cdot K_{hem}(0,\theta_T) \tag{47}$$

The longitudinal plane (index L) runs parallel to the optical axis of the collector, and the transversal plane (index T) is perpendicular to the optical axis. The angles θ_L and θ_T are the projections of the incidence angle θ onto the longitudinal and transversal planes, respectively, see Figure 14 — Typical incidence angle modifiers.

For the correlation between θ, θ_L and θ_T, the following formula holds:

$$\tan^2\theta=\tan^2\theta_L+\tan^2\theta_T \tag{48}$$



Key

X Angle of incidence (degrees)
Y Incidence angle modifier $K_{\mathrm{hem}}(\theta_L,\theta_T)$
1 Transverse IAM
2 Longitudinal IAM

Figure 14 — Typical incidence angle modifiers

The significance of the incidence angle modifier to the test procedures outlined in this International 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 $\eta_{0,hem}$, for a flat plate collector. A separate measurement shall be conducted to determine the value of K_{hem} (θ_L, θ_T) so that the performance of the collector can be predicted under a wide range of conditions and/or time of day using Formula 46.

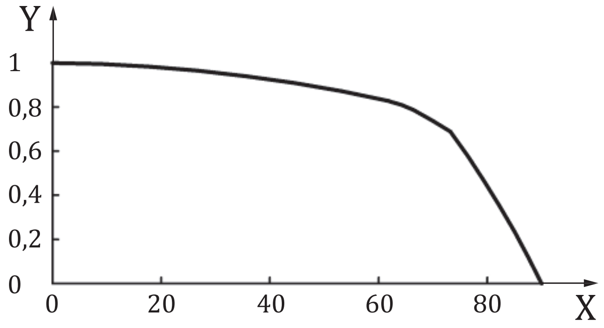
27.1.3 Steady-state unglazed liquid heating collector (optional)

For solar beam incidence which is not near normal, the efficiency $\eta_{0,\mathrm{hem}}$ in Formula 25 may be replaced by K_{hem} $(\theta_L, \theta_T) \cdot \eta_{0,\mathrm{hem}}$, where K_{hem} (θ_L, θ_T) is the incidence angle modifier.

$$\eta_{\mathrm{hem}} = K_{hem}(\theta_L,\theta_T)\cdot\eta_{0,\mathrm{hem}}\cdot(1-b_u\cdot u)-(b_1-b_2\cdot u)\cdot\frac{\vartheta_m-\vartheta_a}{G''} \qquad (49)$$

Figure 15 — Typical incidence angle modifier shows the typical variation of K_{hem} (θ_L, θ_T) 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 27.1.2 apply.



Key

X Incidence angle (degrees)

Y Incidence angle modifier K_{hem} (θ_L, θ_T)

Figure 15 — Typical incidence angle modifier

A separate measurement shall be conducted to determine the value of K_{hem} (θ_L, θ_T) so that the performance of the collector can be predicted under a wide range of conditions and/or time of day using Formula 49.

27.1.4 Quasi dynamic

The Collector incidence angle modifiers (IAM), modelled as K_b (θ_L, θ_T)for direct radiation and as K_d for diffuse radiation (see also 25.1.4.3, Note 1), are mandatory parts of the collector model, Formula 27. 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 formula

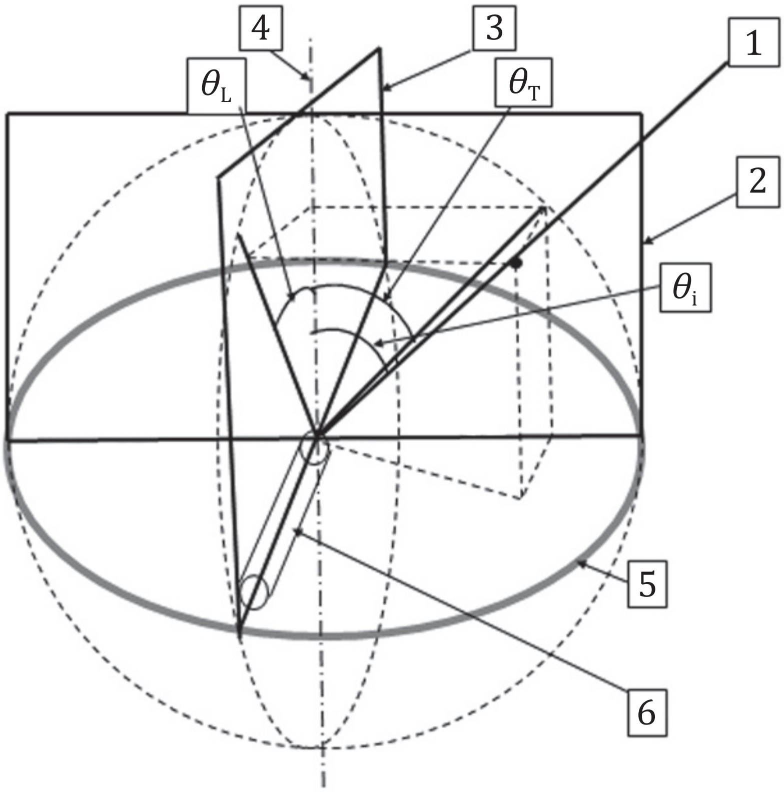
$$K_b\left(\theta_L,\theta_T\right)=1-b_0\cdot\left(\frac{1}{\cos\theta}-1\right) \tag{50}$$

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, Formula 51.

$$K_b\left(\theta_L,\theta_T\right)=K_b\left(\theta_L,0\right)\cdot K_b\left(0,\theta_T\right) \tag{51}$$

The longitudinal plane (index L) runs parallel to the optical axis of the collector, and the transversal plane (index T) is perpendicular to the optical axis. The angles θ_L and θ_T are the projections of the incidence angle θ onto the longitudinal and transversal planes, respectively.



Key

1 Sun position
2 Transversal plane
3 Longitudinal plane
4 Collector normal
5 Collector plane
6 Example vacuum tube

Figure 16 — Symmetry planes and angles relevant for the determination of bi- or multi-axial IAM

For the correlation between θ, θ_L and θ_T, the following formula holds:

$$\tan^2\theta = \tan^2\theta_L + \tan^2\theta_T \qquad (52)$$

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 25.1.4.1. K_d shall be modelled as a collector constant. For general information, also refer to 27.1.2.

27.2 Test procedures

27.2.1 Steady-state liquid heating collectors

27.2.1.1 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 collector shall be greater than 300 W/m^2.

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

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

27.2.1.2 Method 1

This method is applicable for testing indoors using a solar simulator with the characteristics specified in 20.2, 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 angle of incidence between a normal to the plane of the collector 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 24.5.2.

27.2.1.3 Method 2

This method is applicable for testing outdoors using a stationary test rack on which the collector orientation cannot be arbitrarily adjusted 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 24.5.2. As with Method 1, data shall be collected for an 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.

27.2.2 Air collectors

See 27.2.1, noting that one of the three flow rates used for the efficiency measurement shall be used also in this measurement.

27.2.3 Steady-state unglazed liquid heating collectors

See 27.2.1, but the efficiency value shall be determined in accordance with 24.5.4.

27.3 Calculation of collector incidence angle modifier

27.3.1 Steady-state glazed collector

Regardless of which experimental method in 27.2.1 is used, values for the thermal efficiency of the collector shall be determined for each of the mentioned values of incidence angles. 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_{hem} (θ_L, θ_T)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 $(\vartheta_m - \vartheta_a)$ approximately 0. The relationship between K_{hem} $(\theta_L, \theta_T)$and the efficiency is:

$$K_{hem}(\theta_L,\theta_T)=\frac{\eta_{0,hem}(\theta_L,\theta_T)}{\eta_{0,hem}\left(\theta_{L,def},\theta_{T,def}\right)} \tag{53}$$

Since $\eta_{hem}\left(\theta_{L,def},\theta_{T,def}\right)$ will have already been obtained as the y -axis intercept of the efficiency curve, values of K_{hem} (θ_L, θ_T)can be computed for the different angles of incidence (see 27.2). If the mean fluid temperature cannot be controlled to equal the ambient air temperature within ± 1 K, each value of K_{hem} (θ_L, θ_T) shall be computed as:

$$K_{hem}(\theta_L,\theta_T)=\frac{\eta_{hem}(\theta_L,\theta_T)+a_1\cdot\frac{\vartheta_m-\vartheta_a}{G}+a_2\cdot G\left(\frac{\vartheta_m-\vartheta_a}{G}\right)^2}{\eta_{0,hem}\left(\theta_{L,def},\theta_{T,def}\right)} \tag{54}$$

Due to more exact results Formula 54 should be used generally.

27.3.2 Air heating collectors

Regardless of which experimental method in 27.2.2 is used, values for the thermal efficiency of the collector shall be determined for each of the stated values of angles 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_{hem} (θ_L, θ_T)be measured for a different set of angles of incidence). The mean fluid temperature shall be close to the ambient air temperature so that $(\vartheta_m - \vartheta_a)$ approximately equals 0. The relationship between K_{hem} (θ_L, θ_T) and the efficiency is:

$$K_{hem}(\theta_L,\theta_T)=\frac{\eta_{0,hem}(\theta_L,\theta_T)}{\eta_{0,hem}\left(\theta_{L,def},\theta_{T,def}\right)} \tag{55}$$

Since $\eta_{0,hem}$ $(\theta_{L,def}, \theta_{T,def})$ will have already been obtained as the y -axis intercept of the efficiency curve, values of K_{hem} (θ_L, θ_T) can be computed for the different angles of incidence (see 27.2). If the mean fluid temperature cannot be controlled to equal the ambient air temperature within ± 1 K, each value of K_{hem} (θ_L, θ_T)shall be computed as in Formula 54:

Due to more exact results Formula 54 should be used generally.

Alternatively, each data point may be plotted on the same graph with the efficiency curve determined in accordance with 24.5.3, 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 if the mean temperature had been controlled to equal ambient air temperature. Therefore, these values may be used in conjunction with Formula 54 to compute the different values of K_{hem} (θ_L, θ_T).

27.3.3 Steady-state unglazed liquid heating collectors

Regardless of which experimental method in 27.1.3 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°.

NOTE A rating standard using this test method may require that K_{hem} (θ_L, θ_T)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 (ϑ_m - ϑ_a) approximately equals 0. The relationship between K_{hem} (θ_L, θ_T)and the efficiency is:

$$K_{hem}(\theta_L,\theta_T)=\frac{\eta_{0,hem}(\theta_L,\theta_T)}{\eta_{0,hem}\left(\theta_{L,def},\theta_{T,def}\right)} \tag{56}$$

Since η_0 will have already been obtained as the y-axis intercept of the efficiency curve, values of K_{hem} (θ_L, θ_T)can be computed for the different angles of incidence (see 27.2.3). If the mean fluid temperature cannot be controlled to equal the ambient air temperature within ± 1 K, the value of K_{hem} (θ_L, θ_T)shall be computed as:

$$K_{hem}(\theta_L,\theta_T)=\frac{\eta_{hem}(\theta_L,\theta_T)+(b_1+b_2\cdot u)\cdot\left(\frac{\vartheta_m-\vartheta_a}{G''}\right)}{\eta_{0,hem}\left(\theta_{L,def},\theta_{T,def}\right)\cdot(1-b_u\cdot u)} \tag{57}$$

Due to more exact results Formula 57 should be used generally. Alternatively, each data point may be plotted on the same graph with the efficiency curve determined in accordance with 24.5.4, 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 if the mean temperature had been controlled to equal ambient air temperature. Therefore, these values may be used in conjunction with Formula 57 to compute the different values of K_{hem} (θ_L, θ_T).

28 Determination of the pressure drop across a collector (Liquid) (optional)

28.1 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.

28.2 Test installation

The collector shall be mounted in accordance with Clause 21 and coupled to a test loop which conforms broadly to Clause 23, 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 23.1.3. In the case of unglazed collectors the direction of the fluid flow may be recommended by the manufacturer.

28.3 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 flow rate for a short period to force air from the collector.

28.4 Test procedure

a) Glazed solar collectors

The pressure drop between the collector inlet and outlet connections shall be determined for flow rates which span the range likely to be used in real operation. In the absence of specific flow rate recommendations by the manufacturer, pressure drop measurements shall be made over the range of flow rates from 0,005 kg/s to 0,03 kg/s per square meter of collector gross 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 flow rate 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 flow rates, 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. Fifteen 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 flow rate recommendations by the manufacturer, pressure drop measurements shall be made over the range of flow rates from 0,02 kg/s to 0,1 kg/s per square meter of collector gross area.

At least five measurements shall be made at values equally spaced over the flow rate range. The zero level shall be checked as well.

28.5 Measurements

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

a) fluid temperature at the collector inlet;

b) fluid flow rate;

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

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

28.6 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.

28.7 Test conditions

The fluid flow rate shall be held constant to within ± 1 % of the nominal value during test measurements.

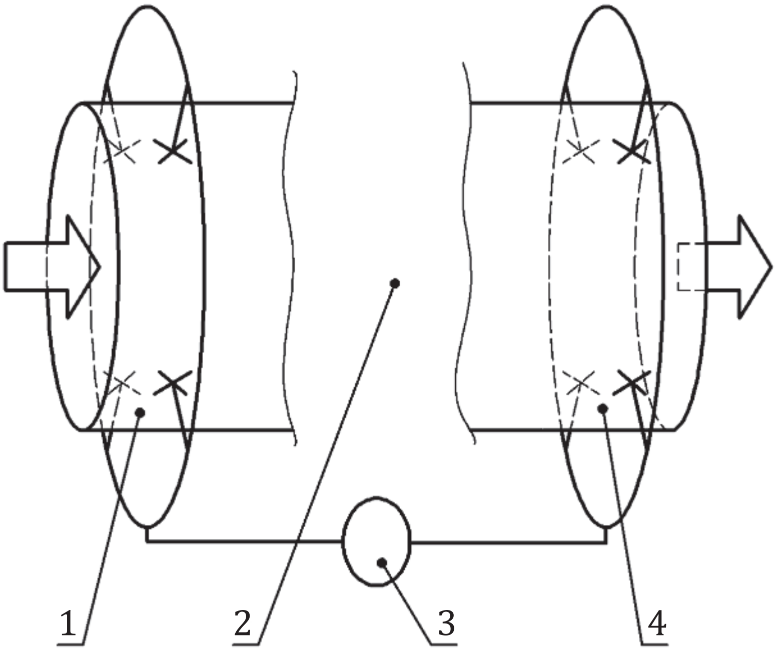
The inlet temperature of the heat transfer fluid shall be held constant to within ± 5 K (± 1 K for unglazed collectors) during test measurements. The test shall be carried out with the collector at a temperature which lies within ± 10 K of that of the surrounding air. Pressure drop tests at other temperatures may be important for oil-based heat transfer fluids.

28.8 Calculation and presentation of results

The pressure drop shall be presented graphically as a function of the fluid flow rate for each of the tests performed, using the format sheets given in A.16.8.

28.9 Pressure drop for air collectors

28.9.1 General



Key

1	air inlet test duct
2	solar collector
3	differential pressure measuring device
4	air outlet test duct

Figure 17 — Schematic representation of the measurement of pressure drop of the solar air heating collector

Measuring points shall be positioned upstream and downstream of the collector, as illustrated in Figure 17 — Schematic representation of the measurement of pressure drop of the solar air heating collector. For collectors tested under negative gauge pressure, the collector inlet gauge pressure shall be below the atmospheric pressure.

28.9.2 Instruments and devices

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

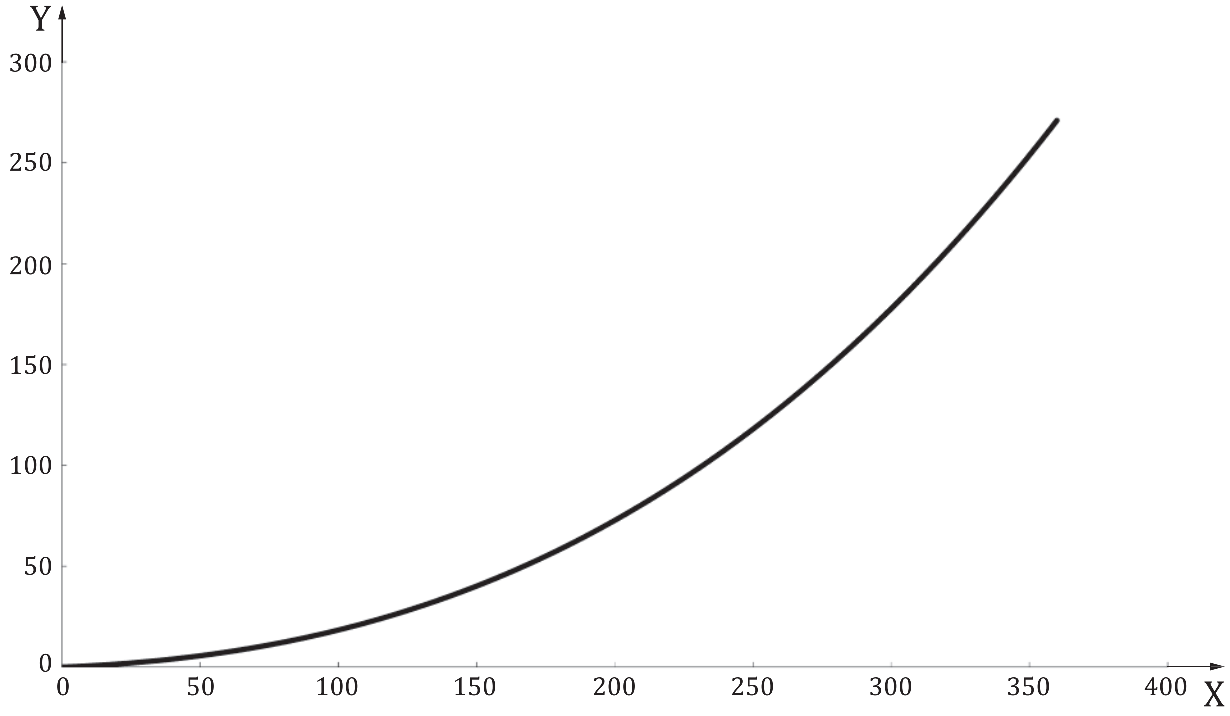
The static pressure drop of an air heating collector and static pressure upstream or downstream of the collector shall be determined with instruments that have an accuracy of ± 10 Pa.

28.9.3 Boundary conditions and methodology

The measurement shall be done at ambient temperature ± 5 K. At least five mass flow rates shall be measured. These shall be distributed over the range of operation as defined by the manufacturer as specified in 24.4.2.3. The maximum shall be 1,5 × mp_{max} given by the manufacturer. At each operation point the pressure shall reach steady-state conditions for at least 10 min. The pressure drop curve shall be given as shown in Figure 18 — Example of a pressure drop curve of an air heating collector.

28.9.4 Calculation and presentation of results

The pressure drop measured during normal working conditions, as represented by the thermal performance test, shall be reported in A.16.8.



Key

X mass flow [kg/h]

Y pressure drop [Pa]

Figure 18 — Example of a pressure drop curve of an air heating collector

Annex A
(normative)

Test reports

Test reports shall be issued in accordance to ISO/IEC 17025. Test reports may be issued on single tests or complete test sequences.

A.1 Solar collector description

For the identification of the solar collector, the description shall be as complete as possible and shall include at least the characteristics listed below if applicable. In case the information is given by the manufacturer this must be clearly stated.

Name of manufacturer:.......................................

Brand Name:.. Serial No:.........

Collector Type:...................... Drawing Document No:

Year of Production:................

Test flow rate:......................... kg/s

Standard stagnation temperature at 1000 W/m^2

and 30 °C ambient temperature:.................. °C

Collector mounting:.............................

Collector:

Type name:............................

e.g. Flat plate/evacuated/sub atmospheric, etc:................
....

Dimensions of collector unit

Length:................................mm

Width:................................mm

Height:................................mm Gross Area: m^2

Weight empty:..............

Fluid content:..............

Enclosure side material:.....................

Enclosure back material:...................

Frame fastening methods (pop rivets, screws, etc.):...................

Air filtration:.....................

☐ yes

☐ no

If yes, please indicate the filter grade according to EN 77
9:..........................

Absorber:

Material:..

Fin Width:.. mm

Fin thickness:... mm

Solar absorptance α:... %

Hemispherical emittance ε:............................. %

Surface treatment:..

Bond between riser and fin/plate (e.g. mechanical, solder, weld-ultrasonic, laser):..................

Number of risers:..................................

Riser diameter or dimensions:.......................... mm

Distance between risers:............................... mm

Dimensions (Length, Width, Height):....................... mm

Header diameter or dimensions:......................... mm

Flow pattern:...................................

Absorber surface (air collectors only):...................... m^2

Type of absorber (air collectors only): overflow/ underflow/ flow through:...................

Absorber “heat exchanger” surface (substitution of “Fin width” and “Fin thickness” for solar air heating collectors):...................................

Glazing:

Thickness:............................. mm

Solar Transmittance:......................... %

Glazing surface characteristics (e.g. clear, textured, coated):

Heat pipe:

External diameter of pipe:............................ mm

External diameter of condenser:............................ mm

Reflector:

Type of reflector:.............................

Dimensions:.. mm

Material:..

Limitations:

Maximum operation temperature:............................. °C

Maximum operation pressure at 45 °C:.................... Pa

Maximum operating pressure at maximum temperature of operation:............................... Pa

Other limitations:...

Photograph of the collector:................................

Comments on collector design:.........................

Schematic diagram of collector mounting:................

Heat transfer medium:.................................. water / oil / other

Specifications (additives etc.):............................

Alternative acceptable heat transfer fluids:.................................

For solar collectors with integrated technical components (ventilator, PV-panel…) all components have to be listed with their technical data:..
....

If a ventilator or other noise emitting component is integrated in the unit the acoustic emission of the uninstalled collector and the installed collector (inside/outside of the building) shall be indicated by the manufacturer according to EN 13142.

A.2 Record of test sequence and summary of main results

All significant damage to the collector, including rain penetration, should be summarized in Table A. 1.

Full details should be given in the individual test result sheets.

Table A.1 — Result summary table

Test		Date		Summary of main test results
		Start	End	
Internal pressure				
Leakage test				
Rupture or collapse test				
High-temperature resistance				
Exposure or pre-exposure				
Active and passive controls test				
External thermal shock	First			
	Second			
Internal thermal shock	First			
	Second			
Rain penetration				
Freeze resistance				
Mechanical load				
Impact resistance (optional)				
Final inspection				
Thermal performance				
Pressure drop measurement				

Remarks:

A.3 Internal pressure tests for fluid channels

A.3.1 General

The test method chosen from Clause 6 and the heat the fluid used shall be reported together with the maximum collector operating pressure specified by manufacturer.

A.3.2 Test conditions

Test temperature:	°C
Test pressure:	kPa
Test duration:	min

A.3.3 Test results

Give details of any observed or measured leakage, swelling or distortion and any of the failures denoting “major failure”, defined in Clause 18.

A.4 Leakage test for closed loop air heating collectors

A.4.1 General

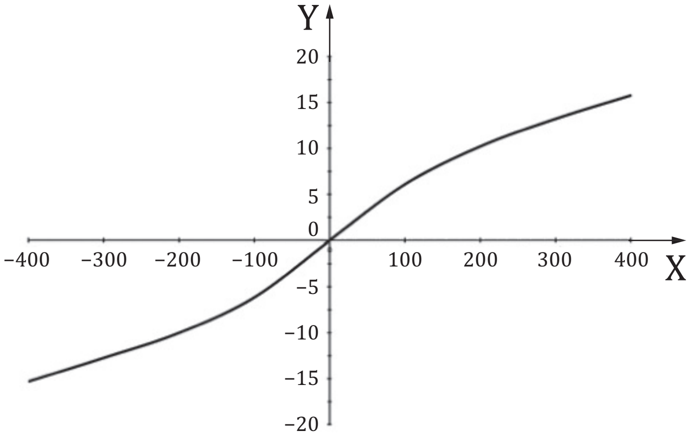
Full details of the test procedure used, including the volumetric flow rate, ambient temperature, intermediate pressure and test periods used, shall be reported with the test results.

A.4.2 Test conditions

Test (ambient) temperature:	°C
Test (fluid) temperature:	°C
Test duration at each pressure:	s

A.4.3 Test results

Leakage flow measured at minimum four positive and four negative pressure values:



Key

X Collector pressure [Pa]

Y Leakage volumetric flow rate [m³/h]

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

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

Collector Pressure over ambient pressure	Leakage volumetric flow rate ($V_{p.L}$)
[Pa]	[m³/s]

A.5 Rupture or collapse test

A.5.1 General

The test report shall include full details of the test procedure, including test conditions such as air pressure, temperature, and test period. Any evidence of collapse of the collector, permanent distortion of the collector, or permanent displacement of collector components shall be reported.

A.5.2 Test conditions

Test (ambient) temperature: °C

Test (fluid) temperature: °C

Test pressure: Pa

Test irradiance (if applicable): s

Test duration: s

A.5.3 Test results

Any evidence of collapse of the collector, permanent distortion of the collector, or permanent displacement of collector components shall be reported.

A.6 High-temperature resistance test and determination of standard stagnation temperature

A.6.1 Method used to heat collectors

Outdoor testing

In solar simulator

A.6.2 Method used for determination of standard stagnation temperature

Measurement and extrapolation (Annex C2)

Calculation out of performance characteristics (Annex C3)

A.6.3 Test conditions

A.6.3.1 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

If a fluid was circulated during the high temperature tests specifications must be given for the flow rate, fluid temperature, and duration of flow.

NOTE If standard stagnation temperature was not determined together with the high temperature resistance test please give additional data on the test conditions valid for this determination within brackets.

A.6.3.2 Additional information required if an evacuated tubular collector was tested

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

A.6.3.2.1 Additional information required if the absorber temperature was measured using a suitable fluid (as described in 9.2, note 2)

The absorber was partially filled with .... and the average pressure was .... Pa, which corresponds to the average absorber temperature given in A.6.3.1.

A.6.4 Results from determination of standard stagnation temperature

Standard stagnation temperature at 1000 W/m^2 and 30 °C ambient temperature

Given by the manufacturer: °C

Determined by the laboratory: °C

☐ Standard stagnation temperature given by the manufacturer is found to be adequate for the installer manual

☐ Standard stagnation temperature given by the manufacturer is found NOT to be adequate for the installer manual and the laboratory value shall be used

A.6.5 Results from high temperature resistance test

Inspection should be conducted according to Clause 18. A full description and evaluation shall be given of any problems or failures observed, including any of the failures denoting “major failure”, defined in Clause 18, together with appropriate photographs.

A.7 Exposure test

A.7.1 Test conditions

Collector tilt angle (degrees from horizontal):

In Tables A.2 and A.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 ϑ_a have values greater than those specified in Table 4 ;
- surrounding air temperature, ϑ_a (°C);

If a fluid was circulated during the exposure test specifications must be given for the flow rate, fluid temperature, and duration of flow.

A.7.2 Climatic conditions for all days during the test

Table A.3 — General exposure test data record

Date	H MJ/m^2	ϑ_a °C
Total: .... days in which $H >$ ....MJ/m^2		

A.7.3 Time periods in which irradiance and surrounding air temperature have values greater than those specified in Table 4

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

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

A.7.4 Test results

Inspection should be conducted according to Clause 18. A full description and evaluation should be given of any problems or failures observed, including any of the failures denoting “major failure”, defined in Clause 18, together with appropriate photographs.

A.8 External thermal shock test:

A.8.1 Test conditions

A.8.1.1 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
Flow rate 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

A.8.1.2 Additional information required if an evacuated tubular collector was tested

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

A.8.1.3 Additional information required if the absorber temperature was measured using a suitable fluid (as described in 12.2)

The absorber was partially filled with .... and the average pressure was ....Pa, which corresponds to the absorber temperature given in A.8.1.1.

A.8.2 Test results

Inspection should be conducted according to Clause 18. A full description and evaluation should be given of any problems or failures observed, including any of the failures denoting “major failure”, defined in Clause 18, together with appropriate photographs.

A.9 Internal thermal shock test:

A.9.1 Test conditions

A.9.1.1 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

Mass flow rate 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

A.9.1.2 Additional information required if an evacuated tubular collector was tested

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

A.9.1.3 Additional information required if the absorber temperature was measured using a suitable fluid (as described in 13.2, note 2)

The absorber was partially filled with .... and the average pressure was ....Pa, which corresponds to the absorber temperature given in A.9.1.

A.9.2 Test results

Inspection should be conducted according to Clause 18. A full description and evaluation should be given of any problems or failures observed, including any of the failures denoting “major failure”, defined in Clause 18, together with appropriate photographs.

A.10 Rain penetration test

A.10.1 Test conditions

A.10.1.1 Collector mounting

Collector mounted on:

Open frame

Simulated roof

Collector tilt angle (degrees from horizontal): °

A.10.1.2 Water spray

Duration of water spray: h

A.10.2 Test results

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

Inspection should be conducted according to Clause 18. A full description and evaluation should be given of any problems or failures observed, including any of the failures denoting “major failure”, defined in Clause 18, together with appropriate photographs.

A.11 Freeze resistance test

A.11.1 Collector type

☐ Freeze-resistant when filled with water

☐ Drain-down

A.11.1.1 Test conditions

A.11.1.2 Tilt angle of collector during test (degrees from horizontal):

°

A.11.1.3 Details of freeze–thaw cycles

Table A.5 — Freeze test record

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.

A.11.1.4 Rate of chamber cooling:

K/h

A.11.1.5 Rate of chamber heating:

K/h

A.11.2 Test results

Inspection should be conducted according to Clause 18. A full description and evaluation should be given of any problems or failures observed, including any of the failures denoting “major failure”, defined in Clause 18, together with appropriate photographs.

A.12 Mechanical load test

A.12.1 Positive pressure test of the collector and the fixings

A.12.1.1 Method used to apply pressure:

Loading with gravel or similar material

Loading with water

Suction cups

Other

A.12.1.2 Test conditions

Maximum positive pressure load applied in test:

A.12.1.3 Test results

In case a deformation can be observed this shall be recorded.

Inspection should be conducted according to Clause 18. A full description and evaluation should be given of any problems or failures observed, including any of the failures denoting “major failure”, defined in Clause 18, together with appropriate photographs.

A failure can be the destruction of the cover or the permanent deformation of the collector box or the fixings. 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 according to A.12. If no failure occurs, then the maximum pressure which the collector sustained shall be reported.

Control functions which have been verified shall be described and reported with the test results.

A.12.2 Negative pressure test of the collector and fixings

A.12.2.1 Method used to apply pressure:

Suction cups

Pressurization of collector box

Other

A.12.2.2 Test conditions

Maximum negative pressure load applied during test:

A.12.2.3 Test results

In case a deformation can be observed this shall be recorded.

Inspection should be conducted according to Clause 18. A full description and evaluation should be given of any problems or failures observed, including any of the failures denoting "major failure", defined in Clause 18, together with appropriate photographs.

A.13 Impact resistance test using steel balls

A.13.1 Test conditions

Diameter of ball:	mm
Mass of ball:	g
Maximum dropping height	m

Test performed using:

☐ Vertical impact (dropping ball)

☐ Horizontal impact (pendulum)

A.13.2 Test results

Give details of any damage to the collector and any of the failures denoting "major failure", defined in Clause 18.

All points of impact shall be reported and illustrated by means of photos in the test report, together with the ice balls' diameters or the heights from which the steel balls were dropped. The results of the collector inspection shall be reported, together with the number of impacts and the impact locations.

The test report shall include notices and illustrations of both minor and major failures.

Minor failures are aesthetical defects (e.g. dents) neither affecting the function and durability nor the power output of the collector.

Major failures are mechanical defects affecting negatively the durability of the collector or its power output, or influencing negatively the safety of the product. They include, e.g. breaking of the glass, other damages of the cover or of other collector parts, leakages, dissolution of coating, radiation scattering through the cover, etc.

A.14 Impact resistance test using ice balls

A.14.1 Test conditions

Diameter of ball: mm

Mass of ball: g

Velocity of ball: m/s

Number of impacts:

A.14.2 Test results

Give details of any damage to the collector and any of the failures denoting “major failure”, defined in Clause 18.

A.15 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	....
g) Any other abnormality resulting in a reduction of thermal performance or service life time			....

A.16 Performance test

A.16.1 Test method

The test method used shall be reported.

A.16.2 Location and orientation

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

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

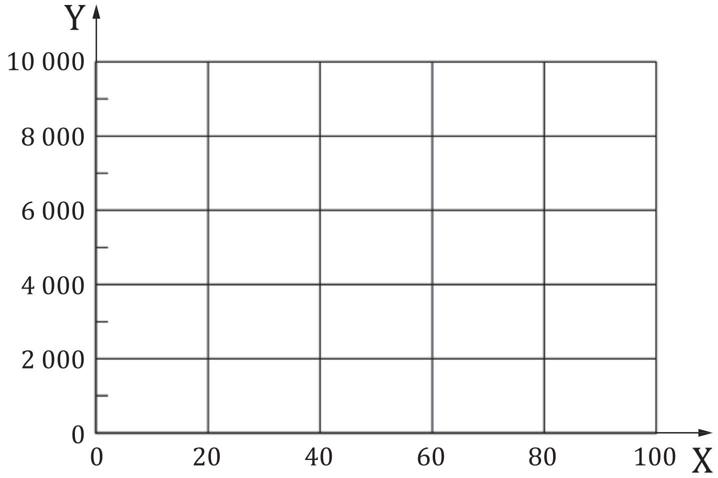
A.16.3 Test results for glazed liquid heating collectors under steady-state conditions

Presentation of the results shall only be given up to the max. temperature difference between mean fluid and ambient plus a maximum of 30 K for which the collector was tested.

Peak Power ($G = 1000\ W/m^2$) per collector unit:......................................W_{peak}

Table A.6 — Collector power output record

	Irradiance		
ϑ_m-ϑ_a in K	400 W/m^2 (G_b = 200 W/m^2, G_d = 200 W/m^2)	700 W/m^2 (G_b = 440 W/m^2, G_d = 260 W/m^2)	1000 W/m^2 (G_b = 850 W/m^2, G_d = 150 W/m^2)
0			
10			
...			
Max. tested temperature difference + 30 K			
NOTE The reported values are for normal incidence.			



Key

X $(\vartheta_m - \vartheta_a)$ [K]

Y Power output per collector unit [W]

Figure A.2 — Power output per collector unit (for G = 1000 W/m²)

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

Gross area used for curve in m²:

The instantaneous efficiency is defined by:

$$\eta_{\text{hem}} = \frac{\dot{Q}}{A_G \cdot G} \tag{A.1}$$

Fluid flow rate used for the tests: kg/s

Second order fit to data:

$$\eta_{\text{hem}} = \eta_{0,\text{hem}} - a_1\left(\frac{\vartheta_m - \vartheta_a}{G}\right) - a_2 G\left(\frac{\vartheta_m - \vartheta_a}{G}\right)^2 \tag{A.2}$$

Table A.7 — Collector performance coefficients

Based on Gross Area		**Std.Deviation**
$\eta_{o,hem}$		
$\eta_{o,b}$ (Estimated)		
a_1		
a_2		

Time constant

τ_c = s

Effective thermal capacity

C = J/K

Determination:

Calculation:

Indoors:

Outdoors:

Incident angle modifier

Angle:

$K_{\text{hem}}(\theta_L, \theta_T)$:

K_d (Estimated[2]):

Observed failures

Give details of any of the failures denoting “major failure”, defined in Clause 18

Delivery of sample:

Start of test:

End of test:

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

A.16.4 Test results for unglazed liquid heating collectors under steady-state conditions

Peak Power (G” = 1000 W/m^2) per collector unit:………………………………W_{peak}

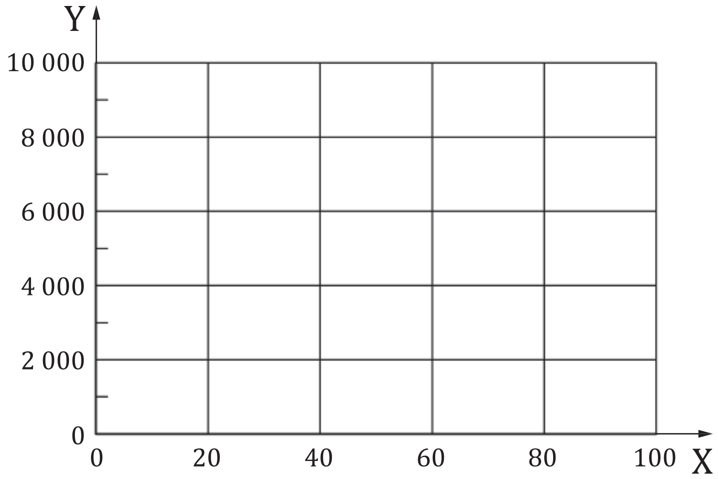
Table A.8 — Collector power output record

	Net Irradiance (G”)		
ϑ_m-ϑ_a = 2 K	400 W/m^2 (G_b = 200 W/m^2, G_d = 200 W/m^2)	700 W/m^2 (G_b = 440 W/m^2, G_d = 260 W/m^2)	1000 W/m^2 (G_b = 850 W/m^2, G_d = 150 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 A.3 — Power output per collector unit for the following wind conditions: u < 1 m/s, u = 1,5 ± 0,5 m/s and u = 3 ± 0,5 m/s

---

[2] Using steady state to QDT conversion according to B.2



Key

X $(\vartheta_m - \vartheta_a)$ [K]

Y Power output per collector unit [W]

Figure A.3 — Power output per collector unit (for G = 1000 W/m²)

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

The instantaneous efficiency is defined by:

$$\eta_{\mathrm{hem}} = \frac{\dot{Q}}{A_G \cdot G''} \tag{A.3}$$

collector gross area used for curve: m^2

Fluid flow rate used for the tests: kg/s

$$\eta_{\mathrm{hem}} = \eta_{\mathrm{o,hem}}(1 - b_u u) - (b_1 + b_2 u)\ \frac{(\vartheta_m - \vartheta_a)}{G''} \tag{A.4}$$

Table A.9 — Collector performance coefficients

Based on Gross Area		**Std.Deviation**
$\eta_{o,\,hem}$		
$\eta_{o,b}$ (Estimated)		
b_u		
b_1		
b_2		

Time constant

τ_c = s

Effective thermal capacity

C = J/K

Determination:

Calculation:

Indoors:

Outdoors:

Incident angle modifier

Angle:

$K_{\mathrm{hem}}(\theta_L, \theta_T)$:

K_d (Estimated[3]):

Observed failures

Give details of any of the failures denoting “major failure”, defined in Clause 18.

Delivery of sample:

Start of test:

End of test:

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

A.16.5 Test results for solar air collectors under steady-state conditions

Presentation of the results shall only be given up to the maximum temperature difference between mean fluid and ambient plus a maximum of 30 K for which the collector was tested.

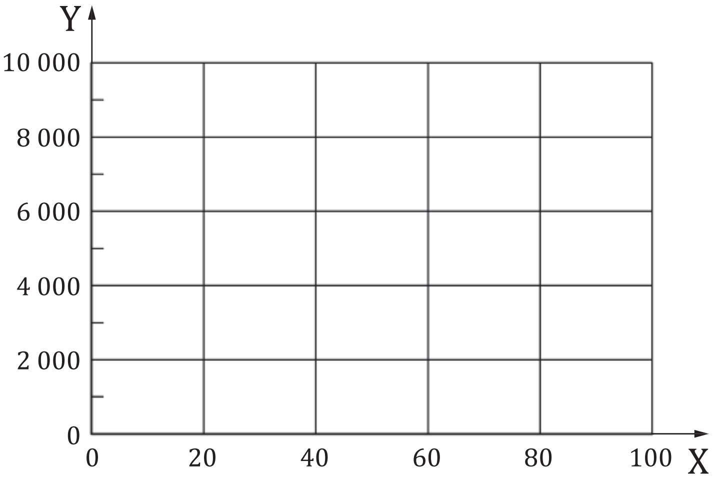
Peak Power, $\dot{Q}_{peak}$ (G = 1000 W/m^2) per collector unit:…………………………………W$_{\mathrm{peak}}$

Table A.10 — Collector power output record

	Irradiance		
ϑ_m-ϑ_a in K	400 W/m^2 (G$_b$ = 200 W/m^2, G$_d$ = 200 W/m^2)	700 W/m^2 (G$_b$ = 440 W/m^2, G$_d$ = 260 W/m^2)	1000 W/m^2 (G$_b$ = 850 W/m^2, G$_d$ = 150 W/m^2)
0			
10			
…			
Max. tested temperature difference + 30 K			
NOTE The reported values are for normal incidence.			

---

[3] Using steady state to QDT conversion according to B.2.



Key

X $(\vartheta_m - \vartheta_a)$ [K]

Y Power output per collector unit [W]

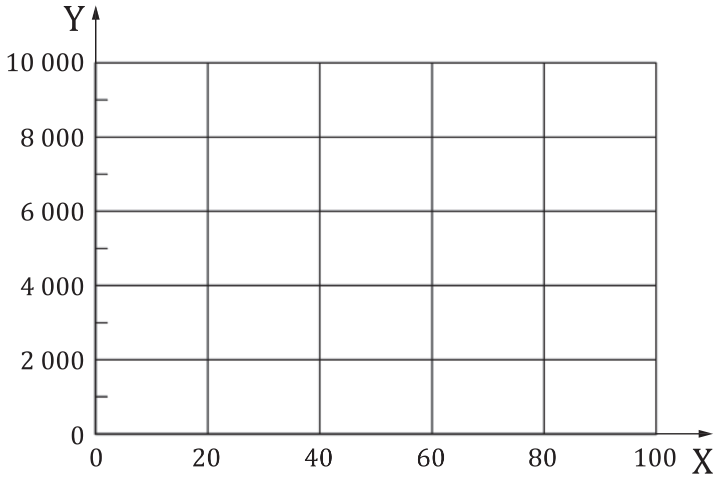
Figure A.4 — Power output per collector unit (for G = 1000 W/m²)

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

Reference Gross area A_G in m²:

The instantaneous efficiency is defined by:

$$\eta_{\text{hem}} = \frac{\dot{Q}}{A_G \cdot G} \tag{A.5}$$



Key

X $(\vartheta_m-\vartheta_a)$ [K]

Y Power output per collector unit [W]

Figure A.5 — Power output per collector unit (for G = 1000 W/m²)

In the test report there shall be a curve for each mass flow rate.

NOTE Performance of open to ambient collectors can only be presented as single data points (one operating temperature) in the diagram.

Fluid flow rate used for the tests:

$\dot{m}_1$ kg/h

$\dot{m}_2$ kg/h

$\dot{m}_3$ kg/h

Second order fit to data:

$$\eta_{\text{hem}} = \eta_{0,\text{hem}} - \mathrm{a}_1\left(\frac{\vartheta_\text{m} - \vartheta_\text{a}}{G}\right) - \mathrm{a}_2 \cdot G\left(\frac{\vartheta_\text{m} - \vartheta_\text{a}}{G}\right)^2 \qquad \text{(A.6)}$$

For closed loop collectors the measured efficiency point should be presented in a similar table:

Table A.11 — Collector performance coefficients for closed loop collectors

Based on Gross Area		**Std. Deviation**
$\eta_{o,hem}$		
a_1		
a_2		
$\dot{m}_1$		
$\eta_{o,hem}$		
a_1		
a_2		
$\dot{m}_2$		
$\eta_{o,hem}$		
a_1		
a_2		
$\dot{m}_3$		

Time constant

τ_c = s at $\dot{m}$ = kg/h

Incident angle modifier:

Angle:

$K_{hem}(\theta_L, \theta_T)$:

Observed failures

Give details of any of the failures denoting “major failure”, defined in Clause 18.

Delivery of sample:

Start of test:

End of test:

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

A.16.6 Test results for open to ambient (glazed /unglazed) air heating collectors

For open to ambient collectors the measured instantaneous efficiency points should be presented in a similar table:

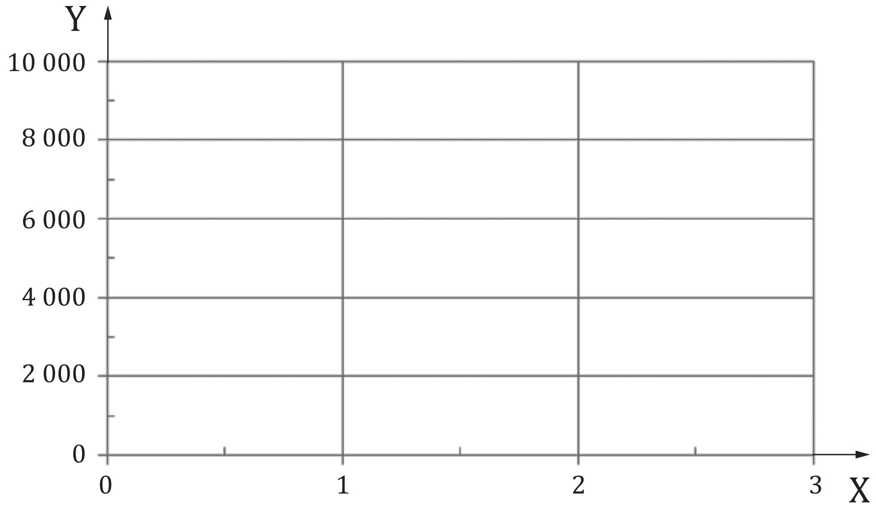
Table A.12 — Collector performance coefficients for open to ambient collectors

Based on Gross Area		**Std. Deviation**
η_{hem}		
$\Delta T/G$		
$\dot{m}_1$		
η_{hem}		
$\Delta T/G$		
$\dot{m}2$		
η_{hem}		
$\Delta T/G$		
$\dot{m}3$		

For unglazed collectors the reference irradiance shall be G”.

Table A.13 — Power output per collector unit (W)

Irradiance				
Wind speed	Flow rate	400 W/m^2	700 W/m^2	1000 W/m^2
0 m/s (or minimum test wind speed)	$\dot{m}$ min			
	$\dot{m}$ middle			
	max			
1.5 m/s	$\dot{m}$ min			
	middle			
	max			
3 m/s	min			
	middle			
	max			
NOTE The reported values are taken at normal incidence.				



Key

X Air speed [m/s]

Y Power output per collector unit at 1000 [W]

Figure A.6 — Power output per collector unit (for G = 1000 W/m²)

Wind dependency:

First order fit to data: $\eta_m = \eta_{\max,\,0\ \mathrm{m/s}} - b_u * u$

Table A.14 — Wind dependency coefficients

m_1 =	$\eta_{\max,\,0\ \mathrm{m/s}}$ =	b_u =
m_2 =	$\eta_{\max,\,0\ \mathrm{m/s}}$ =	b_u =
m_3 =	$\eta_{\max,\,0\ \mathrm{m/s}}$ =	b_u =

Table A.15 — Data from the efficiency test

G	m_{pe}	ϑ_a	ϑ_e	T^*_m	u	η
W/m²	kg/h	°C	°C	K m²/W	m/s	

In case of unglazed collectors G" should be used as reference irradiance

Maximum starting temperature at minimum 1000 W/m² and 20-30 °C ambient temperature:

$T_{\max,\ \mathrm{start:}}$ °C at $\dot{m}$ = kg/h

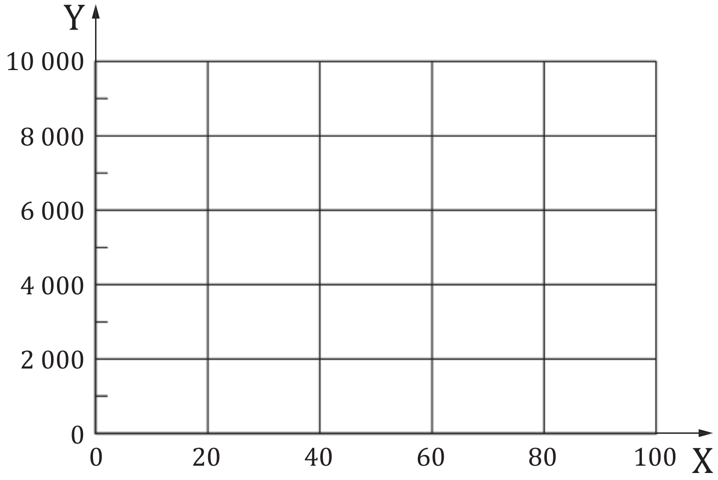
A.16.7 Test results for unglazed/glazed liquid heating collectors under quasi dynamic conditions

Presentation of the results shall only be given up to the max. temperature difference between mean fluid and ambient plus a maximum of 30 K for which the collector was tested.

Peak Power, $\dot{Q}_{peak}$ (G = 1000 W/m^2) per collector unit:......................................W$_{peak}$

Table A.16 — Collector power output record

	Irradiance		
ϑ_m-ϑ_a in K	400 W/m^2 (G$_b$ = 200 W/m^2, G$_d$ = 200 W/m^2)	700 W/m^2 (G$_b$ = 440 W/m^2, G$_d$ = 260 W/m^2)	1000 W/m^2 (G$_b$ = 850 W/m^2, G$_d$ = 150 W/m^2)
0			
10			
...			
Max. tested temperature difference + 30 K			
NOTE The reported values are for normal incidence.			



Key

X (ϑ_m - ϑ_a) [K]

Y Power output per collector unit [W]

Figure A.7 — Power output per collector unit (for G = 1000 W/m^2)

Thermal performance based on gross area and mean temperature of heat transfer fluid:

Gross area used for curve in m^2:

Fluid flow rate used for the tests: kg/s

Multilinear fit to data:

$$\frac{\dot{Q}}{A}=\eta_{0,b}\cdot K_b\left(\theta_L,\theta_T\right)\cdot G_b+\eta_{0,b}\cdot K_{\theta d}\cdot G_d-c_6\cdot u\cdot G-c_1\cdot\left(\vartheta_m-\vartheta_a\right)-c_2\cdot\left(\vartheta_m-\vartheta_a\right)^2$$
$$-c_3\cdot u\cdot\left(\vartheta_m-\vartheta_a\right)+c_4\cdot\left(E_L-\sigma\cdot T_a^4\right)-c_5\cdot\frac{d\vartheta_m}{dt}$$

Table A.17 — Thermal Performance Formula Coefficients

	Gross Area:	
	Value	**Standard deviation**
$\eta_{0,b}$		
K_d		
b_0		
c_1		
c_2		
c_3		
c_4		
c_5		
c_6		

Table A.18 — Incidence angle modifier

θ	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**
$K_b(\theta_L,0)$								
$K_b(0,\theta_T)$								

Observed failures

Give details of any of the failures denoting “major failure”, defined in Clause 18.

Delivery of sample:

Start of test:

End of test:

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

A.16.8 Pressure drop measurements

Pressure drop measured at minimum five mass flow rates shall be reported according to Table A. 19. Flow rates are given in [kg/s] for liquid heating collectors and in [kg/h] for air heating collectors.

Table A.19 — Collector pressure drop record

Flow rate [kg/s] or [kg/h]			
ΔP [Pa]			

Annex B
(informative)

Mathematical models for liquid heating collectors

B.1 Steady-state- and quasi dynamic models

In Clause 25, different mathematical models are used to describe the thermal performance of liquid heating collectors, depending on the collector type (glazed or unglazed collector) and the test method used (steady-state or quasi dynamic test method). This informative annex clarifies the relationship between the different models.

The most comprehensive model is that of Formula 27 used in the quasi dynamic test method:

$$\begin{aligned}\frac{\dot{Q}}{A} &= \eta_{0,b} \cdot K_b\left(\theta_L,\theta_T\right) \cdot G_b + \eta_{0,b} \cdot K_{\theta d} \cdot G_d - c_6 \cdot u \cdot G - c_1 \cdot \left(\vartheta_m - \vartheta_a\right) - c_2 \cdot \left(\vartheta_m - \vartheta_a\right)^2 \\ &\quad - c_3 \cdot u \cdot \left(\vartheta_m - \vartheta_a\right) + c_4 \cdot \left(E_L - \sigma \cdot T_a^4\right) - c_5 \cdot \frac{d\vartheta_m}{dt}\end{aligned} \qquad \text{(B.1)}$$

c_1 is the heat loss coefficient at ($\vartheta_m - \vartheta_a$) = 0, expressed in W/($m^2$·K).

c_2 describes the temperature dependence of the heat loss coefficient, expressed in W/(m^2·K^2).

c_3 describes the wind speed dependence of the heat loss coefficient, expressed in J/(m^3·K).

c_4 describes the long wave irradiance dependence of the heat loss coefficient. It is dimensionless.

c_5 is the effective thermal capacitance, expressed in J/(m^2·K).

c_6 describes the wind speed dependence of the zero loss efficiency, expressed in s/m.

$K_b(\theta_L, \theta_T)$ is the incidence angle modifier (IAM) for beam radiation. It is dimensionless and depends on the incidence angle as described in, e.g. ASHRAE 93-77:

$$K_b(\theta_L, \theta_T) = 1 - b_0((1/\cos\theta) - 1) \qquad \text{(B.2)}$$

For collectors with special IAM-dependence, see 27.1.2

K_d is the Incidence angle modifier for diffuse radiation. It is dimensionless.

The collector model used in the steady-state method for glazed collectors (Formula 20) can also be written as follows:

$$\dot{Q}\ /A_G = \eta_{0,\mathrm{hem}} \cdot G - a_1\ (\vartheta_m - \vartheta_a) - a_2\ (\vartheta_m - \vartheta_a)^2 \qquad \text{(B.3)}$$

This model has been widely used both in testing (ISO 9806-1 and ASHRAE 93-77) and for simulation.

For the irradiance, symbol G is used, although it could have been also G_b to point out that only high irradiance levels are accepted in the test sequence, leading to 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 solar radiation incidence is nearly normal, so that incidence angle effects can be neglected. Finally, the test conditions stipulate that the wind speed shall be in the range 2 to 4 m/s, so that wind speed effects can also be neglected.

For unglazed collectors tested under steady-state conditions the model of Formula (I.1) has been extended to include the wind speed and long-wave irradiance dependences (Formula 24):

$$\dot{Q} = A_G \cdot G''\left(\eta_{0,\text{hem}}\left(1-b_u \cdot u\right)-\left(b_1-b_2 \cdot u\right)\frac{\vartheta_m-\vartheta_a}{G''}\right) \tag{B.4}$$

where

$$G'' = G + \frac{\varepsilon}{\alpha}\left(E_L - \sigma \cdot T_a^4\right) \tag{B.5}$$

The modelling of the long wave irradiance dependence of the collector is made in the same principle way as described in 25.1.3 for testing of unglazed collectors. The Net long wave irradiance is defined as (E_L-σ·T_a^4) where E_L is the measured long wave thermal irradiance in the collector plane. However, a purely mathematical difference exists between the steady-state formula in 25.1.3 and the quasi dynamic formula that eliminates G'' and the use of the $\varepsilon\ /\alpha$ -coefficient in the latter. Physically, the long wave radiation corrections are the same. In this International 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''. The main reason for this is that the collector formula 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 the following a description is given of how the basic Formula 21 can be generalized to obtain the comprehensive model of Formula 27.

Clauses 26 and 27 describe optional test procedures for the determination of the incidence angle dependence of the zero loss efficiency and the effective thermal capacitance of the collector. Therefore, the comprehensive instantaneous collector formula can be written as:

$$\dot{Q}\ /A_G = \eta_{0,\text{b}}K_b(\theta_L,\ \theta_T)G - c_1(\vartheta_\text{m}-\vartheta_\text{a}) - c_1(\vartheta_\text{m}-\vartheta_\text{a})^2 - c_5 \cdot d\vartheta_\text{m}/dt \tag{B.6}$$

As a first step towards Formula 30, the first term of the formula is divided into two parts to separate beam and diffuse irradiance effects. $\eta_{0,\text{b}} \cdot K_b(\theta_L,\ \theta_T) \cdot$ G is expressed as $\eta_{0,\text{b}} \cdot K_b(\theta_L,\ \theta_T) \cdot G_b + \eta_{0,\text{b}} \cdot K_\text{d} \cdot G_\text{d}$ while the other terms in the formula are kept unchanged. To be able to test a wider range of solar collectors including, e.g. unglazed collectors, and also to achieve a more comprehensive characterization of the collector, another correction is applied to the collector model: the wind speed dependence is modelled by means of two terms added to the basic formula. One term describes the effect on the zero loss efficiency ($-\ \text{c}_6 \cdot \text{u} \cdot \text{G}$) and the other one the effect on the heat losses ($-\ \text{c}_3 \cdot \text{u} \cdot\ (\vartheta_\text{m} - \vartheta_\text{a})$). Finally, the long-wave irradiance dependence of the heat losses is included [new term c_4 (EL-σ·T_a^4)], leading to Formula 27.

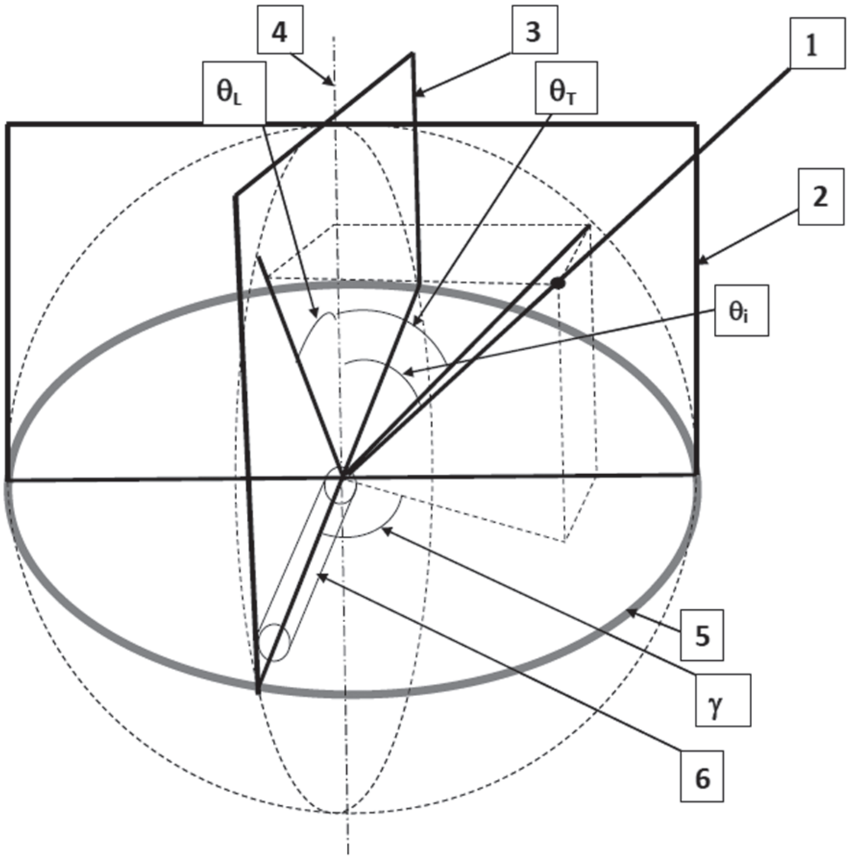
Details of the calculation of a set of steady-state collector parameters for presentation of the power curve starting from the quasi dynamic collector parameters are given in 26.1.4.4.

B.2 Steady-state parameter conversion

For some collector types it has been shown that a separation between direct and diffuse irradiance is needed in the collector model in order to accurately predict their performance. As steady-state testing does not offer this feature, a method has been developed to estimate $\eta_{0,\text{b}}$ and K_d based on steady-state test data. This is an approximate way to precede with existing input data from SS tests in order to be able to use SS test data for QDT-model based annual kWh calculations. Comparisons/Validations of K_d values derived with this method in comparison to K_d derived with the QDT test method under all day weather conditions show that this approximate method to derive K_d will probably slightly underestimate the K_d.

The principle is that the $K_b(\theta_L)$ and $K_b(\theta_T)$ for beam radiation onto the collector are used to integrate and average the diffuse solar radiation acceptance over a quarter sphere above the collector. See Figure B.1 — Geometry defining symmetry planes and angles used in the conversion for the geometry. The quarter sphere is limited by 1) the collector plane, 2) the transversal plane and 3) the longitudinal plane in relation to the collector. It is assumed that $K_\text{d}(\theta_L,\ \theta_T) = K_\text{b}(\theta_L,\ \theta_T)$ in each direction, which is reasonable as we look at small "cones" of diffuse radiation from a certain direction in the sky. The summation is a weighted summation over the quarter sphere, according to both the elemental area size in this direction of (θ, γ) multiplied by the $K_d(\theta_L, \theta_T)$ value in the same direction, as seen from the collector plane. $K_b(\theta_L, \theta_T)$ is calculated with the classical method as $K_b(\theta_L, \theta_T) = K_b(\theta_L)^* K_b(\theta_T)$. Finally to derive the average K_d over the whole quarter sphere the weighted summation over the quarter sphere is divided by the same weighted summation over the quarter sphere, but assuming that $K_d(\theta_L, \theta_T) = 1.00$. A kind of normalization is done with exactly the same formulas.

Figure B.2 — Summary of formulae used for the calculation of $\eta_{0,\text{b}}$ and K_d from $\eta_{0,\text{hem}}$ and K_d presents how, with a set of formulae, $\eta_{0,\text{b}}$ and K_d are calculated from $\eta_{0,\text{hem}}$ and K_d values that are input in the pale yellow cells.



Key

1 Sun position
2 Transversal plane
3 Longitudinal plane
4 Collector normal
5 Collector plane
6 Example vacuum tube

Figure B.1 — Geometry defining symmetry planes and angles used in the conversion

The incidence angle onto the collector projected onto the longitudinal plane (“North-South” plane), θ_{L}, is given by the Formula B.7.

$$\theta_L(\theta,\gamma)=\tan^{-1}\left(\frac{\sin(\theta)\cdot\cos(\gamma)}{\cos(\theta)}\right) \tag{B.7}$$

where

θ is the incidence angle onto collector from the collector normal direction;

γ the solar azimuth angle relative to the north-south plane.

The same analogy goes for the θ_{T} (projection on the “East-West” plane) of the quarter sphere,

$$\theta_T(\theta,\gamma)=\tan^{-1}\left(\frac{\sin(\theta)\cdot\cos(\gamma)}{\cos(\theta)}\right) \tag{B.8}$$

K_{bNS} and K_{bEW} are then interpolated from the input data of the IAM using θ_{L} and θ_{T} respectively, the desired γ value and Formula B.9,

$$K_{bNS}\,(\theta,\gamma)=K_{bNS}\,(\theta_L(\theta,\gamma))\cdot\left(\frac{(\theta_L(\theta,\gamma)+10\,/\,10)\cdot 10-\theta_L(\theta,\gamma)}{10}\right) \tag{B.9}$$

$$K_{bNS}\,(\theta_L(\theta,\gamma)+10)\cdot\left(\frac{(\theta_L(\theta,\gamma)-(\theta_L(\theta,\gamma)\,/\,10)\cdot 10}{10}\right)$$

where $\dfrac{\theta_L(\theta,\gamma)+10}{10}$ and $\dfrac{\theta_L(\theta,\gamma)}{10}$ are rounded down to the closest integer.

The same procedure is then used for determining K_{bEW} with the exception of using θ_T and input values are taken from K_{bEW}.

The summation is then a weighted summation over the quarter sphere, according to both the elemental area size in this direction of (θ, γ) and also multiplied by the K_d (θ_L, θ_T) value in the same direction, as seen from the collector plane. According to the standard method for biaxial IAM, the total incidence angle modifier K_b (θ_L, θ_T) is calculated as the product of the two modifiers,

$$K_b(\theta_L,\theta_T)=K_b(\theta_L)\cdot K_b(\theta_T) \tag{B.10}$$

Finally to derive the average K_d over the whole quarter sphere the weighted summation over the quarter sphere is divided by the same weighted summation over the quarter sphere, but assuming that K_d (θ_L, θ_T) = 1.00. All kind of normalization is done with exactly the same formulas.

$$K_d=\frac{K_d(\theta_L,\theta_T)\cdot\sin(\theta)\cdot\cos(\theta)}{\sum\limits_{\theta=0}^{90}\left(\sin\theta\cdot\cos\theta\right)} \tag{B.11}$$

Annex C
(normative)

Properties of water

C.1 Density of water (at 1 bar) in kg/m^3

$$\rho(\vartheta)=a_0+a_1\cdot\vartheta+a_2\cdot\vartheta^2+a_3\cdot\vartheta^3+a_4\cdot\vartheta^4 \tag{C.1}$$

$(0\leq\vartheta\leq 99{,}5\ °C)$

with

a_0 = 999,85 [kg/m^3]

a_1 = 6,187 10^{-2} [kg/m^3·K]

a_2 = −7,654 10^{-3} [kg/m^3·K^2]

a_3 = 3,974 10^{-5} [kg/m^3·K^3]

a_4 = −1,110 10^{-7} [kg/m^3·K^4]

The deviation of the polynomial to the values published in tables is always smaller than 0,02 %. R^2 equals 0,99998.

C.2 Density of water (at 1 to 12 bar) in kg/m^3

The formula given in C.1 is valid for the temperature range $(0\leq\vartheta\leq 99{,}5°C)$ and an extrapolation to higher temperatures leads to a significant deviation. The following formula results in a fit of data given for water at 1 bar[4)]

$(0\leq\vartheta\leq 99{,}6°C)$ and at 12 bars[5)] $(100\leq\vartheta\leq 185°C)$. The water is assumed to be in liquid phase.

$$\rho(\vartheta)=a_0+a_1\cdot\vartheta+a_2\cdot\vartheta^2+a_3\cdot\vartheta^3+a_4\cdot\vartheta^4+a_5\cdot\vartheta^5 \tag{C.2}$$

$(0\leq\vartheta\leq 185°C)$

with

a_0 = 999,85 [kg/m^3]

a_1 = 5,332 10^{-2} [kg/m^3·K]

a_2 = −7,564 10^{-3} [kg/m^3·K^2]

a_3 = 4,323 10^{-5} [kg/m^3·K^3]

a_4 = −1,673 10^{-7} [kg/m^3·K^4]

[4)] Verein Deutscher Ingenieure (editor): VDI Wärmeatlas, 10. ed,; Springer-Verlag Berlin, 2006.

[5)] Wagner et al.: The IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam; ASME, Journal of Engineering for Gas Turbines and Power, Volume 122, 2000.

a_5 = 2,447 10^{-10} [kg/m^3·K^5]

The deviation of the polynomial to the values from those references is always smaller than 0,03 % [compared to VDI $(0 \leq \vartheta \leq 99{,}6°C)$] or 0,12 % [compared to IAPWS $(0 \leq \vartheta \leq 185°C)$]. The extrapolation to higher temperatures does not lead to such a high deviation as that of C.1 but in case of need it shall be checked or another formula shall be used.

C.3 Specific heat capacity of water (at 1 bar) in kJ/(kg·K)

$$c_p(\vartheta) = a_0 + a_1 \cdot \vartheta + a_2 \cdot \vartheta^2 + a_3 \cdot \vartheta^3 + a_4 \cdot \vartheta^4 + a_5 \cdot \vartheta^5 \qquad \text{(C.3)}$$

$$(0 \leq \vartheta \leq 99{,}5\,°C)$$

with

a_0 = 4,217 [kJ/kg·K]

a_1 = −3,358 10^{-3} [kJ/kg·K^2]

a_2 = 1,089 10^{-4} [kJ/kg·K^3]

a_3 = −1,675 10^{-6} [kJ/kg·K^4]

a_4 = 1,309 10^{-8} [kJ/kg·K^5]

a_5 = −3,884 10^{-11} [kJ/kg·K^6]

The deviation of the polynomial to the values published in tables is always smaller than 0,02 %. R^2 equals 0,9994.

C.4 Specific heat capacity of water (at 1 to 12 bar) in kJ/(kg·K)

The formula given in C.3 is valid for the temperature range $(0 \leq \vartheta \leq 99{,}5°C)$ and an extrapolation to higher temperatures leads to a significant deviation. The following formula results in a fit of data given for water at 1 bar[6] $(0 \leq \vartheta \leq 99{,}6°C)$ and at 12 bars[7] $(100 \leq \vartheta \leq 185°C)$. The water is assumed to be in liquid phase.

$$c_p(\vartheta) = a_0 + a_1 \cdot \vartheta + a_2 \cdot \vartheta^2 + a_3 \cdot \vartheta^3 + a_4 \cdot \vartheta^4 + a_5 \cdot \vartheta^5 + a_6 \cdot \vartheta^6 \qquad \text{(C.4)}$$

$$(0 \leq \vartheta \leq 185°C)$$

a_0 = 4,2184 [kJ/kg·K]

a_1 = −2,8218 10^{-3} [kJ/kg·K^2]

a_2 = 7,3478 10^{-5} [kJ/kg·K^3]

a_3 = −9,4712 10^{-7} [kJ/kg·K^4]

a_4 = 7,2869 10^{-9} [kJ/kg·K^5]

a_5 = −2,8098 10^{-11} [kJ/kg·K^6]

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[6] Verein Deutscher Ingenieure (editor): VDI Wärmeatlas, 10. ed,; Springer-Verlag Berlin, 2006.

[7] Wagner et al.: The IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam; ASME, Journal of Engineering for Gas Turbines and Power, Volume 122, 2000.

$a_6 = 4{,}4008\ 10^{-14}$ [kJ/kg·K^7]

The deviation of the polynomial to the values from those references is always smaller than 0,04 % [compared to VDI $(0 \le \vartheta \le 99{,}6°C)$] or 0,14 % [compared to IAPWS $(0 \le \vartheta \le 185°C)$]. The extrapolation to higher temperatures does not lead to such a high deviation as that of D.3 but in case of need it shall be checked or another formula shall be used.

Annex D
(informative)

General guidelines for the assessment of uncertainty in solar collector efficiency testing

D.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 International 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 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 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).

D.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 behaviour of the collector can be described by a M-parameter single node, steady-state or quasi-dynamic model:

$$\eta=c_1p_1+c_2p_2+...+c_Mp_M \tag{D.1}$$

where

η is the collector instantaneous efficiency

$p_1, p_2,...,p_N$ are quantities, the values of which are determined experimentally through testing

$c_1, c_2,...,c_M$ 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 on the model used. From these primary measurements the values of parameters $\eta, p_1, p_2,...,p_M$ are derived for each point of observation j, $j = 1...J$. 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 $\eta_j, p_{1,j}, p_{2,j},...,p_{M,j}$.

For the determination of uncertainties, it is essential to calculate the respective combined standard uncertainties $u(\eta_j)$, $u(p_{1,j})$, $...u(p_{M,j})$ in each observations point. It should be noted that in practice the uncertainties $u(\eta_j)$, $u(p_{1,j})$, ...$u(p_{M,j})$ 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:

$$u=\left(\sum_k u_k^2\right)^{1/2} \tag{D.2}$$

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:

$$s=\frac{\sum_{i=1}^{I} s_i}{I}\text{, and } u_A(s)=\left(\frac{\sum_{i=1}^{I}(s_i-s)^2}{I(I-1)}\right)^{1/2} \tag{D.3}$$

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*:

$$u(y)=\left(\sum_{i=1}^{P}\left(\frac{\partial f}{\partial x_i}\right)^2 \left(u(x_i)\right)^2+2\sum_{i=1}^{P-1}\sum_{j=i+1}^{P}\frac{\partial f}{\partial x_i}\frac{\partial f}{\partial x_j}\operatorname{cov}(x_i,x_j)\right)^{1/2} \tag{D.4}$$

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 flow rate 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.

D.3 Fitting and uncertainties in efficiency testing results

During analysing the data a least square fitting of the model formula is performed, in order to determine the values of coefficients c_1, c_2,...,c_M for which the model of Formula (D.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 $(\eta_j, p_{1,j}, p_{2,j},...,p_{M,j})$ 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-squared function:

$$\chi^2 = \sum_{j=1}^{J} \frac{(\eta_j - (c_1 p_{1,j} + c_2 p_{2,j} + ... c_N p_{M,j}))^2}{u_j^2} \tag{D.5}$$

where u_j^2 is the variance of the difference:

$$\eta_j - (c_1 p_{1,j} + c_2 p_{2,j} + ... c_N p_{M,j} \tag{D.6}$$

$$u_j^2 = (\eta_j - (c_1 p_{1,j} + c_2 p_{2,j} + ... c_N p_{M,j})) = (u(\eta_j))^2 + c_1^2(u(p_{1,j}))^2 + ... + c_M^2(u(p_{M,j}))^2$$

Finding coefficients c_1, c_2,...,c_M and their standard uncertainties by minimizing chi-squared function is complicated, because of the nonlinearity present in Formula (D.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 JxM components $k_{j,m}$ are constructed from M basic functions evaluated at the J experimental values of p_1, ...,p_M weighted by the uncertainty u_j:

$$k_{j,m} = \frac{p_{m,j}}{u_j}\ ,\ K = \begin{vmatrix} \frac{P_{1,1}}{u_1} & . & . & \frac{P_{1,M}}{u_1} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ \frac{P_{1,J}}{u_J} & . & . & \frac{P_{M,J}}{u_J} \end{vmatrix} \tag{D.7}$$

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:

$$l_j = \frac{\eta_j}{u_j}\ ,\ L = \begin{vmatrix} \eta_1 / u_1 \\ . \\ . \\ . \\ \eta_j / u_j \end{vmatrix} \tag{D.8}$$

The *normal formula of the least square problem* can be written:

$$(\mathrm{K}^{\mathrm{T}} \cdot \mathrm{K}) \cdot \mathrm{C} = \mathrm{K}^{\mathrm{T}} \cdot \mathrm{L} \tag{D.9}$$

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,...,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 Formula (D.6) for the calculation of u_j^2, $J = 1...J$ and the formation of matrix K and of vector L. The solution of Formula (D.9) gives the new values of coefficients c_1, c_2,...,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($K^T \cdot K$) 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:

$$u(c_m) = \sqrt{z_{m,m}}$$

, $m=1,\ldots,M$ (D.10)

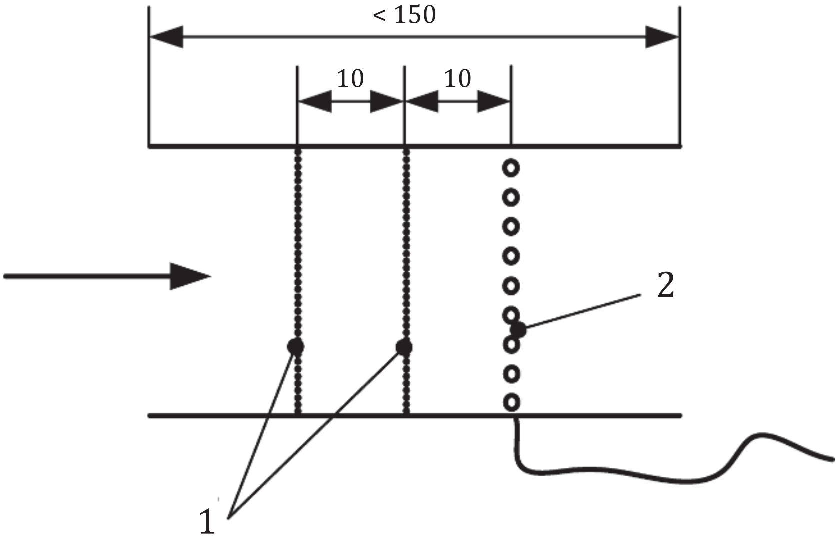
$Cov(c_k,c_l) = z_{k,l} = z_{l,k}$, $k=1,\ldots,M$ and $l=1,\ldots,M$ and $k \neq l$ (D.11)

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(η) in the predicted values of η using Formula (D.1) and Formula (D.4). Formula (D.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 E
(informative)

Measurement of the velocity weighted mean temperature

A mean-value forming temperature sensor shall be evenly distributed in an Archimedean spiral of the whole cross-section. This mean temperature ϑ_m can be determined in the air channel with a sensor. In front of the sensor, two fine-mesh nets are installed at a distance of 10 mm. The distance between the two nets should be 10 mm. The average temperature ϑ_m is equal to the thermal mean fluid temperature $\vartheta_{m,th}$ if the flow distribution is homogeneous.

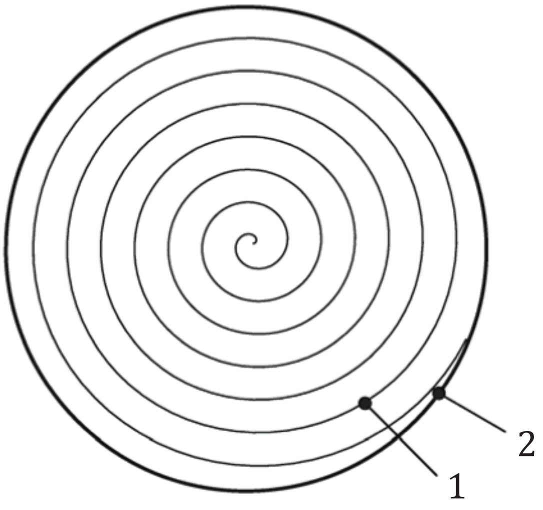


Key

1 Flow conditioner sieve

2 Temperature sensor

Figure E.1 — Arrangement in the sensor



Key

1 Temperature sensor (e.g. ϑ_{in})

2 Insulated pipe

Figure E.2 — An example of a temperature sensor

Calibration Recommendation: The sensor can be calibrated over the full range when it is installed in the air channel. The homogeneity of the temperature shall be at any temperature < 0,2 K. This can be achieved and monitored in the flow channel by measuring at least 12 temperature points using an adequately positioned air swirler behind the mean-value forming temperature sensor. The measuring points shall be chosen so that each measuring point represents the temperature of an equal area.

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