GUIDE TO STANDARD ISO 9806:2017

A Resource for Manufacturers, Testing Laboratories, Certification Bodies and Regulatory Agencies

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Register

1 Purpose and Scope

The purpose of this guide is to provide guidance about the application and use of the ISO 9806:2017 standard concerning the testing of solar thermal collectors. It is intended to support the interpretation and application of the standard. The guide has been developed with three different target groups and objectives in mind.

1. A guide directed to **established and new test laboratories** for collector testing. The main purpose here is to give a quick introduction to the standard for new laboratories and in general to contribute to a uniform interpretation of the standard and presentation of results.
2. A guide directed to **manufacturers and importers of collectors**. Here, the purpose is to give a very light introduction to the standard and to explain how it is used for type testing as well as for innovation and development support.
3. A guide directed to **certification bodies**. The intention here is to provide access to easy evaluation of the presented results.

How to use the present guide?

The present guide is divided into single Fact Sheets, usually one per chapter of ISO 9806:2017.

Fact Sheet 1
gives very general information about the guide and the single fact sheets as well as the target group description.

Fact Sheet 2
gives very general information about the normative reference.

Fact Sheet 3
gives information about certification issues in alignment with ISO 9806:2017.

Fact Sheet 4
describes the different solar thermal collector types.

Fact Sheet 5.1
gives a schedule for the test sequence.

Fact Sheet 5.2
gives information for testing collectors with specific attributes.

Fact Sheets 6 to 27
are the most important. Each of these Fact Sheet concisely gives:
- an introduction to the test procedure in the form of a flow chart (where possible);
- an information box about the main boundary conditions for testing without repeating all conditions from ISO 9806:2017;
- some "Tips and Tricks" about testing, mainly addressed to new and established testing laboratories;
- a "Manufacturers Information Box", giving a very light introduction to the standard and to explain how it is used for type testing as well as for innovation and development support;
- the "Exemplary Results" on one hand represents typical results for standard collectors and on the other hand provides an idea for presentation of the results in the report.

2 Normative References

The following standards are referred to in the text of ISO 9806:2017 in such a way that some or all of their content constitutes requirement of this standard. For dated references only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 9488, Solar energy - Vocabulary

A Rough Comparison with other Solar Thermal Collector Standards

Beside ISO 9806:2017 there are a couple of other established testing standards. The following table shows a rough comparison regarding the scope as well as the necessary tests and measurements of different collector test standards.

Table 1: Comparison of scope, thermal performance and tests required by different standards.

Standard	EN 12975-1:2006	ISO 9806:2017	CSA F 378.1,2, 2011
Scope			
SLHC (Solar Liquid Heating Collectors)	✓	✓	✓
SAHC (Solar Air Heating Collectors)	×	✓	✓
WISC (Wind and Irradiance Sensitive Collectors)[1]	×	✓	×
ICS (Integrated Collector Storage)	×	×	×
CSC (Concentrating Solar Collector)[1]	×	✓	×
PV-T (Photovoltaic Thermal Collector)[1]	×	✓	×
Thermal Performance			
Efficiency measurement on SLHC	✓	✓	✓
Efficiency measurement on SAHC	×	✓	✓
Determination of the thermal capacity	✓	✓	×
Determination of the leakage flow rate[2]	×	✓	×
Collector time constant	×	✓	✓
Durability and Reliability Tests			
Internal Pressure Test	✓	✓	✓
Rupture and Collapse Test[2]	×	✓	✓
Exposure Test	✓	✓	✓
External Thermal Shock Test	✓	✓	✓
Internal Thermal Shock Test	✓	✓	×
Rain Penetration Test	✓	✓	×
Mechanical Load Test	✓	✓	✓
Determination of the Stagnation Temperature	✓	✓	×
Determination of the max. Start Temperature[2]	×	✓	×
Determination of Pressure Drop	×	✓	✓
Impact Resistance Test	×	✓	×
Freeze Resistance Test	✓	✓	×
Final Inspection	✓	✓	✓

[1]Could be SLHC or SAHC
[2]Only for SAHC

3 Certification (Solar Keymark, IAPMO and SRCC)

This Fact Sheet gives a slight overview on the basic operation of certification. As an example, a rough comparison between the testing requirements for solar Keymark, IAPMO and SRCC is used.

Figure 1: Solar Keymark, IAPMO and SRCC

Involved Parties and their Responsibility with the Example of Solar Keymark Certification

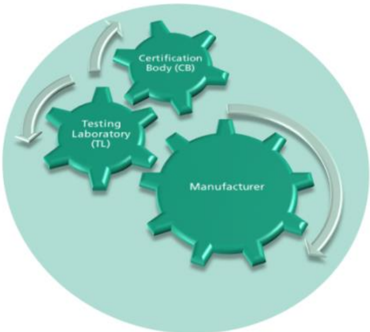


Figure 2: Involved parties (©Fraunhofer ISE)

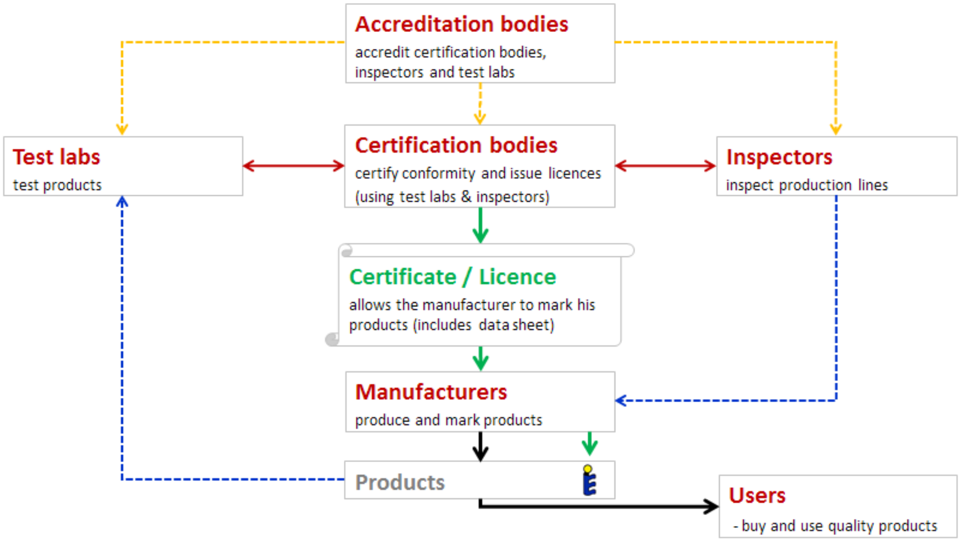


Figure 3: Certification flowchart with all parties involved (Source: Solar Heat Europe)

Certification Procedure with the Example of Solar Keymark Certification

The flow chart shows the general certification process of Solar Keymark Certification. Due to legal requirements, a Solar Keymark Certificate can only be issued on the basis of tests according to a European standard. For this reason, the European collector test standard EN 12975 is mentioned within this chart. Nevertheless the tests and measurements must be performed according to ISO 9806, which defines the testing requirements and is the reference in EN 12975.

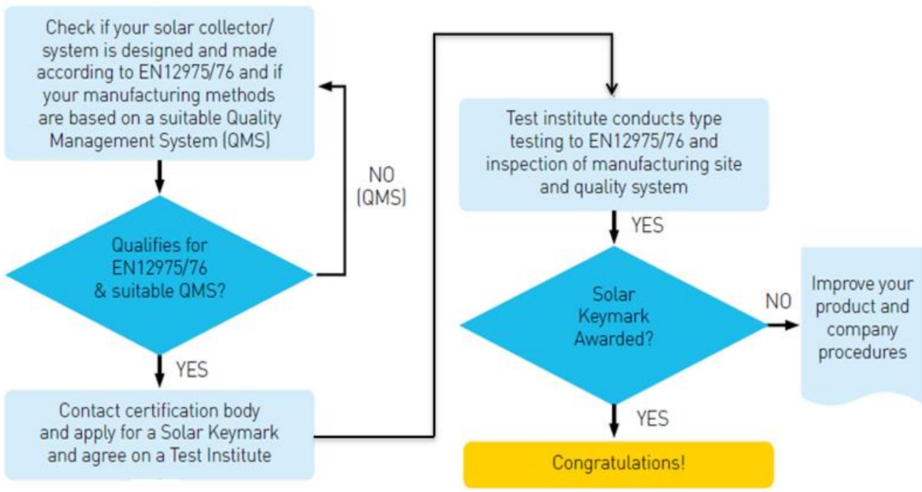


Figure 4: Solar Keymark certification procedure (Source: Solar Heat Europe)

A Rough Comparison of Different Schemes

Solar Keymark certificates are issued by different empowered certification bodies (CBs), while in the US both the Solar Rating and Certification Corporation (SRCC) and the International Association of Plumbing and Mechanical Officials (IAPMO) provide certification to a number of solar-related standards, including SRCC Standard 100, which is based largely on ISO 9806. In all cases tests and measurements are performed by accepted laboratories, which send the test results to the CB. Laboratories must be accredited in accordance with ISO/IEC 17025 (General requirements for the competence of testing and calibration laboratories), including accreditation to perform tests according to ISO 9806:2017. CBs must be accredited in accordance with ISO/IEC 17065 (Requirements for bodies certifying products, processes and services), and inspection bodies must be accredited in accordance with ISO 17020 (Requirements for the operation of various types of bodies performing inspection).
Solar Keymark requires that testing laboratories be recognized by one or more CB, while in the US recognition by other CBs is not a requirement. CBs may impose additional requirements on testing laboratories, such as surveillance of the quality system and the test equipment. The following chart shows a comparison of the specific tests required, scope and certification schemes for Solar Keymark, IAPMO and SRCC.

Table 1: Comparison of certification requirements

	Scope	SLHC (Solar Liquid Heating Collectors)	SAHC (Solar Air Heating Collectors)	WISC (Wind and Infrared Sensitive Collector)	CSC (Concentrating Solar Collector)	PVT (Photovoltaic Thermal Solar Collector)	**Thermal Performance**	SLHC performance measurement	SAHC performance measurement	Effective thermal capacity	Leakage rate	Time constant	**Durability, Reliability and Safety**	Internal Pressure Test	Rupture and Collapse Test	Exposure Test	External Thermal Shock Test	Internal Thermal Shock Test	Rain Penetration Test	Mechanical Load Test	Standard Stagnation Temperature	Maximum Start Temperature	Pressure Drop	Impact Resistance	Freeze Resistance	Final Inspection	**Certification Requirements (surplus)**	Factory Inspection	Remote Sampling
SKM		✓	✓	✓	✓	✓		✓	✓	✓	×	×		✓	×	✓	✓	✓	✓	✓	✓	×	✓	×	✓	✓		✓	✓
SRCC		✓	✓	✓	✓	✓		✓	✓	✓	×	✓		✓	×	✓	✓	✓	×	×	×	×	✓	✓	×	✓		✓	✓
IAPMO		✓	✓	✓	✓	✓		✓	✓	✓	×	✓		✓	×	✓	✓	✓	×	×	×	×	✓	✓	×	✓		✓	✓

Global Solar Certification Network (GSCN)

Global Solar Certification Network
A global network of certification bodies, inspectors, test labs and solar thermal industry representatives

Figure 5: Global Solar Certification Network (GSCN), source GSCN

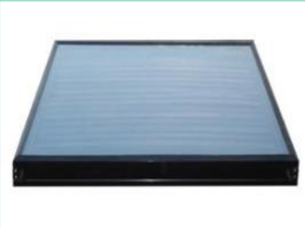
The aim of "Global Solar Certification Network" (GSCN) is to facilitate cross-border trading for manufacturers and other suppliers of solar thermal products; its objective is to minimize the need for re-testing and re-certification in every new country where products are to be marketed and sold. The concept of "Global Solar Certification" is being implemented for solar thermal collectors and is based on the test procedures given by ISO 9806:2017.

The "Global Solar Certification Network" is cooperation between solar certification bodies/schemes around the world. When a product has been certified by one of the participating certification bodies/schemes, the product can obtain certification from other participating certification schemes without re-testing of the product and without re-inspection of production facilities. (Source: http://www.gscn.solar)

4 Solar Collector Types

The ISO 9806:2017 standard covers performance, durability and reliability testing of almost all collector types available in the market. The standard is applicable to liquid heating collectors, air heating collectors, hybrid solar collectors co-generating heat and electric power, as well as to solar collectors using external power sources for normal operation and/or safety purposes (e.g. tracking concentrating collectors). Within the following table the most common types of solar collectors are described, including their characteristics and their typical field of applications.

Collector Types

Collector type		Characteristics	Typical applications
WISC liquid heating collectors	 *(Picture source: RISE)*	- High performance at low temperatures and highly dependent on wind speed and thermal irradiance; - Can often withstand freezing; - Sometimes designed for working under dew-point of ambient air (heat pumps).	- Swimming pools - Evaporators for heat pumps
Flat plate collector	 *(Picture source: QAiST - IEE/08/593/SI2.529236)*	Good performance at higher temperatures (typical temperatures for domestic hot water)	- Domestic hot water systems - Combi- systems - District heating
Vacuum tube collector	 *(Picture source: RISE)*	Good performance at higher temperatures (typical temperatures for domestic hot water and above)	- Domestic hot water and Combi-systems - District heating - Solar assisted cooling - Process heat
Stationary concentrating collector	 *(Picture source: RISE)*	Good performance at high temperatures	- Domestic hot water and Combi-systems - District heating - Solar assisted cooling - Process heat

Collector with external power source	 *(Picture source: QAiST - IEE/08/593/SI2.529236)*	Can be of Linear-Fresnel, parabolic trough or dish type	- Solar assisted cooling - Process heat - Power plants
Air-collectors (incl. WISC)	 *(Picture source: QAiST - IEE/08/593/SI2.529236)*	Can be of closed or open loop type, WISC or non-WISC	- Drying of crops - Pre-heating of air for building ventilation
Hybrids (incl. WISC)	 *(Picture source: QAiST - IEE/08/593/SI2.529236)*	Broad variation of subtypes: - WISC/non-WISC - Liquid/Air heating - Concentrating/non-concentrating	

5.1 Test Overview

During the collectors' lifetime some severe climatic and working conditions will be met. It is required that the collectors do not suffer major failures under these conditions. The reliability and durability tests were designed to reproduce the most probable extreme conditions that a collector would be subjected to. For each test, the standard describes in a very simple way the conditions that are intended to be simulated.

Table 1 clarifies the test list taken from ISO 9806:2017 summarizing all tests covered in the standard along with the preconditions or comments related to each test.

Table 1: Test list based on ISO 9806:2017

SLHC	SAHC CL	SAHC OTA	Polymerics	Clause	Test
–	✓	–	△	Clause 7	Air Leakage Rate Determination
–	△	△	△	Clause 8	Rupture and Collapse Test
△	△	△	△	Clause 9	Standard Stagnation Temperature Determination
✓	✓	✓	✓	Clause 10	Exposure Test
✓[1]	✓[1]	✓[1]	✓[1]	Clause 11	External Thermal Shock Test
✓	–	–	✓	Clause 12	Internal Thermal Shock Test
✓	✓	✓	✓	Clause 13	Rain Penetration Test
✓[2]	–	–	✓[2]	Clause 14	Freeze Resistance Test
✓	–	–	△	Clause 6	Internal Pressure Test for Fluid Channels
(✓)	(✓)	(✓)	(✓)	Clause 15	Mechanical Load Test
(✓)	(✓)	(✓)	(✓)	Clause 16	Impact Resistance Test
✓	✓	✓	✓	Clause 17	Final Inspection
✓	✓	✓	✓	Clause 19 - 26	Thermal Performance Test
✓	✓	✓	✓	Clause 27	Pressure Drop Measurement

✓ mandatory, ✓[1] only for collectors without toughened glass, ✓[2] only for collectors claimed to be freeze resistant and collectors containing heatpipe, (✓) mandatory but the manufacturer can define the maximum load to be zero, – not mandatory or not possible, △ mandatory and under SSC (Standard Stagnation Conditions; clause 9).

SLHC	Solar Liquid Heating Collector
SAHC CL	Solar Air Heating Collector with Closed Loop operation
SAHC OTA	Solar Air Heating Collector with Open To Ambient operation
Polymerics	collectors in which organic materials are used for fluid channels thereby being exposed to high temperatures and pressures respectively

5.2 Testing of Collectors with Specific Attributes

The ISO 9806:2017 covers the most current standard products. Some of those collector technologies require special considerations in testing which are described here.

Test Procedure

Due to special collector attributes the test procedures for functional as well as efficiency testing might be customized in accordance to the certain attribute.

Boundary Conditions

Collectors may have one or several attributes.
Attributes not mentioned in the test report shall not be considered as applicable for the tested collector.

Collector Types with Specific Attributes

Specific Attribute	Explanation	Examples
External power sources	Collector types that need an external power source for normal operation.	SAHC with integrated fans, tracking and concentrating collectors
Active or passive measures for normal operation and self-protection	In order to prevent damages caused by operating conditions like stagnation, pump-malfunction and others, some collector technologies are equipped with active and/or passive protection devices. Examples for active protection devices are: - UPS-Systems, ensuring that power interrupts do not negatively influence normal operation of the product. - MSR-Technology to avoid damages caused by system malfunctions, sudden changes of surrounding conditions, etc.	Tracking and concentrating collectors
Co-generating thermal and electrical power	Collectors producing thermal energy and electricity simultaneously.	PV-T Collectors
Wind and/or infrared sensitive collectors (WISC)	Wind sensitive means that the surrounding wind velocities significantly influence the thermal behavior (convective losses) of the collector. This is always given if the heat conducting components of a collector are directly exposed to the surrounding air. Infrared sensitive means that the collector's efficiency is significantly influenced by infrared irradiation. This is always given if there is no transparent cover in between the absorber and the radiation source/sink or if the transparent cover is in direct contact with the absorber.	SAHC where the heat transfer fluid is in direct contact with the transparent cover. Formerly those collectors were often called "Non-covered collectors" like swimming pool heaters, PV-T Collectors, Transpired SAHC's.
Façade collectors	Collectors that, according to the manufacturer's specifications, can be operational at inclination angles above 75° shall be considered as façade collectors.	Those products are often highly integrated in the function of a buildings envelope. Testing has to be customized.
Air and liquid heating	Collectors which are constructed to operate with liquid heat transfer fluids as well as air as heat transfer fluid.	This combination often appears in the context of solar thermal combined with heat pump technology.

Special Testing Considerations for:

Collectors using external power sources and/or active or passive measures for normal operation and self protection:

- If the collector which is using external power sources and/or active or passive for normal operation and self-protection is installed at the testing side of the testing laboratory, it is recommended that the manufacturer is present during the installation to avoid installation errors, errors in commissioning, and errors in system-settings;
- External parts of collectors like cabinets, sensors, etc. shall be weatherproof. Components which are an integral part of the collector (e.g. actuators, motors, cabinets, etc.) for which water penetration can be expected shall be a part of the rain penetration test;
- The function of a USP-System (undisturbed power supply) can easily be checked by interruption of main power supply.

Tracking and concentrating collectors CSC

- To be tested using the supplier's tracking system;
- Specific aspects related to durability testing, e.g. active protection;
- The procedure for the determination of the incident angle modifier as given within ISO 9806:2017 might not be applicable in case of unsymmetrical collector constructions without further adaptions;
- In-Situ testing might be necessary in case of large concentrating collectors;
- Testing shall be close to real operation conditions (e.g. pressure, temperature).

Collectors co-generating heat and electrical power PV-T

- All thermal performance tests shall be made under maximum electrical power point conditions (MPP-Mode);
- For all durability tests, the electrical power shall not be connected to any load (open circuit) to prevent cooling and to simulate worst case operating conditions;
- Electrical safety is not included in the test procedure of ISO 9806:2017.

Wind and Infrared Sensitive Solar Collector WISC

- Long wave irradiance and wind speed are important variables during performance testing and special considerations for measurements apply;
- Condensation effects on the performance are not accounted in the thermal performance test method.

Evacuated Tubular Solar Collector ETC

- Bi-axial incidence angle modifier (IAM) measurement required;
- Heat pipes and heat conduction paste, if present, need special attention;
- Heat pipe collectors must undergo a full exposure test before efficiency testing is started.

Façade collectors

- 50% of the initial outdoor exposure shall be made with the collector vertically installed.

Solar Air Heating Collectors SAHC

- The procedure for the determination of the incident angle modifier as given within ISO 9806:2017 might not be applicable. Mostly IAM is determined by an estimation on the basis of the collector design;
- The inflow conditions can significantly influence the collector efficiency.

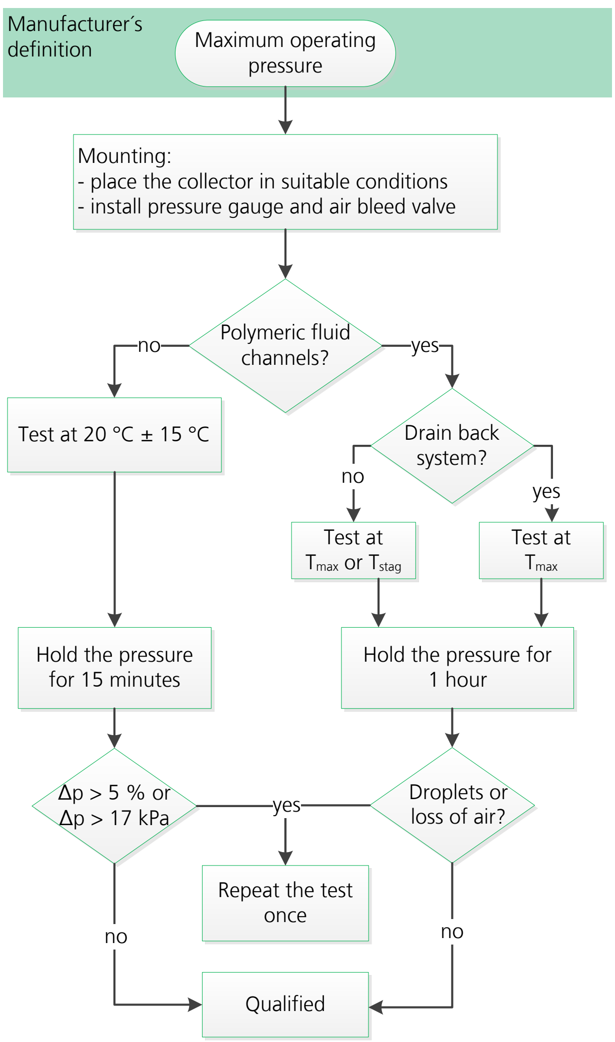
On-Side build collectors, customized collector

- In-situ or in-field testing maybe reasonable for collectors that are design for a specific costumer.

6 Internal Pressure Test (liquid heating collectors only)

The objective of the test is to determine if the absorber can withstand pressures which might occur during normal operation. The apparatus and procedures for an internal pressure test are strongly dependent on the type of material that the absorber is comprised of.

Test Procedure



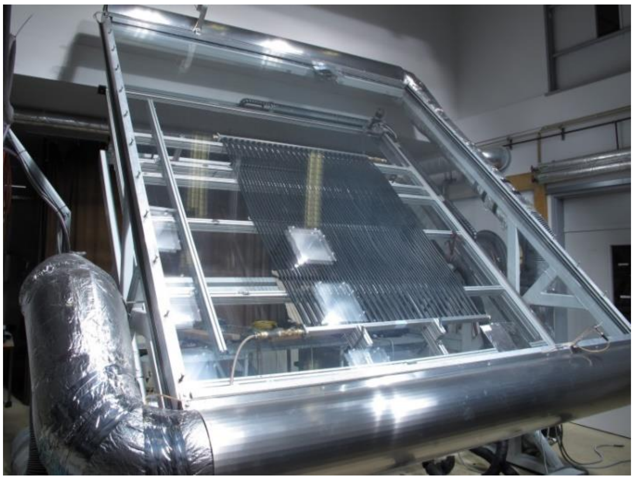


Figure 1: Internal pressure test of a polymeric collector at the indoor solar simulator of the TestLab Solar Thermal Systems, Fraunhofer ISE.

Boundary Conditions

Table 1: Differences between pressure tests for Polymeric and Non-Polymeric absorbers

	Non-Polymeric fluid channels	**Polymeric fluid channels**
Duration	> 15 min	> 60 min
Temperature	20 ± 15°C	Maximum operating temperature or stagnation temperature
Pressure source	Hydraulic or pneumatic	
Pressure	1.5 × maximum operating pressure	
Pre-conditioning	-	Half-exposure is required before start of the test
Requirement	5 % or 17 kPa (whichever is greater)	Droplets or loss of air

"Tips and Tricks"

- Note that "absorber" includes both the absorber plate as well as the fluid containing tubes;
- This test is only applicable for liquid heating collectors;
- This test is the last test of the test sequence before final inspection;
- Pay attention to avoid overpressure during pressurizing the collector;
- Be aware that there is a significant safety risk if the collector does not pass;
- The collector must be completely filled with fluid. Use an air bleed valve to ensure that no air remains;
- For fluid channels made of polymeric materials, one of the following methods can be used:

Table 2: Summary of the heating procedures for internal pressure tests using hydraulic pressure source.

Stagnation temperature/Test temperature	Pressure source	Fluid used	Heating procedure	Precautions during test
< 90°C	Hydraulic	Water	Submerge the absorber in a heated water bath.	For safety reasons, the collector shall be encased in a transparent box to protect personnel in the event of explosive failure during this test.
> 90°C	Hydraulic	Oil	Connect the collector to a hot oil circuit. Connect the collector to an oil circuit / heat the collector using a solar simulator. Connect the collector to an oil circuit / heat the collector using natural solar irradiance.	Take safety measures to protect personnel from hot oil in the event of explosive failure during test.
> 90°C	Pneumatic	Air	Heat the collector using a solar simulator. Heat the collector using natural solar irradiance.	For safety reasons, the collector shall be encased in a transparent box to protect personnel in the event of explosive failure during this test.

Manufacturers Information Box

- The manufacturer shall define the maximum operating pressure;
- Preliminary In-house-testing is recommended to check whether the collector withstands those requirements (especially in case of polymeric fluid channels).

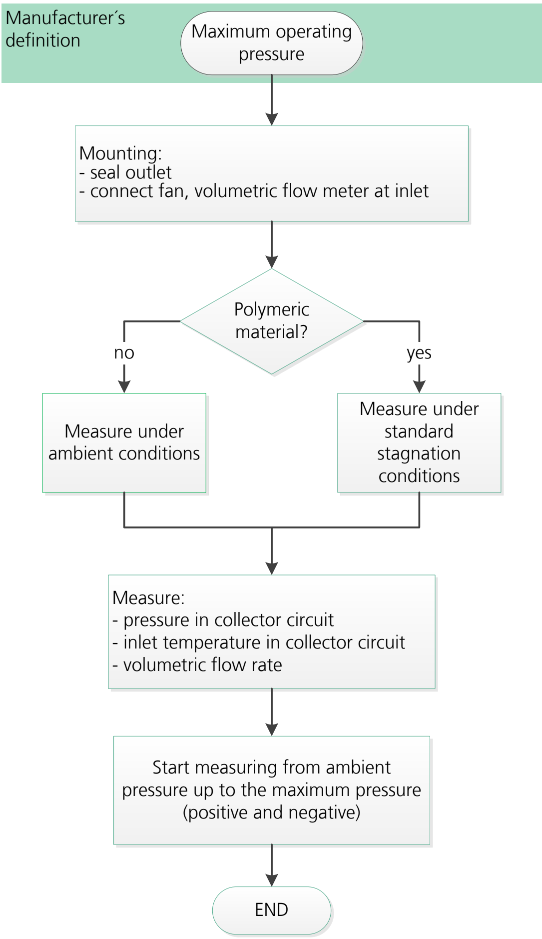
Exemplary Results

- Absorber leakage or such deformation that forms permanent contact between absorber and cover;
- As deformation of fluid channels cannot be recognized until the collector has been opened, it is strongly recommended to check the fluid channels during the final inspection.

7 Leakage Rate Test (closed loop operation only)

The objective of the test is to quantify the volumetric leakage flow rate of solar air heating collectors with dependence on the operation pressure.

Test Procedure



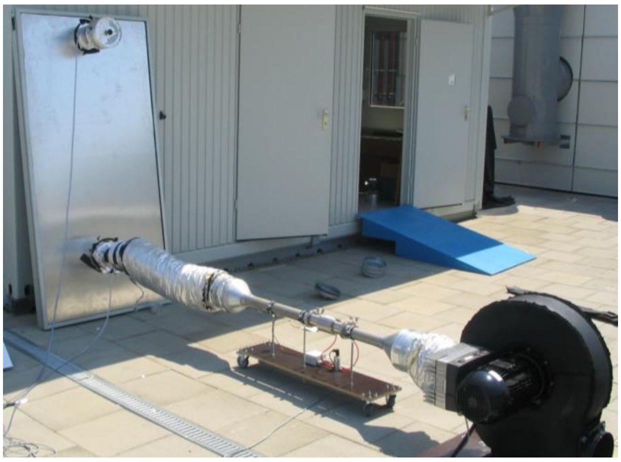


Figure 1: Test setup including a fan, a volumetric flow meter and an electrical pressure gauge at TestLab Solar Thermal Systems, Fraunhofer ISE.

Boundary Conditions

For collectors with polymeric materials in direct contact with the working fluid, it is necessary to determine the leakage rate under stagnation conditions. (see chapter 9)

For all other collector designs, it is recommended to determine the leakage rate at ambient temperature and without irradiance.

Note: There is no range defined for measuring the leakage rate. It is recommended to set the range limits for maximum positive and maximum negative pressure at 1.5 times the maximum operating pressure specified by the manufacturer.

"Tips and Tricks"

- Preliminary quantified leakage rates resulting from testing facility itself shall be subtracted from the collector test results;
- Realizing at least four positive and four negative pressure values to identify the correct curve, often it can be fitted with a 3rd order function;
- Hold each pressure level for at least 10 minutes.

Manufacturers Information Box

- For collectors with polymeric materials in direct contact with the working fluid, the test will be conducted under standard stagnation conditions (see Fact Sheet 9);
- The higher the leakage rate, the lower the power output of the collector;
- The leakage rate should be reduced as far as possible.

Exemplary Results

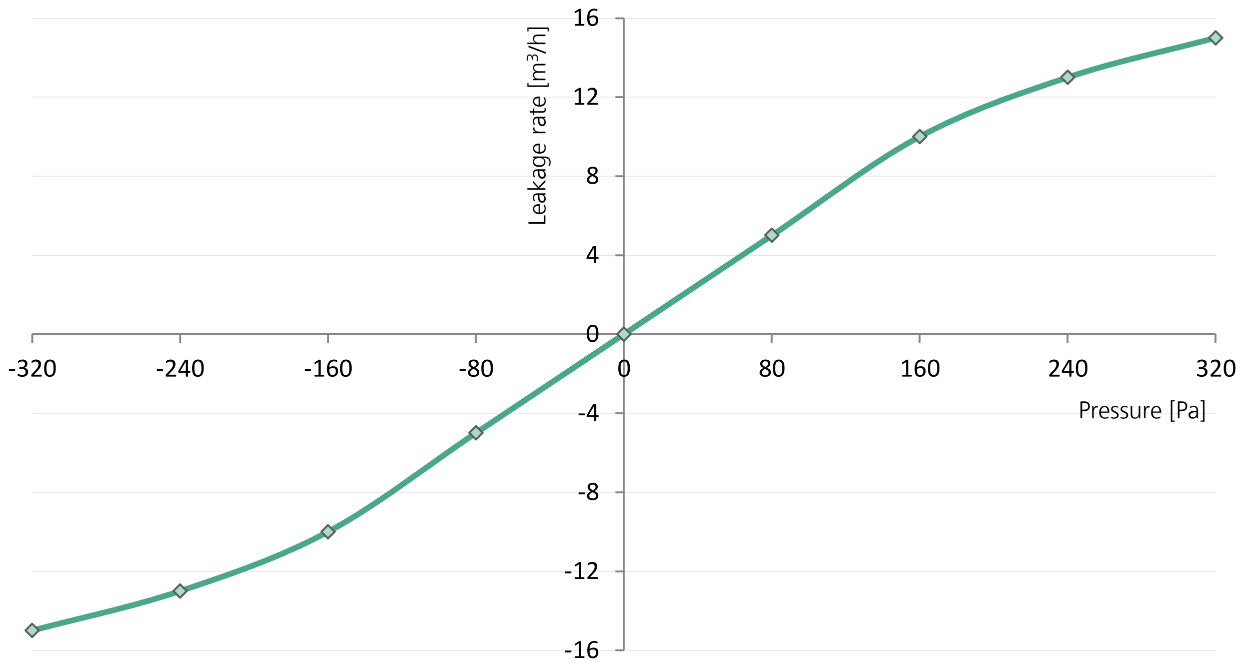
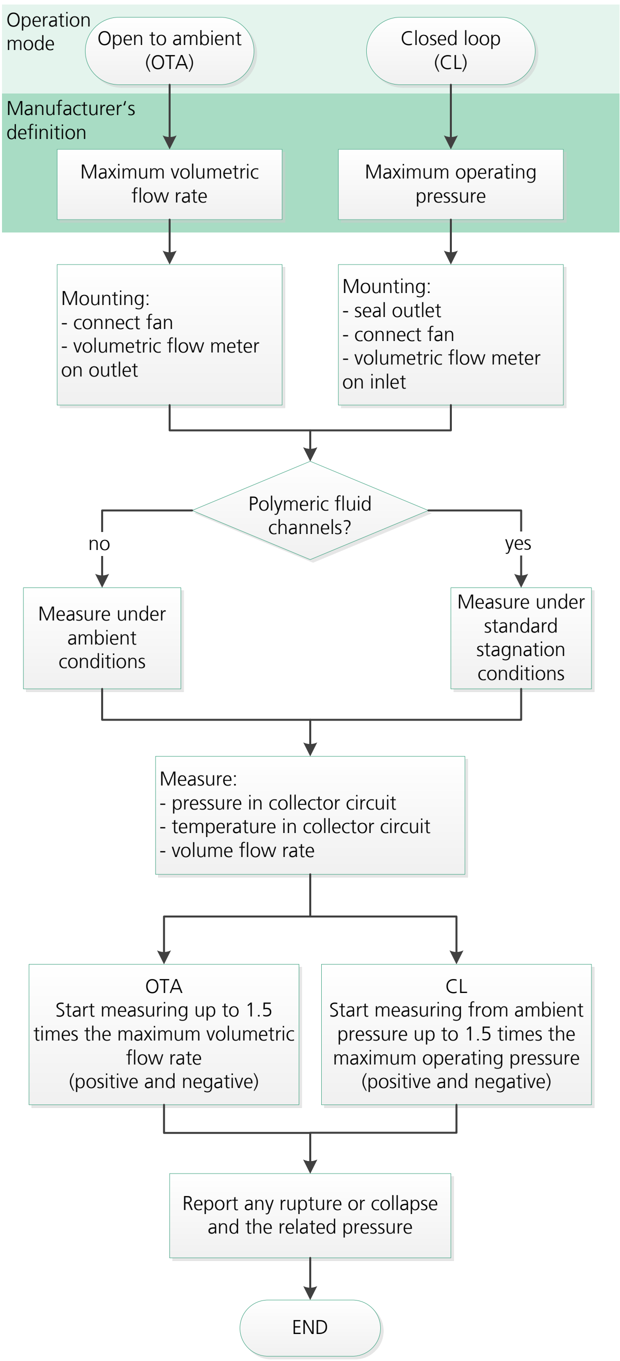


Figure 2: Typical Leakage rate curve fitted with a 3rd order polynomial on the basis of flow measurement points for positive and negative pressures.

8 Rupture and Collapse Test (solar air heating collectors only)

The objective of the test is to assess the ability of SAHC to withstand the pressure levels expected in the air duct system with which the collector is incorporated. This test is analogous to the internal pressure test for liquid heating collectors.

Test Procedure



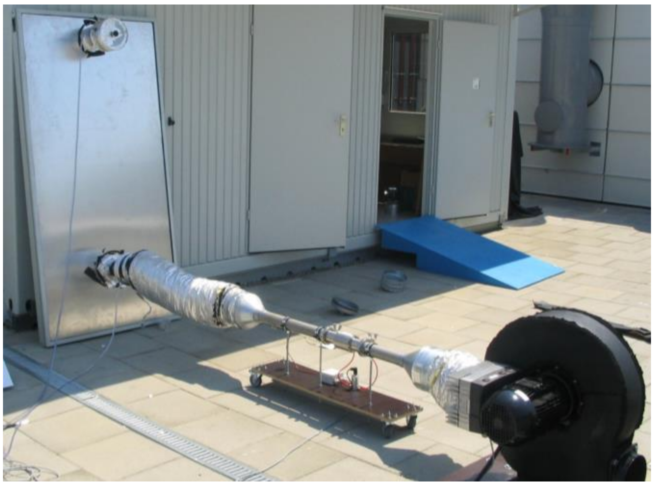


Figure 1: Test setup including a fan, a volumetric flow meter and an electrical pressure gauge at TestLab Solar Thermal Systems, Fraunhofer ISE.

Boundary Conditions

There are different test methods for open to ambient and closed loop collectors as well as for collectors with polymeric materials.

<u>Closed loop Operation:</u>

- Pressure of 1.5 times the maximum (positive or negative) collector operating pressure as specified by the manufacturer
- Maintain this pressure for 10 minutes
- At ambient temperature

<u>Open to ambient Operation:</u>

- Raise air supply to 1.5 times the maximum flow rate specified by the manufacturer in less than 15 seconds
- To be tested in normal use configuration
- Maintain air flow rate for at least 10 minutes

<u>Collectors with polymeric materials in direct contact with the working fluid:</u>

- Shall be tested at maximum operation temperature by using a heater, a solar irradiance simulator or outdoors under natural solar irradiance

"Tips and Tricks"

- Caution: Protect personnel in the event of rupture failure.

- In case of polymeric materials, which are in direct contact to the hot heat transfer fluid, the test at maximum operating temperature is required by chapter 8 of ISO 9806:2017 for testing. Deviating from this standard stagnation conditions are required by chapter 9 of ISO 9806:2017. Therefore it is recommended to perform the test under from stagnation temperature;

- In case of open to ambient collectors with polymeric materials in direct contact with the working fluid, the maximum operating temperature is reduced because of testing with 1.5 times the maximum flow rate, if no artificial heater is used;

- For closed loop SAHC's the test setup can be identical to that of the leakage rate test (see Fact Sheet 7) or to the test setup of the performance test (see Fact Sheet 19);

- With proper planning, this test could be performed consecutive to the leakage rate test to reduce the mounting effort;

- Make sure that the connection from the air ducts to the collector is tight and fastened.

Manufacturers Information Box

- Closed loop collectors are tested with 1.5 times the maximum operating pressure (positive and negative) specified by the manufacturer;

- Open to ambient collectors are tested with 1.5 times the maximum mass flowrate specified by the manufacturer;

- Collectors with polymeric materials in direct contact with the working fluid are tested at elevated temperatures;

- In-house testing is recommended.

Exemplary Results

On the collector:
- Distortion, deformation, loss of bonding, leakages

The following test results will be deemed as major failures:
- Unintended contact between absorber and transparent cover
- Collapsing of structure
- Permanent displacement of (internal) collector components
- Structural damage
- Permanent deformation

Major failures shall be reported with photos in the test report.

9 Standard Stagnation Temperature

The purpose of this test is to determine the collectors´ maximum temperature with no heat removal under high solar radiation and high ambient temperature. This temperature is used for the right choice of insulation and piping material.

Test Procedure

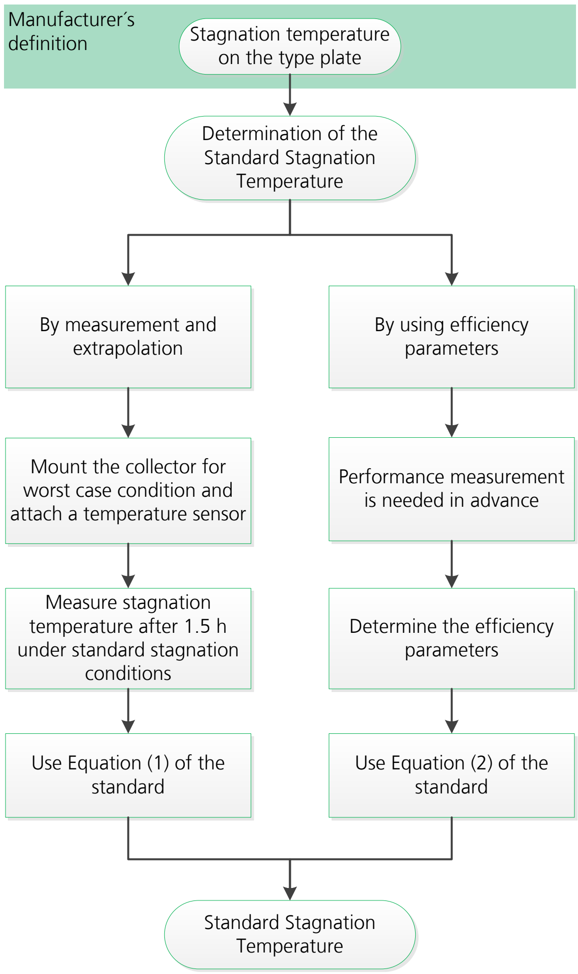


Figure 1: Test setup at TestLab Solar Thermal Systems, Fraunhofer ISE.

Boundary Conditions

Standard Stagnation Conditions (SSC) are defined as:

Irradiation: 1000 W/m² ± 100 W/m²

Ambient temperature: 30 °C ± 10 °C
Surrounding air speed: < 1 m/s

The standard stagnation temperature is furthermore needed for the following tests:

- Internal pressure test, for collectors with polymeric parts in direct contact with the working fluid
- Air leakage rate test, for air heating collectors with polymeric parts in direct contact with the working fluid
- Rapture or collapse test, for air heating collectors with polymeric materials
- Exposure test

"Tips and Tricks"

Sensor installation:

- The installation of the temperature sensor (position and connection to the absorber) has a significant influence on the measured temperature and affects the stagnation temperature. There are solutions for taping, clamping or riveting.
- For flat plate collectors, the “hottest point” can be estimated as farthest away from all the edges. If the tilting angle at the exposure is significant, the hottest point is in the upper third rather than in the middle.
- For Heat pipe collectors, often a single tube is exposed with the temperature sensor on the condenser in a very

well isolated and rain protected mounting.

Method1:

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

Method 2:

- To have a good approximation the thermal performance test shall include test data with T^*_m approaching $T^*_{m, stagnation}$. If all efficiency data have values of T^*_m less than half of $T^*_{m, stagnation}$, method 1 above shall be used.
- Measurements of performance data is done at a much higher wind speed than in stagnation conditions which is compensated by a factor of 1.2 in equation 2 of ISO 9806:2017.

Manufacturers Information Box

This test provides information on the design temperature for all materials used in the collector. Manufacturers should pay attention to the standard stagnation temperature value when designing the collector or choosing materials, recommending insulation materials downstream, and selecting the heat transfer fluid.

In-house testing is recommended to check whether the collector withstands those requirements.

Exemplary Results

The following chart shows exemplary temperature ranges of reachable standard stagnation temperatures depending on the collector technology.

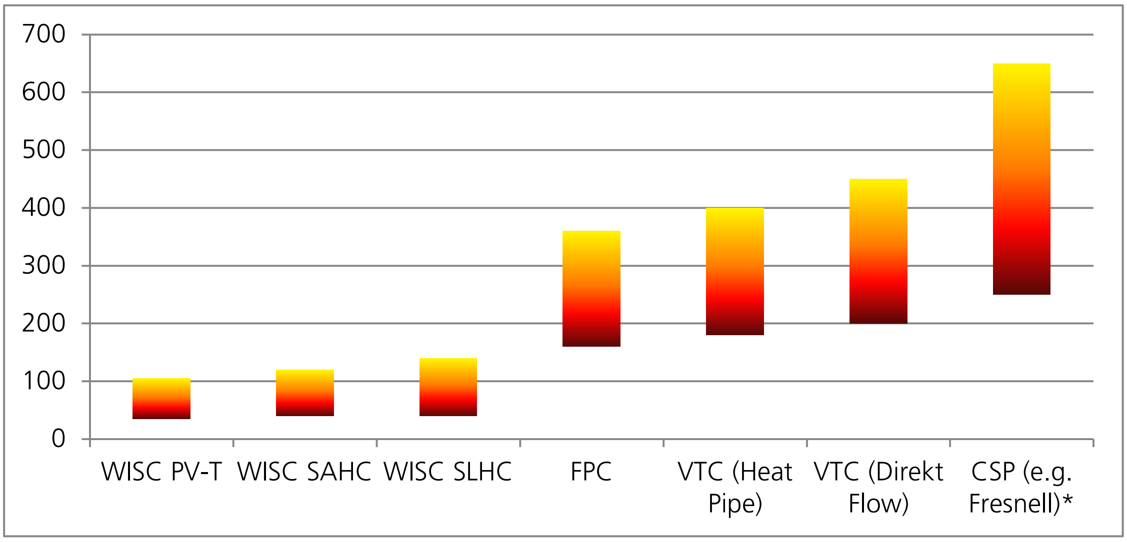


Figure 2: Attainable range of standard stagnation temperatures for different collector technologies. (Source: Fraunhofer ISE)
*Stagnation is avoided by defocusing for CSP because temperatures can be too high

10 Exposure and Half-Exposure Test

Exposure and half-exposure are short term ageing tests with the objective to give an indication of the ageing effects which are likely to occur during a longer period of natural ageing. Particularly adverse situations including cycles of high and low temperature, high and low irradiance (between solar noon and night) and humidity variation are taken into account.

Test Procedure

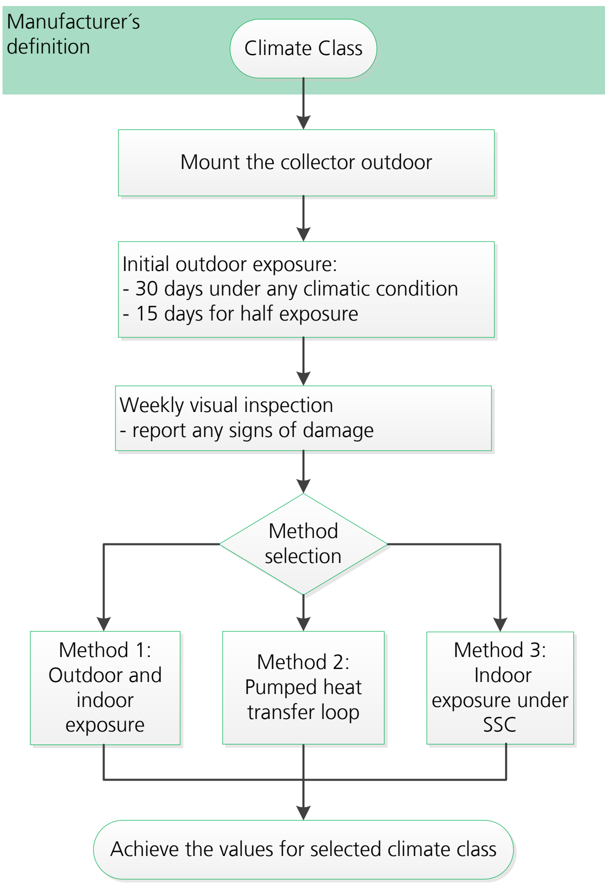


Figure 1: Outdoor exposure at the testing facility of Fraunhofer ISE

Boundary Conditions

The collector shall be exposed until the minimum irradiation H and the minimum hours at certain irradiation and temperature levels as defined in Table 2 of ISO 9806:2017 are reached. This can be done by either a single initial outdoor exposure or the combination of the initial outdoor exposure with one of the following three additional methods.
Choosing method 1 means to finalize the exposure test outdoors under same conditions as the initial outdoor exposure.
Choosing method 2 requires that a heat transfer medium is pumped through the collector at the highest possible mass flow rate. The temperature of the heat transfer medium shall be 10°C higher than the standard stagnation temperature.
Choosing method 3 means to fulfil the requirements given in Table 2 of ISO 9806:2017 by using a solar simulator.
Particular boundary conditions for all of these methods are given in chapter 10 of ISO 9806:2017.

"Tips and Tricks"

- It is absolutely important to check the collectors' appearance at least once a week. It is further recommended to document this check by photographs;
- The test duration can significantly be shortened by the usage of tracking devices;
- Method 2 (pumped heat transfer loop) leads obviously not to an equal aging process of the whole collector as no degradation caused by UV-Radiation occurs.

Manufacturers Information Box

The standard now offers the opportunity for the manufacturers to choose the climate reference class for the exposure test (also valid for external and internal thermal shock tests).

The reference conditions given in Table 1 of ISO 9806:2017 are correlated to the annual global horizontal irradiation values as given within the following table and figure. Threshold values for the different classes were defined based on the irradiation map. Values for an actual location can be taken from this map or other similar sources.

Table 1: Annual Global Horizontal Irradiation values for different climate classes

Property	C	B	A	A+
Annual Irradiation (H) [kWh/m²]	H≤1000	1000<H≤1600	1600<H≤2000	H>2000

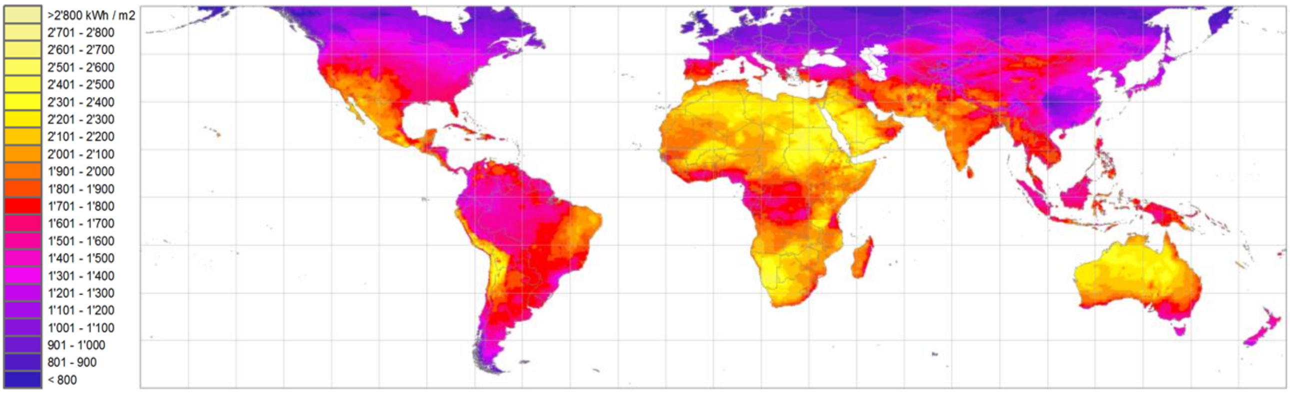


Figure 2: Yearly sum of Global Horizontal Irradiation (GHI); ; Source Metenorm 7.0 (www.meteonorm.com); uncertainty 8%; Period 1986 – 2004; grid cell size: 0.25°

Test Evaluation and Typical Failures

The evaluation of the exposure test and classifying of potential problems as minor problem or major failure shall be done based on visual observation of the collector at the end of the test. A 'major failure' can be defined as a problem that may have a strong impact either on the thermal performance of the collector or on the durability of the collector. This classification is dependent on the judgment of the test laboratory. Table 1 gives guidance on the criterion for classification of major failure after the exposure test.

Table 2: Recommendations for classification of a potential problem as major failure after exposure test

Collector component/s	**Potential problem**	**Evaluation** **Consider as major failure if:**
Collector box/fasteners	Cracking Warping Corrosion Rain penetration	Large areas are affected resulting in future rain penetration problems If exceeding the limits of rain penetration test
Seals/gaskets	Cracking Adhesion Elasticity	Large areas are (potentially) affected resulting in future rain penetration problem; also smaller failures that can be expected to progress during longer exposure
Cover/reflector	Cracking Crazing Buckling Delamination	Areas affected will result in decrease of thermal performance. Fast increase of the problem during the test period*
Absorber coating	Cracking Crazing Blistering	Areas affected will result in decrease of thermal performance. Fast increase of the problem during test period*
Insulation	Outgassing	Will result in decrease of thermal performance

*This criterion will only be possible to evaluate if the laboratory makes a daily register of observations of the collector.

11 External Thermal Shock Test

The objective of the test is to assess the capability of a collector to withstand a severe thermal shock that can result from a sudden rainstorm on a hot sunny day.

Test Procedure

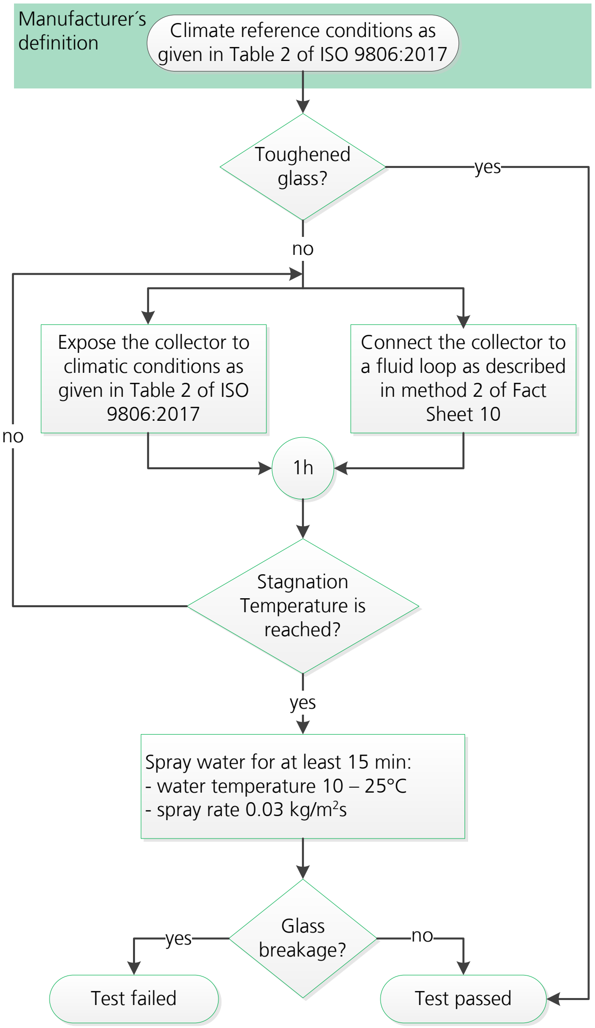


Figure 1: External Thermal Shock Test; Fraunhofer ISE

Boundary Conditions

Liquid heating collectors shall either be operated under standard stagnation conditions (SSC).

An array of water jets shall provide a uniform distribution of water spraying over the front of the collector.

The collector shall be exposed for 1 hour prior to the test with the selected climate reference conditions as given in Table 2 of ISO 9806:2017.

The collector shall be sprayed with water at a temperature between 10°C – 25°C at the spraying rate of 0.03 kg/m^{2}s for at least 15 minutes.

This test shall be performed twice on the collector.

Collectors with overheating protection shall be operated close to the self-protection trigger temperature.

"Tips and Tricks"

- Take care of the water spraying temperature. On hot sunny days, the water can be heated up within the inlet tube;
- Make sure that the spray covers the whole collector front or if it is a very large collector, at least two complete glass planes.

Manufacturers Information Box

- Climate reference conditions as given in table 2 of ISO 9806:2017 must be chosen by the manufacturer;
- In-house testing is recommended to check whether the collector withstands those requirements (also in case of toughened glass).

Exemplary Results

- Cracking or breakage of collector cover and rain penetration are problems that could be detected within this test;
- Fogging i.e. condensation of gases on the inside of the cover usually occurs when it is cooled by water. However this often looks much worse when observed directly after the shock compared to some time after. The result therefore may need to be reevaluated after the temperature of the collector cover is close to the ambient temperature.

12 Internal Thermal Shock Test (liquid heating collectors only)

The objective of this test is to assess the capability of a collector to withstand a severe internal thermal shock that can result from the intake of a cold fluid on a hot sunny day. This is likely to occur during system installation when the collector loop is filled or after a period of shutdown, when the installation is brought back into operation.

Test Procedure

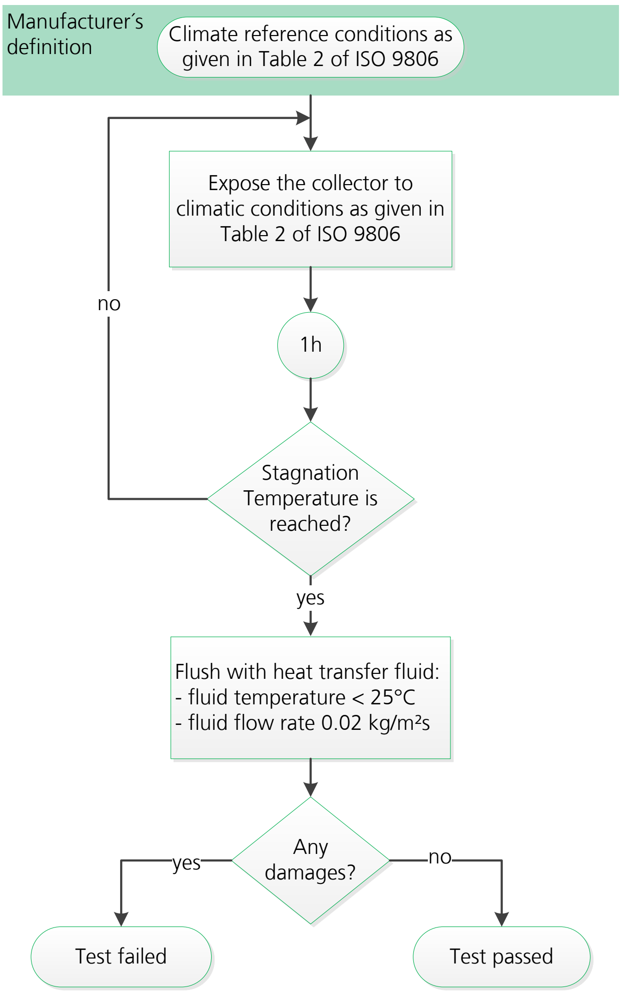


Figure 1: Internal thermal shock test; Fraunhofer ISE

Boundary Conditions

- The collector shall be mounted either outdoors or in a solar simulator and operated under standard stagnation conditions (SSC).
- The collectors shall not be filled with fluid.
- One of the fluid pipes shall be connected via a shut of valve to a heat transfer fluid source.
- The collector shall be exposed for 1 hour prior to the test with the selected climate reference conditions as given in Table 2 of ISO 9806:2017.
- The collector is flushed with cold heat transfer fluid (<25°C) at a fluid flow rate of 0.02 kg/m²s for at least 5 minutes.
- This test shall be performed twice on the collector.
- Collectors with overheating protection shall be operated close to the self-protection trigger temperature.

"Tips and Tricks"

- The test is usually performed in association with the exposure test. To perform the test, keep the collector in dry stagnation on a sunny day and, after solar noon, flush cold water (mains water) in the collector for 5 minutes. The fluid flow rate should be similar to the flow rate recommended for the collector in normal operation;

- Pay attention to the blowout of water vapor;

- Direct flown vacuum tube collectors are often highly sensible to internal shocks. Pay attention to the glass breakage at the lower tube end.

Manufacturers Information Box

- Climate reference conditions as given in table 2 of ISO 9806:2017 must be chosen by the manufacturer;
- In house testing is recommended to check whether the collector withstands the requirements (especially in case of direct flow vacuum tube collectors).

Exemplary Results

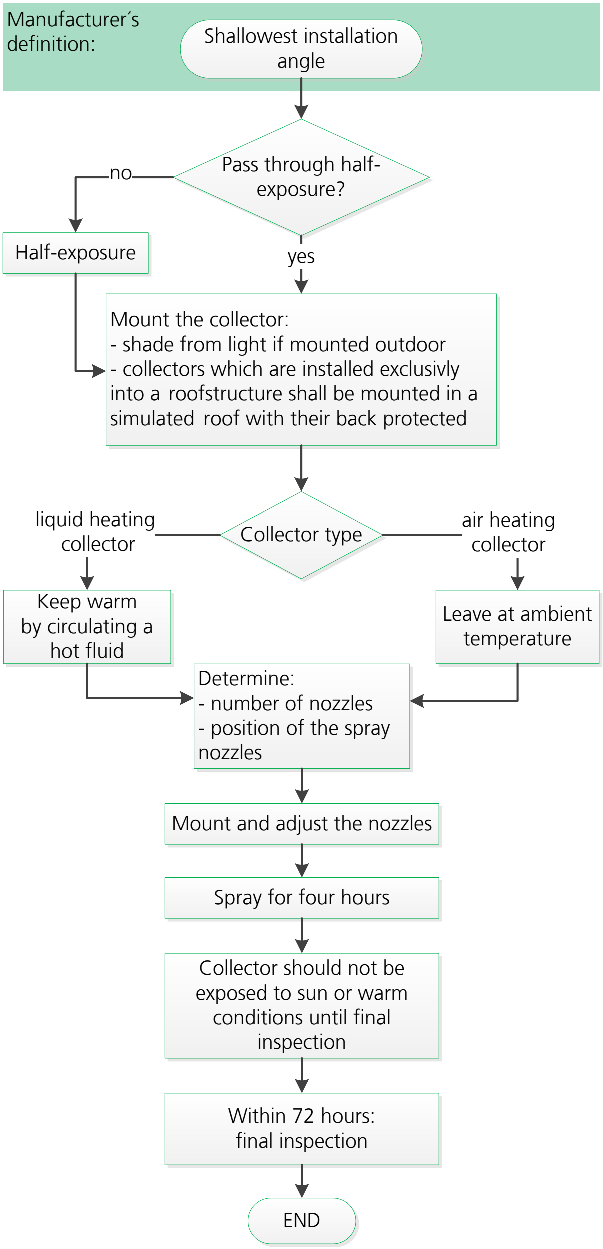
- Loss of vacuum or breakage of the tubes in evacuated tubular collectors, loss of bonding between tubes and absorber plate or permanent deformation of the absorber plate in flat plate collectors are the most common problems that can be detected with this test;
- Glass breakage most often occur while testing direct flow vacuum tube collectors. The following pictures show typical signs of glass breakage.

Figure 2: Damaged collectors after testing; Fraunhofer ISE

13 Rain Penetration Test

The objective of the test is to assess if collectors are substantially resistant to rain penetration. Collectors may be equipped with ventilation and/or drain holes but these shall not permit the entry of drifting rain.

Test Procedure



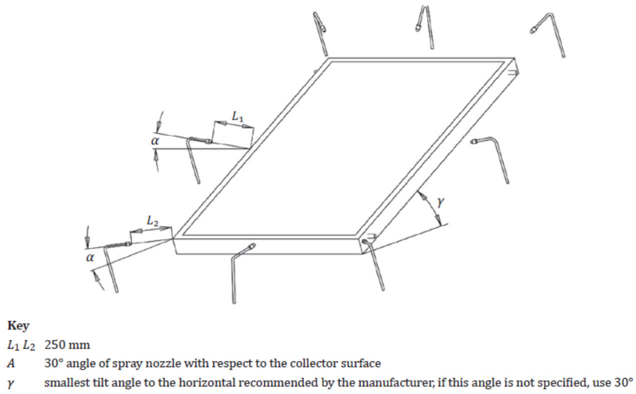


Figure 1: Positioning of collector and spray nozzles for rain penetration test; Source: ISO 9806:2017

Boundary Conditions

Even for ETC rain is spread on header and bottom support including caps respectively because water accumulation at that part would lead to freezing damage.

Original mounting shall be used especially if the collector is sold with an in-roof solution.

The detailed test conditions including information about the required spray nozzles, mass flow rate, spray angle, and drop size are given in chapter 13.3 of ISO98026:2017.

Please not that it is not possible to give the exact positioning of the spray nozzles for each type of collectors. It is in the responsibility of the testing laboratory to identify all critical points (areas) where water penetration could occur.

The number and description of positions of spray nozzles shall be reported.

"Tips and Tricks"

- In case of SAHC, sometimes rain can enter the collector casing quite easily, which maybe not be problematic issue if the collector is drying out in time according to the standard;

- Water penetration shall be determined by the final inspection within 72 hours after the rain penetration test. But in-between rain penetration and final inspection tests, the collector has to undergo internal pressure test, mechanical load test and impact resistance test;

- If the internal pressure test needs to be done at elevated temperatures, it is not admissible to perform both tests on the same collector;

- If the above mentioned three tests are performed on the same collector as the rain penetration test, the collector shall be handled in such a way that the result of the rain penetration test is not negatively influenced;

- If the collector does not pass one of these three preceding tests, no evaluation of the rain penetration test shall be given within the report. The report shall only state that the test has taken place without valid evaluation;

- It is strongly recommended to use a further collector to avoid the aforementioned circumstances;

- Problems are more likely to occur if the collector is mounted with a low tilt angle.

Manufacturers Information Box

The manufacturer can recommend the shallowest collector tilt angle at which the collector can be used in order to avoid rain penetration problems. If this angle is not indicated the test is performed with a 30° tilt.

Exemplary Results

Examples of problems that are likely to occur if water penetrates and stays in the collector are corrosion of the collector casing and absorber surface, reduced thermal performance due to persistent condensation on the inner side of the glass, or reduced insulation properties when the insulation is wet.

14 Freeze Resistance Test

The objective of the test is to assess if a collector which is claimed to be freeze resistant can withstand freezing and freeze/thaw cycling.

Test Procedure

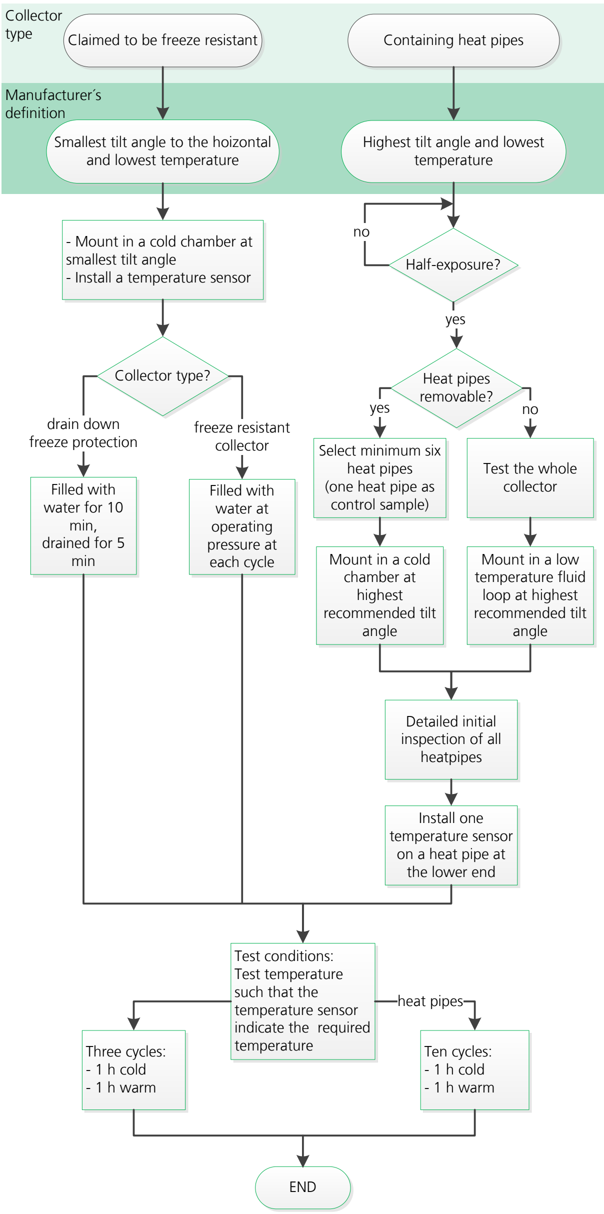


Figure 1: Climate chambers of the TestLab PV-Modules, Fraunhofer ISE

Boundary Conditions

Two test procedures are recommended, one for collectors which are claimed to be freeze resistant when filled with water or are claimed to resist freezing after being drained, and the other for collectors containing heat pipes.

For collectors claimed to be freeze resistant, 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. Water in the collector absorber shall be maintained at - 20 ± 2°C for at least 30 minutes during the freezing part and raised to above 10 °C during the thawing cycle. Duration of thaw cycle shall be at least 30 minutes. The collector shall be subjected to three freeze-thaw cycles and then inspected for failures.

For collectors containing heat pipes the test can also be performed in a low temperature fluid loop. The difference for heat pipe collectors is the tilt angle. Here the highest recommended tilt angle is considered. The freeze resistance test consists of ten cycles for this type of collectors.

"Tips and Tricks"

Freeze resistant collectors:
Collector shall be filled with water at operating pressure and cold chamber temperature, and shall be cycled. At the end of each cycle the collector shall be refilled with water to operating pressure. Water temperature shall be monitored during the whole test.

Collectors with drain-down protection:
Collector shall be filled with water and kept at operating pressure for 10 minutes and then drained using the device installed by the manufacturer.

Collectors containing heat pipes:
The documentation of the shape (round, oval, etc.) and the outside dimensions of all parts of the heat pipes during the initial inspection as well as the final inspection shall be done by photographs on a graph paper (millimeter paper), in order to have a direct comparison.

Manufacturers Information Box

Collectors claimed to be freeze resistant:
The test laboratory needs the lowest tilt angle and also the lowest temperature. The test shall be at -20 °C or as specified by the manufacturer.

Collectors containing heat pipes:
The test is mandatory for all heat pipe collectors. The test laboratory needs the highest tilt angle and also the lowest temperature. The test shall be at -20 °C or as specified by the manufacturer.

Exemplary Results

Typical results of freeze resistance tests are cracking and/or breaking of fluid channels. The following pictures shows typical results of a freeze resistance test on heat pipes, done within the project HPQUAL - Investigation of freeze resistance testing of heat pipes. Both shown results, cracking as well as the deformation shall be deemed as major failure.

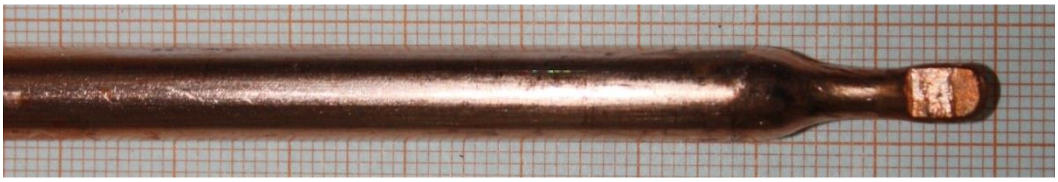


Figure 2: Heat pipe before freeze resistance test (Source: HPQUAL - Investigation of freeze resistance testing of heat pipes; Fraunhofer ISE)

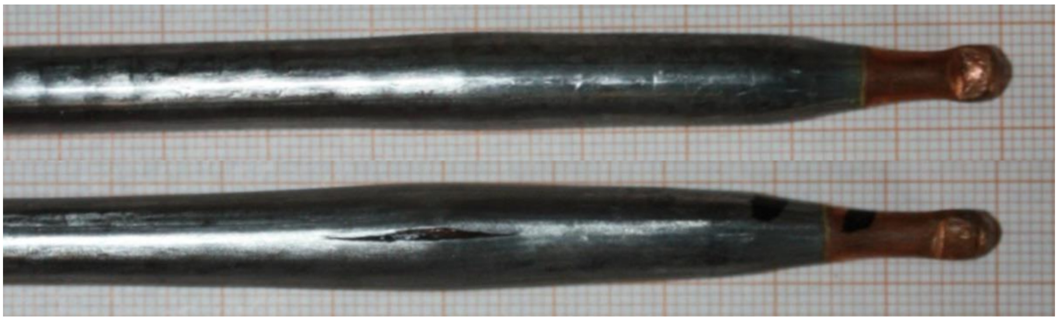


Figure 3: Heat pipes after freeze resistance test (Source: HPQUAL - Investigation of freeze resistance testing of heat pipes; Fraunhofer ISE)

15 Mechanical Load Test

The mechanical load tests are intended to assess the extent to which the collector and its attachment points are able to resist positive pressure load due to wind or snow, and negative pressure or uplift forces caused by wind.

Note: The mounting hardware itself is not evaluated by this standard.

Test Procedure

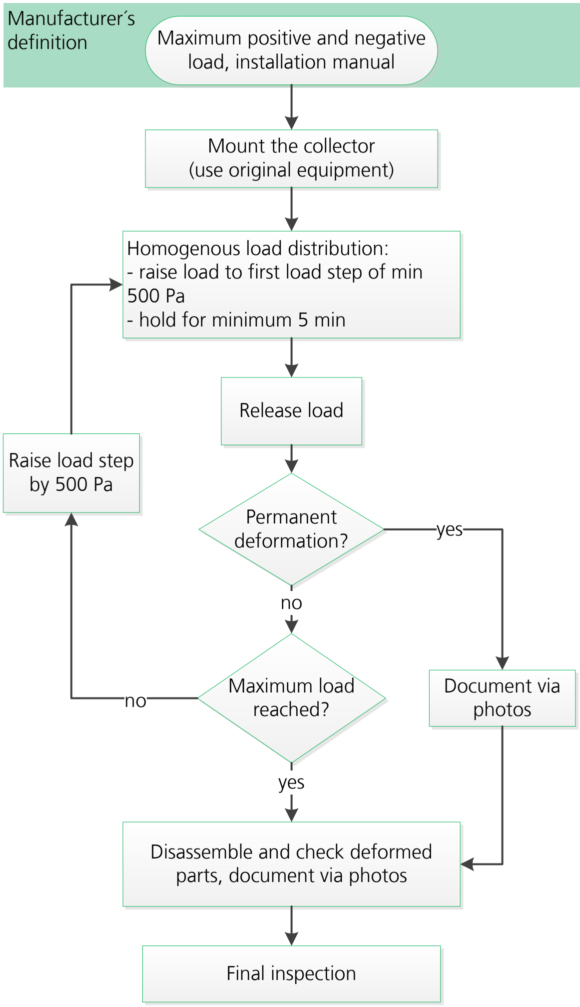


Figure 1: Mechanical load test; Fraunhofer ISE

Boundary Conditions

<u>Methods:</u>
- Use of flexible foil and gravel, sand or water
- Suction cups
- Air pressure

<u>Mounting:</u>
- Collector is placed horizontally
- Using the manufacturer´s original mounting equipment

<u>Maximum test pressure:</u>
- Not specified; is to be define by the manufacturer

<u>Load steps:</u>
- Max. 500 Pa
- Min. 5 minutes per load step

Note 1: If none of these methods is applicable (e.g. for tracking and concentrating collectors), the laboratory shall design specific procedures.

Note 2: Depending on the collector type, other methods may be suitable as well.

"Tips and Tricks"

- For the method using suction cups an equal distribution of the pressure is very important;
- The distance between the suction cups and the collector frame shall be half of the distance between the suction cups itself;
- A continuous measurement of the deflection is recommended to determine if a permanent deformation occurs;
- If a failure of the fixing or mounting system occurs, the test cannot be continued as the degree of freedom for the collector movement has changed in a way that the representative result for the collector is no longer valid. In this case, it is recommended to state that the collector resisted one load step before the fixing or mounting failed;
- If different fixing and/or mounting systems are applicable, it is recommended to use the one with the smallest load resistance according to the documentation of the manufacturer;
- Relieving the pressure after every load step to 0 Pa is very important to possibly state that the last load step has withstood before a possible failure occurred.

Manufacturers Information Box

The collector has to be installed using the manufacturer's original mounting equipment. The documented pressure is the maximum negative and positive pressure the collector resists during the test.

These values divided by a safety factor can be related to permissible snow and wind load. In each country there are specific legislations on wind and snow loads since building envelopes have to resist these loads.

Exemplary Results

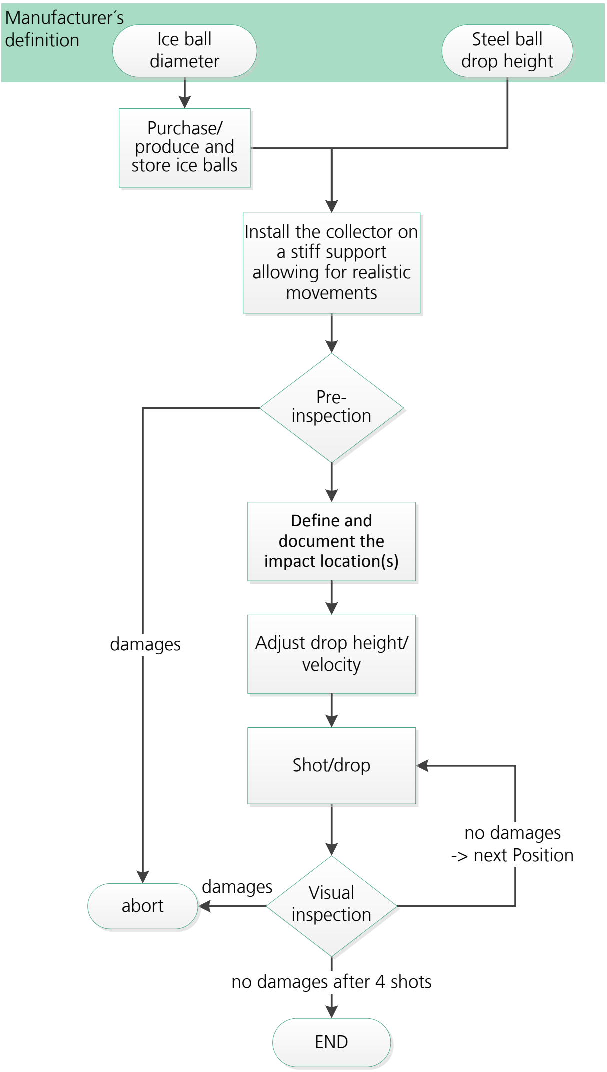
Typical failures:

- In testing and handling:
    - Suction cups, gravel or sand not evenly distributed over the collector
- On the collector:
    - Permanent deformation or distortion
    - Glass breakage in case of evacuated tube collectors
- Failure of the fixing or mounting system

16 Impact Resistance Test

The objective of the test is to assess the extent to which a collector can withstand the effects of impact.

Test Procedure



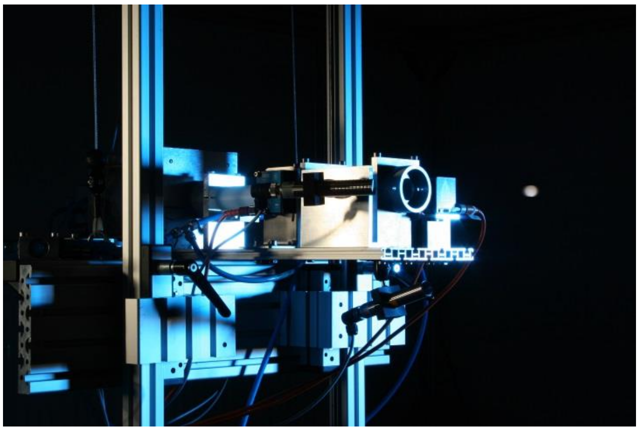


Figure 1: Impact resistance testing facility at Fraunhofer ISE

Boundary Conditions

- The test can be performed using ice or steel balls
- The test procedure consists of 4 shots/drops of the same impact strength
- Impact locations depending on the collector technology are defined

Using ice balls:
- The collector shall be mounted on a stiff support, perpendicular to the path of the projected ice ball
- Ice ball and test specifications are:

Diameter [mm]	15	25	35	45
Mass [g]	1.63	7.53	20.7	43.9
Velocity [m/s]	17.8	23.0	27.2	30.7

Using steel balls:
- The collector shall be mounted on a stiff support, perpendicular to the path of the dropping steel ball
- Steel ball and test specifications are:

Mass [g]	150 ± 10
Drop Height [m]	0.4, …2 m (0.2 m increment)

"Tips and Tricks"

- In case of ETCs, severe impacts can lead to small (non-visible) cracks and loss of vacuum. This can be identified by the tone of the tubes when softly hit or by whitening of the getter material at the lower end of the tube;

- Proper preparation is important, as in case of a glass breakage the shot/drop cannot be repeated;

- The points of impact shall be defined before testing;
- Special considerations on ETCs: If one tube breaks, the test shall be repeated on another tube. If the second one also breaks, the test shall be considered as failed;
- Perpendicular shot/drop can be difficult, especially when testing ETCs.

Manufacturers Information Box

- The test is started with the smallest ice ball diameter or the lowest steel ball dropping height specified by the manufacturer;
- The test will be stopped at the largest ice ball diameter or highest steel ball dropping height, or after the first visible damage;
- The largest ice ball diameter or the highest steel ball dropping height without any damages will be reported.

Exemplary Results

- The collector is visually inspected after testing. Typical results can be small cracks or dents in header box mirrors or frames, broken glass, or loss of vacuum in case of vacuum tubes;
- The results can often be reported easily by photo documentation;
- Obviously no damages occur on toughened glasses of FPCs with a thickness ≥ 3.2 mm when using ice balls with diameters ≤ 25 mm.

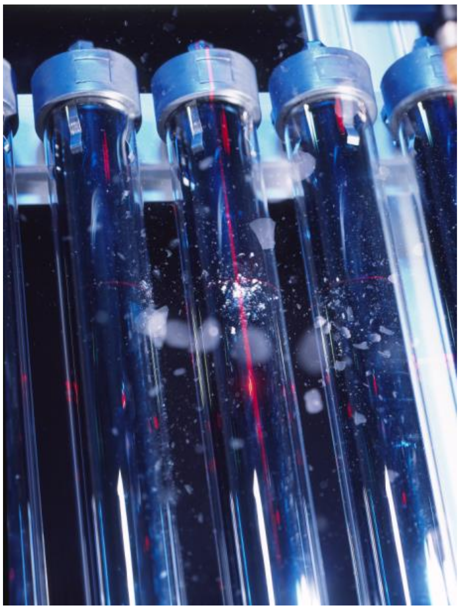


Figure 2: Collector after ice ball impact test

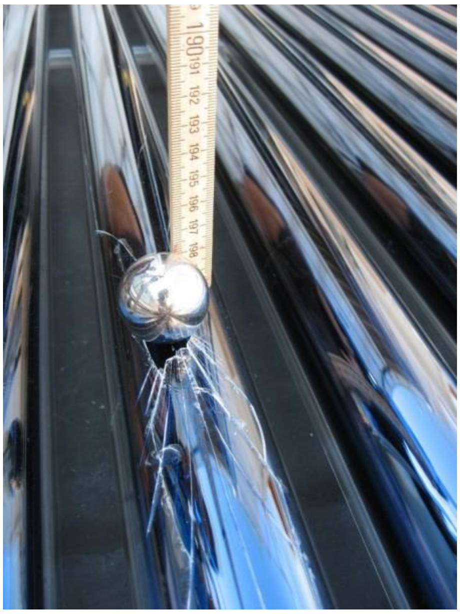
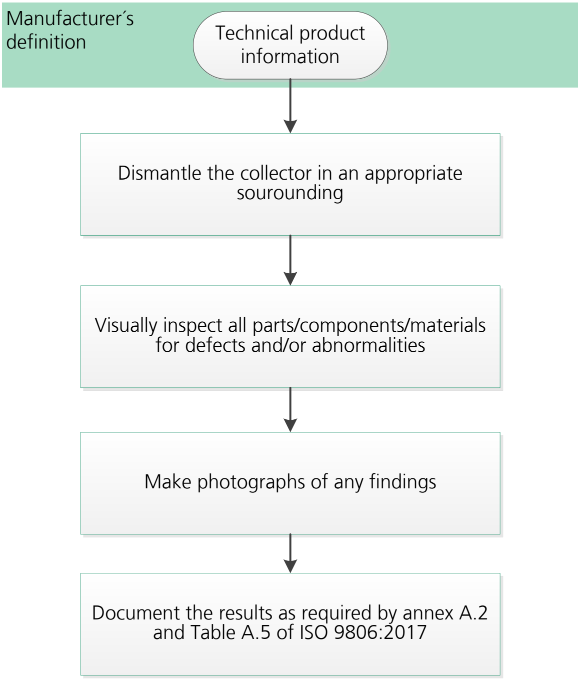


Figure 3: Damaged collector after steel ball impact test

17 Final Inspection

The final inspection corresponds to the dismantling of the collector(s) and shall be done for all tested collector(s). Most of the results of reliability testing are found at the final inspection. All abnormalities shall be documented and accompanied by photographs.

Test Procedure



Boundary Conditions

The final inspection shall be done in a suitable surrounding (e.g. indoors, without irradiation, at room temperature, etc.).

The final inspection is a destructive test and shall therefore be the concluding test.

It is recommended to do a final inspection test every time a durability test procedure is completed. Especially if the collector fails in one of the tests given in Fact Sheet 6 to 16.

The collector shall be dismantled and inspected. Any defects and abnormalities shall be documented. It is recommended to document all defects and abnormalities by photographs.

"Tips and Tricks"

- Collectors may contain harmful materials (fluid within heat pipes, getter material within vacuum tubes, thermal insulation materials made of glass fiber, etc.). It is advisable to obtain the exact material specifications beforehand from the manufacturer of the collector. Appropriate protective measures should also be taken;
- Dismantling the collector should not influence the results from preceding tests;
- It is recommended to check the material specifications and the design according to the manufacturer´s specifications during the final inspection;
- In case of tracking and concentrating collectors all collector parts which are required for normal operation like tracking device, actuators, sensors, etc. shall be inspected.

Manufacturers Information Box

Collectors which are undergoing a final inspection are not usable anymore. Nevertheless in some critical cases it could be helpful to store the collector at the laboratory or to send it back to the manufacturer. This provides the possibility for the manufacturer to improve the collector construction on the basis of the visible test results.

Exemplary Results

Results shall be presented as required in chapter A.2 and Table A.5 of ISO 9806:2017.

Any defect and/or abnormality shall be classified in one of the following classifications:

- No problem: If the performance, durability, safety and visual appearance are considered as not affected by preceding tests. The collector is deemed to remain stable for the expected lifetime.
- Minor problems: These are mainly aesthetical defects. Durability and safety are considered to remain stable over the expected lifetime.
- Major failures: These are severe premature failures concerning performance, durability, safety or visual appearance. Table 1 gives a slight overview of major failures found during the final inspection.

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

Table 1: Recommendations for classification of a potential problem as major failure during final inspection

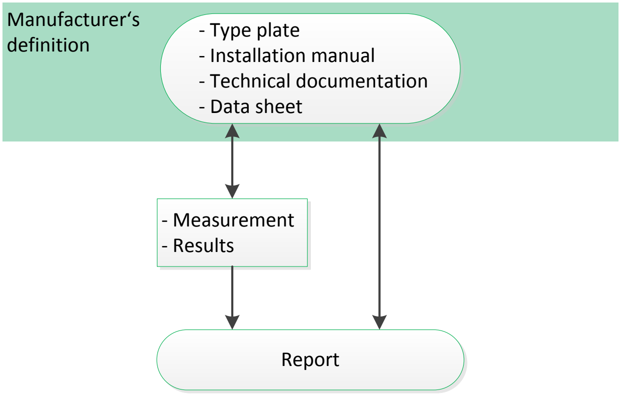
Potential problem	Picture	Potential problem	Picture
Corroded collector box. Manifold casing after exposure test		Crack on absorber coating	
Cracked collector box		Deformation of absorber tubes and headers	
Cracking of polymeric parts of manifold		Loss of bonding in absorber tubes	
Deformation of polymeric parts of manifold		Outgassing	
Cracked glass after external thermal shock test		Degradation of PU foam insulation in manifold casing after exposure test	 
Outgassing within Heat Pipe Tubes		Degradation of insulation	

(Picture source: QAiST - IEE/08/593/SI2.529236)

18 Test Report

The compilation of an ISO 9806:2017 compliant test report is carried out in accordance with Annex A2 and A3 of the standard. Surplus to these requirements, the present Fact Sheet addresses additional rules of conduct in the preparation of test reports as well as the information required beyond the normative requirements to improve the intelligibility of the report. The target group for the information given in this Fact Sheet is primarily the testing laboratories. However, also for manufacturers and certifiers it can help to understand the results documented in the report.

Test Procedure



"Tips and Tricks"

- A Test Report shall not be published in excerpts to avoid misuse;
- The Test Report is the product the contractor pays for. So it belongs to the contractor. If a third party asks for it, only with agreement of the owner a test report can be provided;
- A report shall be signed by two responsible persons;
- Test Reports always describe only what has been done with the specific test sample. Based on this information, a certification scheme might allow for transferring results to technically similar products;
- A Test Report is the 'product' of a testing laboratory. In case the laboratory is EN/EC/ISO 17025 accredited, the Test Report is part of the tracked documents. Therefore a report contains numbering and versioning information as well as all the details necessary to track the equipment used in this very test, down to the details of calibration of used sensors;
- A Test Report has no expiry date;
- To implement any corrections, a new version has top be issued saying that it supersedes the pervious version.

Manufacturers Information Box

- To write and issue a report according to ISO 9806:2017 it is absolutely essential that all the data as required by chapter A.2 of ISO 9806:2017 is available for the testing laboratory. Otherwise the collector design cannot be clearly fixed and following it cannot be unambiguously assigned to which product design the result relates;

- Besides, the collector must be accompanied by a type plate showing for e.g. the serial number, the sizes, etc., and an installation manual must be available for the testing laboratory to check whether there are information regarding installation, safety and precautions as well as maintenance is given;

- The results given within the test report are only valid for the tested collector.

Exemplary Results

Exemplary results for the single tests and measurements are given on the related Fact Sheets. Here mentioned is the newly implemented Standard Reporting Conditions (SRC). The SRC were implemented into the ISO 9806:2017 to report the power output of the collector in a comparable form, independent of the tests method and the collector technology. The following definitions are made:

- The SRC distinguish between “Blue Sky”, “Hazy Sky” and “Grey Sky” conditions. For each of those conditions certain irradiation levels are defined. The exact values are given within Table 7 of ISO 9806:2017;

- The SRC distinguish between global and diffuse Irradiation, meaning, that the power output considers a defined diffuse fraction, independent from the testing method (SST or QDT). This leads on the one hand to comparable results. On the other hand the question raises “How to consider the diffuse fraction in case of SST-Measurements. An answer on this question is given in Fact Sheet 24.1;

- The ambient temperature has been fixed to 20 °C;

- The longwave irradiance, which is to consider in case of measurements on WICS’s, has been set to -100 W/m²;

- The wind speed velocity, which is to consider in case of measurements on WICS’s, has been set to 1.3 m/s;

- The thermal capacity, resulting from QDT-Measurement is always set to zero to calculate the power output;

- The table below shows the detailed SRC:

Table 1: Detailed Standard Reporting Conditions

Climatic conditions	Blue sky	Hazy Sky	Grey sky
G_b	850 W/m²	440 W/m²	0 W/m²
G_d	150 W/m²	260 W/m²	400 W/m²
ϑ_a	20 °C	20 °C	20 °C
$E_L - \sigma.\vartheta_a^{4}$ [a]	- 100 W/m²	-50 W/m²	0 W/m²
u [a]	1.3 m/s	1.3 m/s	1.3 m/s
$d\vartheta_m/dt$ [b]	0 K/s	0 K/s	0 K/s

a For WISC collectors only.
b For quasi dynamic tested collectors only.

19.1 Thermal Performance Testing

Performance testing includes the assessment of the power output efficiency parameters by the collector under various operating conditions. This is achieved by determining collector parameters like conversion factor, incident angle modifier, heat capacity and time constant. The aim of Thermal Performance Testing is to compare different collectors as well as collector technologies with each other in a fair and transparent way. It is also needed to calculate the collectors' yearly energy gain (collector annual output, CAO) using different simulation tools.

Test Procedure

Table 1: Test method to be followed for different types of collectors.

Collector type	SST	QDT
Concentrating Collector (SLHC)	-	✓
SLHC	✓	✓
SAHC	✓	-
OTA-SAHC	✓	-
WISC	✓	✓

SST	Steady State Testing
QDT	Quasi Dynamic Testing
SLHC	Solar Liquid Heating Collector
SAHC	Solar Air Heating Collector
OTA	Open To Ambient
WISC	Wind and Irradiance Sensitive Collector

Figure 1: Typical outdoor test facility, Fraunhofer ISE

Advantages/Disadvantages of Different Methods

The two performance test methods, Steady State Testing (SST) and Quasi Dynamic Testing (QDT) exist as equivalent methods in the standard. Since only the QDT model includes the differentiation of diffuse and direct radiation, this method is more applicable for collector technologies whose thermal performance is sensible to the diffuse fraction (e.g. concentrating collectors). For QDT, no tracking facility is necessary which could be an advantage. In case of SST, the boundary conditions have a direct influence on the collector parameters. Thus the influence of single development steps (e.g. new absorber coating, etc.) can be easily observed in direct relation to the surrounding conditions. The methods have been compared in several round-robin tests and the overall uncertainty achieved was around ±2% (pp) for the η_{hem} value.

Overview of Thermal Performance Testing related Fact sheets

Fact Sheet 19.2	Thermal performance testing using a solar Irradiance simulator
Fact Sheet 20	Collector mounting and location
Fact sheet 21	Instrumentation
Fact Sheet 22.1	Test installation for liquid heating collectors
Fact Sheet 22.2	Test installation for air heating collectors
Fact Sheet 23	Performance test procedures
Fact sheet 24.1	Computation of results; liquid heating collectors
Fact sheet 24.2	Computation of results; air heating collectors
Fact Sheet 25.1	Measurement and calculation of the effective thermal capacity
Fact sheet 25.2	Determination of the collector time constant
Fact Sheet 26	Determination of the incident angle modifier
Fact Sheet 27.1	Determination of the pressure drop; liquid heating collectors
Fact Sheet 27.2	Determination of the pressure drop; air heating collectors

19.2 Solar Irradiance Simulator

A solar simulator creates the possibility of the weather-independent performance test, which can be scheduled at a short notice, with a very high repeatability. On the other hand, it is subject to certain restrictions due to the characteristics of the artificial irradiation.

Test Procedure

Following tests can be conducted using a solar irradiance simulator:

Performance measurements:
- Steady-state efficiency measurement
- Determination of the thermal capacity and time constant
- Determination of the Incident angle modifier (IAM)

Functional tests:
- Standard stagnation temperature
- Internal pressure test
- Air leakage test
- Rapture or collapse test
- Exposure test (after the initial outdoor exposure)
- External thermal shock test
- Internal thermal shock test

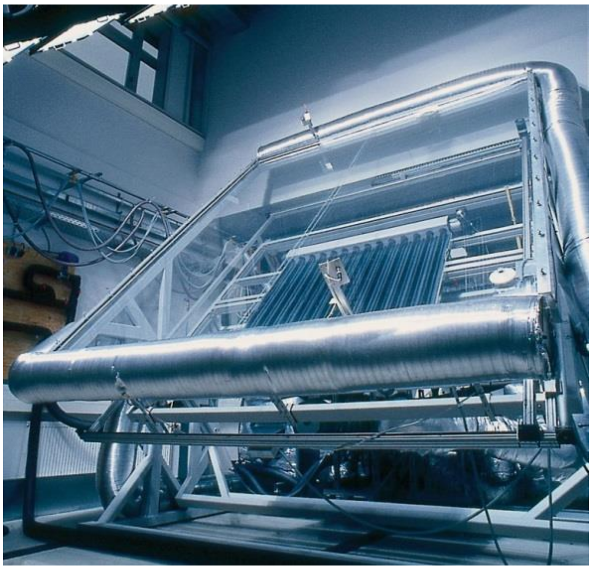


Figure 1: Solar Irradiance Simulator at Fraunhofer ISE

Irradiation Requirements of a Solar Irradiance Simulator for Steady State Efficiency Measurements

As the performance of collectors is sensitive to the amount of direct and diffused irradiation, only solar simulators can be used where a near-normal incidence beam of simulated solar irradiation is directed to the collector.

The lamps shall be capable of producing a mean irradiance over the collector gross area of at least 700 Wm^2.

The irradiation G is usually measured with an automated X-Y system that moves the Pyranometer every 150 mm in both directions over the whole collector gross area and in the plane of the absorber.

Uniformity of the Simulated Solar Irradiation

At any time the irradiance at a point on the collector gross area shall not differ from the mean irradiance over the aperture by more than ± 15 %.

The uniformity of the solar simulator must be checked before each efficiency test.

It is desirable that the lamps' intensity settings can be individually controlled from a computer. In this way it is continuously possible to see the radiation map on the collector and it is possible to adjust the uniformity of the lamps in a visual and easy way.

Collimation of the Simulated Solar Irradiation

At least 80% (90% for IAM measurements) of the simulated solar irradiance shall lie in the range in which the incident angle modifier varies by no more than ± 2% from its value at normal incidence.

One way to check the collimation requirement is to use a cylinder that geometrically fulfills the requirements specified. This cylinder, which must be painted black inside to minimize the reflectance, is placed over the Pyranometer and irradiance measurements are made at the same point of the collector plane with and without cylinder. The measurement obtained with the tube must be above 80% for efficiency tests and 90% for incidence angle modifier tests compared to the irradiance measured without tube in the same point.

Spectral Distribution of the Simulated Solar Irradiation

The spectral distribution of the simulated solar radiation shall be approximately equivalent to that of the solar spectrum at optical air mass 1.5. It is difficult to find equipment or laboratories that can measure the spectrum from 0.3 µm to 3 µm, especially from 2.5 µm. The spectral distribution of the lamps must be measured by a Spectroradiometer or outsourcing the characterization of the lamp to an accredited laboratory. It is recommended to do these measurements for each replacement of the lamps.

In case of spectrally selective absorbers or covers, a check shall be made to establish the effect of the difference in spectrum on the product for the collector. If the effective values under the simulator and under the optical air mass 1.5 solar radiation spectrum differ by more than 1%, a correction shall be applied to the test results. 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.

Infrared Thermal Radiation

The amount of infrared thermal energy at the collector plane shall be suitably measured and reported. The thermal irradiance at the collector shall not exceed that of a blackbody cavity at ambient air temperature by more than 5% of global irradiance. To verify this requirement a Pyrgeometer can be used to measure the thermal radiation. Several measurements are performed in the same plane of the collector and values have to fulfill the standard requirements by calculation. This measurement is enough to perform for each change of lamps or whenever changes are made in the simulator or its environment.

To minimize the effect of thermal radiation it is recommended to use a cold sky consisting of a double glass through which cold air is circulating to get a glass temperature near to room temperature in between the collector and the lamps.

"Tips and Tricks"

- In some cases, when the collector is manufactured with selective absorbers or covers, the value of the optical performance measured in the solar simulator can differ from the optical performance value of the same collector measured under outdoor conditions. This difference depends on the type of lamps used by the simulator and selective materials used in the collector. It is recommended to check this difference to evaluate if it is necessary to apply a correction factor;
- If the collimation of the simulator does not meet the requirements of the standard, results of the determination of the optical performance value will be seriously influenced. Especially when measuring vacuum tubes collectors or other collectors with odd IAM behaviors, or in incidence angle modifier measurements in general;
- Concentrating collectors should not be measured at all in solar simulators;
- Values in the range 300 W/m² to 1000 W/m² may also be used for specialized tests, provided that the accuracy requirements can be achieved and the irradiance values are noted in the test report;
- It is recommended to use lamps with levels of radiation that can reach up to 1100 W/m², so that the simulator can also be used for function tests according to ISO 9806:2017;
- It is important to take the distance between the collector and the solar simulator into consideration to assure the desired levels and distribution of radiation;
- It is important to age lamps at the beginning of their life to stabilize the different components of the lamp. It is also recommended to stabilize lamps of the simulator before any test, the period required being dependent on the type of lamps used.

20 Collector Mounting and Location

The way in which a collector is mounted will influence the results of thermal performance tests. The present Fact Sheet gives introduction to normative mounting requirements and some special considerations in case of special collector types.

Mounting Procedure

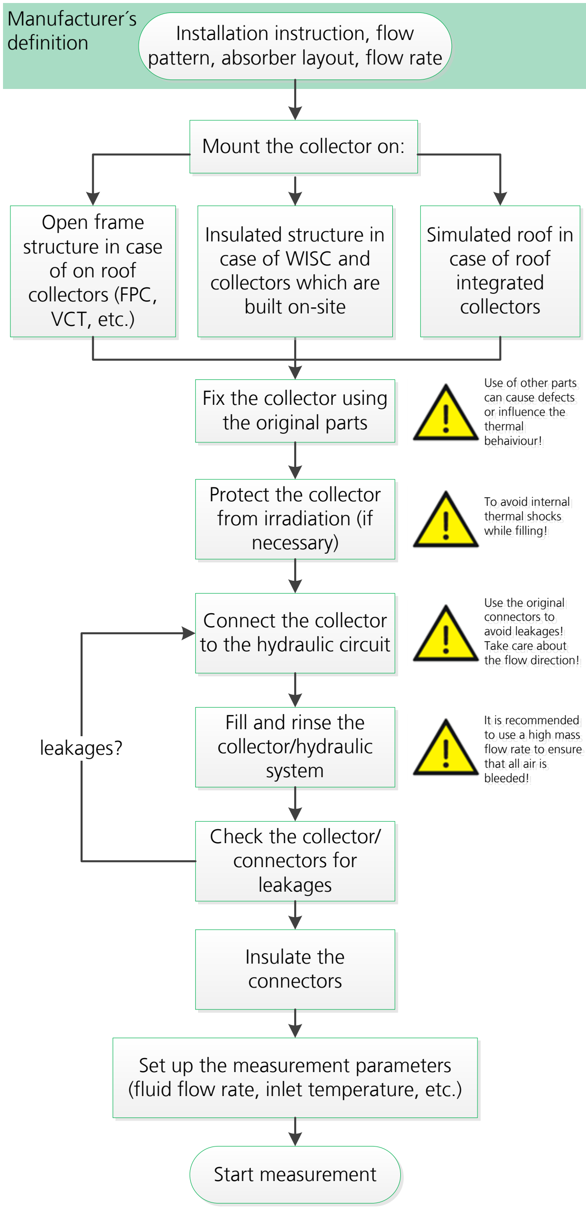


Figure 1: Testing facilities of the TestLab Solar Thermal Systems, Fraunhofer ISE

Boundary Conditions

<u>Normative mounting requirements:</u>

- Mounting shall be done in the manner specified by the manufacturer;
- Mounting 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);
- Open mounting structures 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. When collectors are tested on the roof of a building, they shall be located at least 2 m away from the roof edge.

<u>Special considerations / collector types</u>

- WISCs without backside shall be mounted on an insulated backing with a thermal conductivity of 1W/m²K ± 0.3W/m²K, and the upper surface painted matt white and ventilated at the back;
- ETC without back side mirror shall be mounted on a dark surface to avoid irradiation on the tubes´ back side.
- Roof integrated collectors shall be mounted using their original roof covering as delivered by the manufacturer.

"Tips and Tricks"

- Always use the original mounting equipment to fix the collector to your testing facilities;
- Always use the original installation instruction to install the collector in the right manner;
- Always notice manufacturer's limitations (e.g. inclination, mass flow rate);
- Always check the internal flow distribution before connecting the collector to your hydraulic circuit (e.g. by a technical drawing);
- The minimum inclination of the collector should be reasonable in comparison to its technology;
- Air within the hydraulic circuit can be bled through a high mass flow rate. It's important to install an air bleed valve within the hydraulic circuit; vary the mass flow rate and temperature for bleeding;
- As the performance of collectors is sensitive to the wind conditions, the use of artificial wind generators is recommended. Note that the turbulence level of artificially generated wind is often higher compared to that of natural wind adjacent to the collector surface (esp. at required collector area of at least 3 m^2) that leads to an overestimation of heat loss and the wind depending coefficients;
- Long wave radiation: Due to the specific characteristics of infrared sensitive collectors it is particularly important that surfaces in the field of view of the collector (including back side) are kept at temperatures close to the ambient;
- Currents of warm air, such as those which rise up the walls of a building or an exhaust chimney, shall not be allowed to pass over the collector;
- The use of inappropriate mounting equipment can lead to damages, which are not directly visible but influencing the performance and/or the functionality.

Manufacturers Information Box

- The manufacturer should deliver the original mounting equipment;
- The manufacturer should deliver an installation manual describing how to install the collector as well as all the limitations (mass flow rate, internal pressure, inclination, etc.).

21 Instrumentation

Solar Radiation Measurement – General

Accurate irradiance measurements are quite difficult to perform but indispensable for accurate determination of collector efficiency. Care should be taken to avoid shading and reflected irradiance on collector and measuring equipment. Measurement equipment shall always be well aligned with the collector tilt and azimuth. If a Pyrheliometer is used, the tracking errors associated to the mounting on the tracker must not exceed ± 0.5°. All irradiance sensors must be Class I or better, as specified in ISO 9060.
A good maintenance of radiation instruments includes regular cleaning and checking of desiccant condition.

Global, Diffuse and Direct Irradiance

The power output of some collector designs such as ETCs, CPCs and any other concentrating type of collector will strongly depend on the distinction between beam and diffuse irradiance. Diffuse irradiance can be measured by a Pyranometer equipped with a shadow ring or tracking ball, direct irradiance by a tracked Pyrheliometer, global irradiance by a regular Pyranometer. Depending on the combination of instruments chosen, one of the quantities can be calculated from the formulas:

$$G_b = DNI \cos\theta$$
$$G_d = G_{hem} - G_b$$

Best results will be reached with a combination including a Pyrheliometer to measure the direct normal irradiance (DNI). For highly concentrating collectors (CR > 3) the usage of a Pyrheliometer is mandatory.

Thermal Radiation Measurement

The consideration of the long wave irradiance E_L is needed for the characterization of infrared sensitive collectors (e.g. collectors for swimming pool heating) and can be measured using a Pyrgeometer mounted in the plane of the collector. If long-wave irradiance is accounted for, it shall be determined to a standard uncertainty of 10 W/m².

Temperature Measurement - General

Mounting position, immersion depth and fluid flow characteristics are crucial for the quality of temperature measurements. The sensors shall not be more than 200mm from the collector inlet and outlet. The pipework should be carefully insulated, ideally including the sensor head itself.

Liquid Heating Collectors

The sensor probe shall always point upstream, and a bend in the pipe work, an orifice or a fluid-mixing device shall be placed upstream of the sensor to ensure turbulent flow at the position of temperature measurement. A large immersion depth up to 10 times the inner pipe diameter minimizes temperature losses to the outside. The difference between the collector outlet and inlet temperatures (ΔT) shall be determined to a standard uncertainty of < 0.05 K and to an accuracy of better than 1 %.

Air Heating Collectors

The flow distribution shall be homogenized constructively over the channel cross-section. The temperature measurement shall be designed in a way that temperature gradients are balanced over the channels cross-section. The temperature of the heat transfer fluid at the collector inlet shall be measured to a standard uncertainty of ± 0.2 K.

Surrounding Air Temperature

A highly reflecting casing with forced ventilation is strongly recommended. Additionally, the sensor itself should be positioned in the shade and no more than 10 meters away from the collector. The ambient air temperature shall be measured to a standard uncertainty of < 0.5 K.

Flow Rate Measurement

The standard uncertainty of the mass flow rate measurement shall be within ± 1 % of the measured value for liquid heating collectors and ± 2 % for air heating collectors.

Air Speed Measurement

Air speed measurement is not referring to meteorological wind speed but air velocity over the collector surface. This quantity is difficult to measure as the sensors are positioned at the collector edges. The sensor monitoring the air speed during performance testing shall be calibrated relative to the mean air speed measured 50mm over the collector surface by a handheld anemometer.

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.

Elapsed Time Measurement

A simple computer clock can be used to measure the elapsed time within acceptable uncertainty.

Humidity Measurement (Air Collectors)

The humidity ratio X_W shall be measured to an accuracy of ± 0.001 (kg water/kg dry air) at 25 °C fluid temperature.

Collector Dimensions

The collector dimension shall be measured to a standard uncertainty better than 0.3 %. Measurements shall be performed at a collector temperature of 20 °C ± 10 °C.

22 Test Installation

This fact sheet contains information about the test installation.

Test Setup for Liquid Heating Collectors

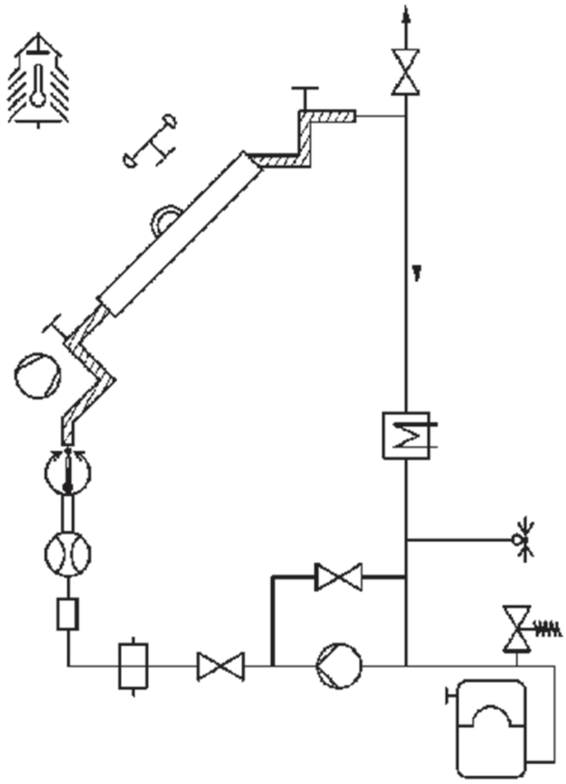


Figure 1: Example of a closed test loop. Description of the components can be referred to from the Standard.

Test Setup for Air Heating Collectors

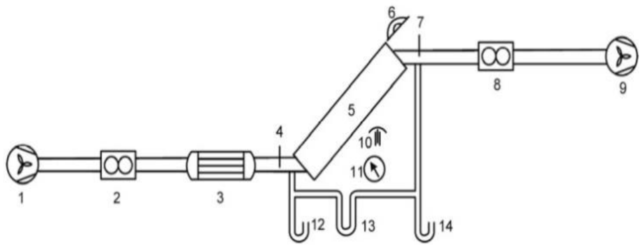


Figure 2: Closed test loop for SAHC

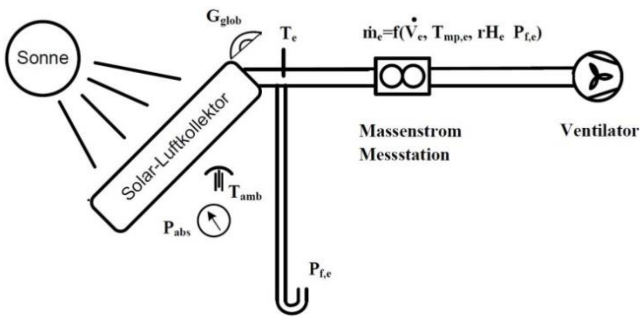


Figure 3: Open to ambient test layout for SAHC

Boundary Conditions

Use water or a fluid recommended by the collector manufacturer (the specific heat capacity and density should be within ± 1 % over the range of fluid temperatures used during the test).

The pipe work and the fittings shall be insulated such that the temperature gains or loses between the temperature measuring point and collector inlet and outlet are reduced as much as possible. Air bubbles and any contaminants shall be removed.

The mass or volume flow rate through the collector shall be stable within 1% despite temperature variation.

Boundary Conditions

Every component in the measurement loop shall have a leakage rate less than 2 m³/h at 250 Pa.

The mass flow rate through the collector shall be stable within ± 1.5 % despite temperature variations. The waste heat from the fan shall not influence the temperature measurement.

The preconditioning of the collector inlet temperature shall be controlled by a device which can hold the inlet temperature stable within ±1.0 K during the test period.

The humidity ratio shall be the same in the collector and of the surrounding air, if the test pressure is negative, for example, by testing in an open loop.

"Tips and Tricks"

- The mass flow rate of the heat transfer fluid should be the same during the test sequence used to determine the power curve, time constant and incident angle modifier for a given collector;

- Pipe lengths should generally be kept short to reduce the effects of the environment on the (inlet) temperature of the fluid;

- Insulate the pipes and use reflective covers (also weather proof for outdoor measurements);

- Install a short length of transparent tube in the fluid loop: air bubbles, contaminants can be observed;

- Avoid any drift in the collector inlet temperature.

Note: If non-aqueous fluids are used the compatibility with system materials should be confirmed.

Manufacturers Information Box

The test laboratory needs the fittings for the test installation and other installation materials.

"Tips and Tricks"

General:
- To avoid any drift in the collector inlet temperature an air preconditioning apparatus shall be used;
- It is important to measure and control the humidity at the different measuring points. Especially it is important to avoid condensation that occurs within the testing loop.

Closed loop:
- If a speed controlled (RPM regulated) fan is used, a flow meter should be used at the inlet and outlet;
- Measured at ambient pressure (can be realized by using two fans).

Open to ambient:
- The mass flow can only be determined at the collector outlet;
- The collector inlet temperature corresponds to the ambient temperature.

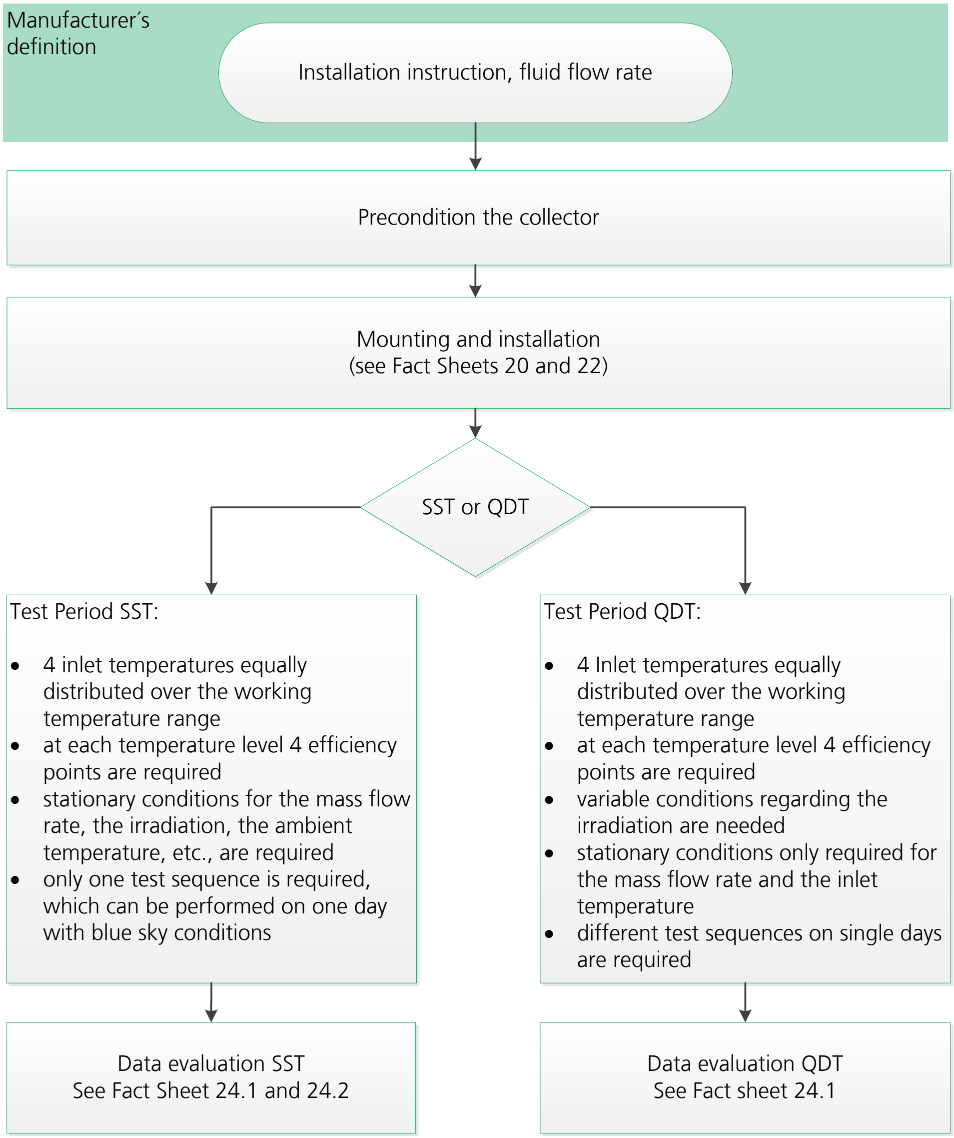
Manufacturers Information Box

The test laboratory needs the installation materials. In cases of special connectors or special forms of collector inlet and outlet, the test laboratory needs adaptors for round flexible tubes with a standard diameter like 200mm.

23 Performance Test Procedures

The thermal performance of a collector shall either be tested according to the Steady-State Testing (SST) or the Quasi-Dynamic Testing (QDT) procedure as given in ISO 9806:2017.

Procedure



"Tips and Tricks"

- In case of SAHC, it is important to measure the time constant first because it can reduce the time effort for testing significantly and avoid failures in testing;

- In case of liquid heating FPCs, usually a "time constant" of 10 minute is sufficient. The time constant shall be long enough to make sure that the steady state conditions have been reached;

- It is recommended to check the flow pattern against the chosen flow rate before testing. Often a simple calculation shows that the fluid flow will change from transient to intransient behavior by the temperature rise. This could lead to a discontinuous efficiency curve;

- In case of WISCs, it is important that the radiation towards the collector´s acceptance angle is well known and taken into account by the radiation sensor. A close-by building, lake or even window refection can cause significant influence.

Manufacturers Information Box

There has been inter-comparison test on different methods as well as different testing laboratories. The variation for example $\eta_{0,hem}$ result was within ± 2% (pp). From an accredited laboratory one can expect such an uncertainty at maximum.

Exemplary Results

The power output curves shown in the following figure are based on the SRC. For more information about the SRC see Fact Sheet 18. These power curves show the behavior of the collector under different irradiation conditions over its working temperature rage.

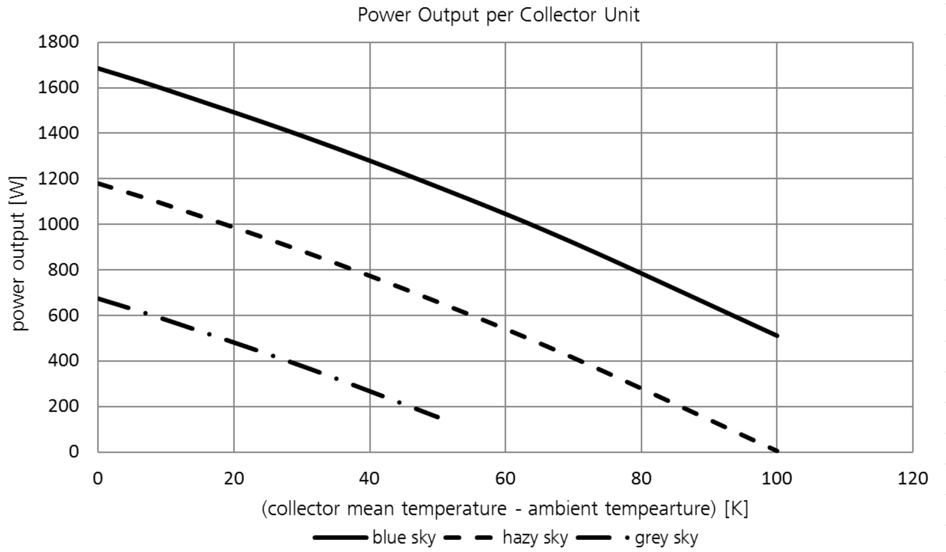


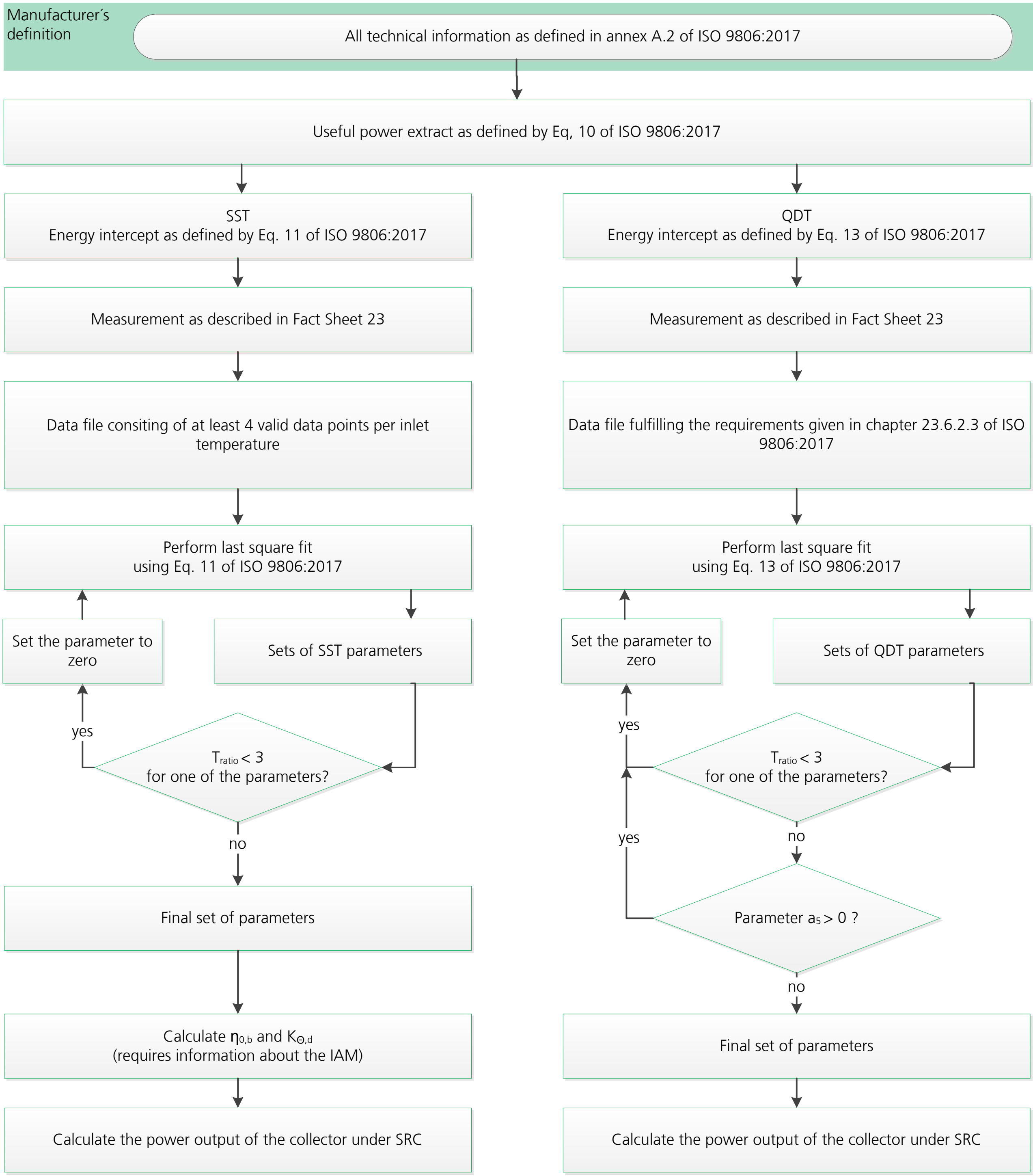
Figure 1: Power output curves per collector unit under different irradiation conditions

- The power output is given in Watt (y-axis) over the difference of the collector mean temperature and the ambient temperature (x-axis). Since extrapolation causes a high risk of errors, the power curve shall only be drawn in a range of maximum +30 K over the highest tested inlet temperature and maximum -10 K lower than the lowest inlet temperature;
- The peak power is reached where the collector middle temperature is equal to the ambient temperature, meaning that no thermal losses occur;
- The peak power must always be stated within the test report;
- Furthermore, it must be clearly stated that the results is only valid in the shown range;
- The power output is always given per collector unit;
- Negative power outputs shall not be given within the chart and/or the related table.

24.1 Computation of Parameters (liquid heating collectors)

This Fact Sheet contains information about the computation of collector parameters including the power extracted $\dot{Q}$, the solar energy intercepted, and information about modelling the instantaneous efficiency and the power output of liquid heating collectors.

Procedure



"Tips and Tricks"

- Under no circumstances it is admissible to set parameters to zero without repeating the data analysis and without re-fitting the other parameters;
- For WISC or collectors with a concentration ratio the parameter a_8 may set to zero;
- For covered collectors tested with artificial wind source the coefficients a_3, a_4, a_6 and a_7 are set to zero;
- Concentrating collectors without transparent cover and a concentration ration of $C_R < 10$ shall be treated as WISC collectors;
- Concentrating collectors with transparent cover and with a concentration ratio of $C_R < 3$ shall be treated as any other collector;
- For concentrating collectors with a transparent cover and a concentration ratio of $C_R > 3$, wind speed dependency can be neglected;
- For evacuated concentrating collectors wind speed dependency can be neglected independent of the concentration ratio C_R;
- The thermal performance of highly concentrating tracking collectors is usually tested according the quasi-dynamic test method. The steady-state method may be used if a distinction between beam and diffuse irradiance is taken into account. However, in this case the requirements for quasi-dynamic testing related to concentrating collectors shall be followed;
- For collectors with a concentration ratio of $C_R < 20$ the use of $\eta_{0,b}$, $K(\Theta_L, \Theta_T)$, a_1, a_2 and a_5 is mandatory for the computation of the efficiency result;
- For collectors with concentration ratio $C_R > 20$, the parameters a_2, a_3, a_4, a_6, a_7 and K_d may be set to zero. a_5 is mandatory an shall be identified;
- Since SST does not distinguish between direct and diffuse irradiation, an additional calculation step is necessary to determine the parameters $\eta_{0,b}$ and K_d, which are necessary to calculate the power output according to the SRC. Basic information for the calculation of these parameters is the result of the IAM-Measurement. This leads to the situation that, unlike the former standards, the SST efficiency measurement will be incomplete without performing the IAM measurement.
- The measured wind speed (u) is normalized by subtracting 3m/s from it into u'. This should be done before fitting the parameters.
- When using u' follow standard reporting conditions and use u' for calculation of power output $\dot{Q}$.

Manufactures Information Box

It is important to deliver all the technical information as defined in annex A.2 of ISO 9806:2017 to the testing laboratory. Otherwise the test lab cannot estimate if the result is plausible for the tested product.

Exemplary Results

The data file for the last square fit shall contain at least the information given within the following table.

Table 1: Measurement Data from SST or QDT measurement as a basis for the last square fit

					tilt angle	hemispherical irradiation	diffuse fraction	ambient temperature	angle of incidence	alignment of the testing facility	normalised wind velocity	mass flow rate	inlet temperature	outlet temperature	temperure rise	medium temperature of the heat transfer medium	reduced tempearure differenz	instantanious efficiency	$EL - \sigma * T_a^4$
P	Day	Month	Year	Time	β [°]	G [W/m²]	G_d/G [%]	ϑ_a [°C]	θ [°]	phi [°]	u' [m/s]	$\dot{m}$ [kg/h]	ϑ_{in} [°C]	ϑ_e [°C]	$(\vartheta_e - \vartheta_{in})$ [°C]	ϑ_m [°C]	T^*_m [m²K/W]	η_{hem} (G)	[W/m²]
1																			
2																			
...																			
16																			

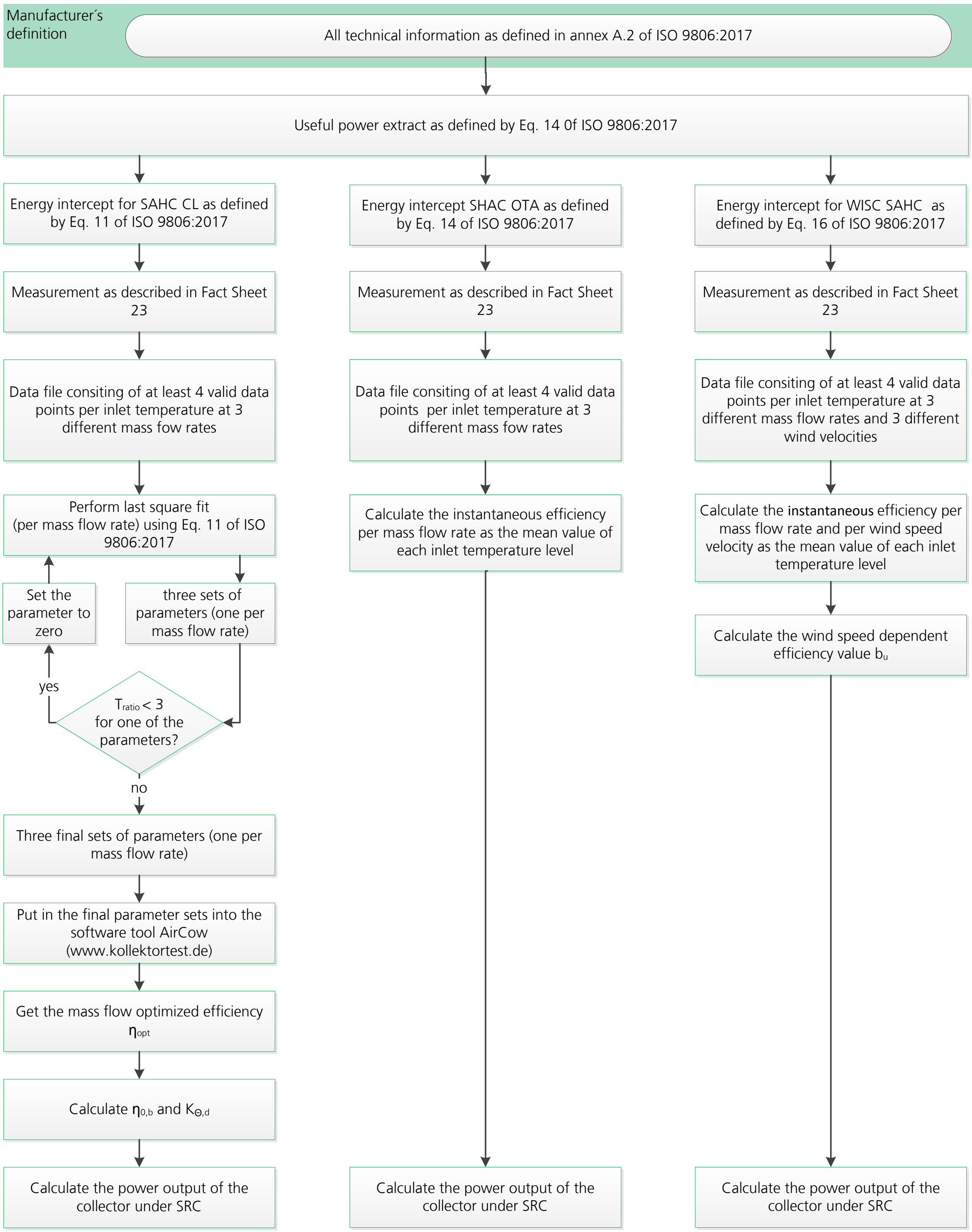
- In case of liquid heating collectors as well as closed loop solar air heating collectors, the results of the last square fit must be reported as shown in Table A.6 of ISO 9806:2017;
- For a good comparability It is important to use exactly the decimal places as given within Table A.6 of ISO 9806:2017;

  The calculation of the power output is to perform on the basis of the values given within Table A.6 of ISO 9806:2017 according to the SRC.

24.2 Computation of Parameters (air heating collectors)

This Fact Sheet contains information about the computation of collector parameters including the power extracted $\dot{Q}$, the solar energy intercepted, and information about modelling the instantaneous efficiency and the power output of air heating collectors.

Procedure



"Tips and Tricks"

- In case of air heating collectors only SST-Measurements are possible;
- The equation for the useful power extracted (Eq. 14 of ISO 9806:2017) requires to take both inlet and outlet fluid flow rate into consideration as both flow rates can differ from each other due to leakages;
- In case of closed loop SAHCs, the same equations for the last square fit are used as the computation of SST-Parameters of liquid heating collectors;
- The parameters of closed loop WISC SAHC are computed in the same manner as SST-Parameters of liquid heating collectors;
- Under no circumstances it is admissible to set parameters to zero without repeating the data analysis and without re-fitting the other parameters;
- To make the results of air and liquid heating collectors comparable to each other, a software tool called AirCow was developed by Fraunhofer ISE. This tool calculates on the basis of three sets of parameters, one optimum mass flow rate as well as the mass flow rate optimized efficiency value. Therewith it is possible to feed in the results into e.g. Solar Keymark data sheets in the same manner as the liquid heating collectors. Besides the calculation of the yearly energy gain can be done in a comparable way (e.g. using ScenoCalc);
- Since SST does not distinguish between direct and diffuse irradiation, an additional calculation step is necessary to determine the parameters $\eta_{0,b}$ and K_d, which are necessary to calculate the power output according to the SRC. Basic information for the calculation of these parameters is obtained from IAM-Measurement. This leads to the situation that, unlike the former standards, the SST efficiency measurement will be incomplete without performing the IAM measurement;
- In case of open to ambient SAHCs the inlet temperature cannot be adjusted to certain levels. This leads to the situation, that for those collector technologies only instantaneous efficiency points can be determined. If closed loop testing is possible (e.g. by constructing individual inlet ducts), it is strongly recommended to perform a closed loop measurement. This could avoid disadvantages in marketing and heighten the comparability to other products;
- In case of open to ambient SAHC-Measurements it is not possible to calculate $\eta_{0,b}$ and K_d. A calculation of the power output according to SRC is not possible yet. However to calculate the power output of OTA SAHCs, it is recommended to calculate it on the global hemispherical irradiation G_{hem}.

Manufactures Information Box

- It is important to deliver all the technical information as defined in annex A.2 of ISO 9806:2017 to the testing laboratory. Otherwise the test lab cannot estimate if the result is plausible for the tested product;
- The manufacturer shall deliver suitable air ducts to connect the collector to the hydraulic circuit of the testing facility;
- The manufacturer shall define the range of mass flow rates in which the SAHC is operated.

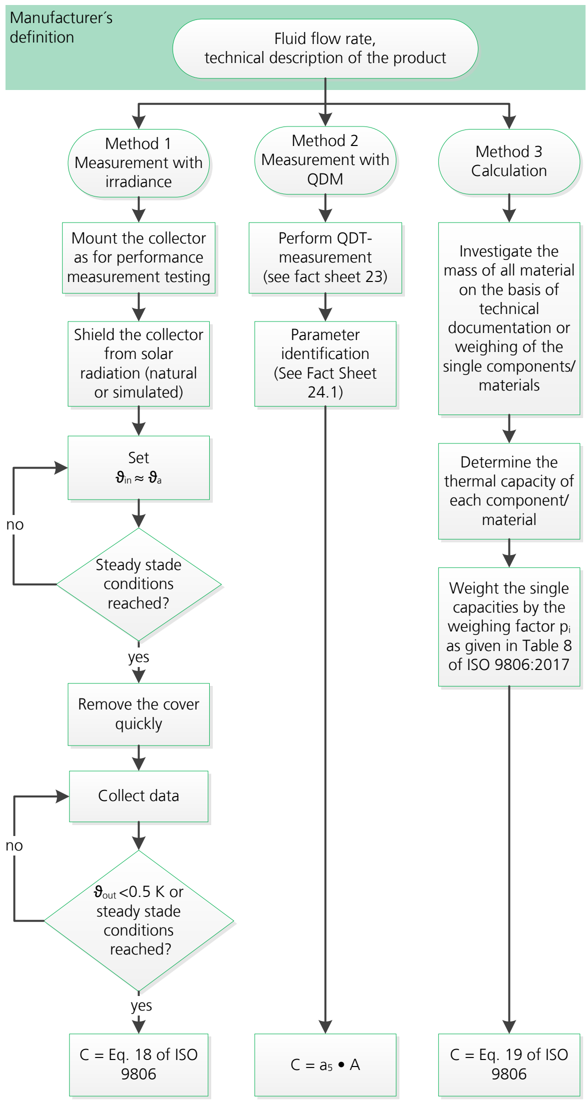
Exemplary Results

- The data file for the last square fit shall at least contain the same information as shown in Fact Sheet 24.1;
- The power curve for closed loop SAHCs are presented in the same manner than shown in Fact Sheet 23;
- The thermal performance of open to ambient SAHCs shall be presented as required by Table A.9 of ISO 9806:2017;
- The power output of open to ambient SAHCs shall be presented in form of single instantaneous power points over the temperature difference of the collector mean temperature and the ambient temperature.

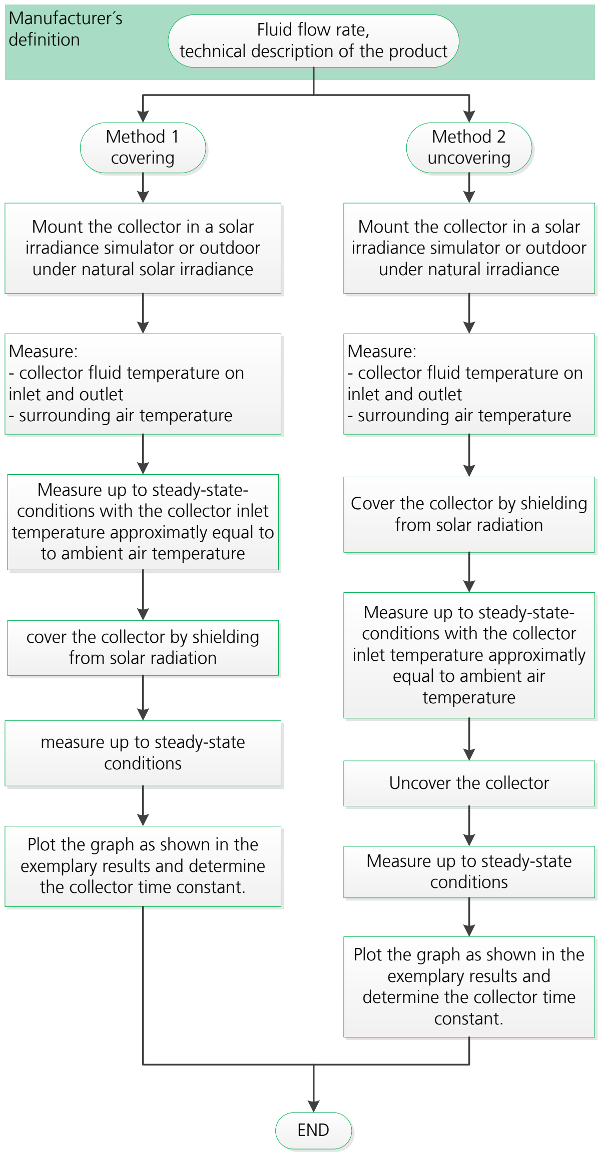
25 Effective Thermal Capacity and Time Constant

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

Determination of the Effective Thermal Capacity



Determination of the Time Constant



Boundary Conditions

- The effective thermal capacity of a collector can be determined directly via quasi dynamic testing (term c_5), through a separate indoor or outdoor measurement or via a calculation;
- If QDT method is chosen-
  - o use a flow rate equal to that of the efficiency measurement

Boundary Conditions

- The time constant of a collector can be determined through covering or uncovering the collector;
- Use a flow rate equal to that of the efficiency measurement;
- 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

- Test under SST conditions
- Use a reflecting coverage material

- If QDT is used, a high variability in solar radiation during the test is required so that the thermal capacitance effects will be significant. If the parameter c_5 cannot be properly identified by QDT, it can be calculated by method 2;
- If the calculation method is used, the thermal capacity of the collector C (expressed as Joules per Kelvin) is calculated as the sum, for each constituent element of the collector (glass, absorber, liquid contained, insulation), of the product of its mass m_i (expressed in kilograms), its specific heat c_i (expressed as joules per kilogram Kelvin) and a weighting factor p_i.

"Tips and Tricks"

- In case of SLACs the fluid content has a high effect on the effective thermal capacity and shall not be neglected. The thermal capacity of the heat transfer fluid used shall be considered for the calculation of the effective thermal capacity;
- In case of SAHCs the 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;
- 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.

Manufacturers Information Box

- Higher the effective thermal capacity of a collector, slower is its response to temperature changes;
- The knowledge of the effective thermal capacity allows the precise calculation of the annual collector energy gain within several simulation tools.

Exemplary Results

Table 1 shows typical range of the effective thermal capacity for different collector technologies.

Table 1: Effective thermal capacity

	FPC	ETC	SAHC
C_{eff} (kJ/m²K)	6 – 12	10 – 25	15 - 45

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;

- Alternatively a method that provides equivalent results 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 required measurement quantities.

"Tips and Tricks"

- Since outdoor conditions are often unstable it is recommended to perform indoor measurements to determine the collectors' time constant;
- The calculation of the factor b as well as the result presentation can be done by the following equation:

$$\Delta T = \Delta \mathrm{T}(100\%) \times (1 - e^{(b \times t)})$$

which leads to:

$$b = \ln \frac{\Delta T(100\%) - T}{\Delta T(100\%)} / t$$

Manufacturers Information Box

The time constant of the collector is 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.

Exemplary Results

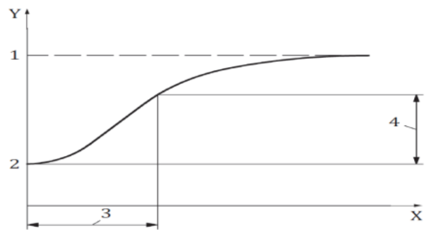
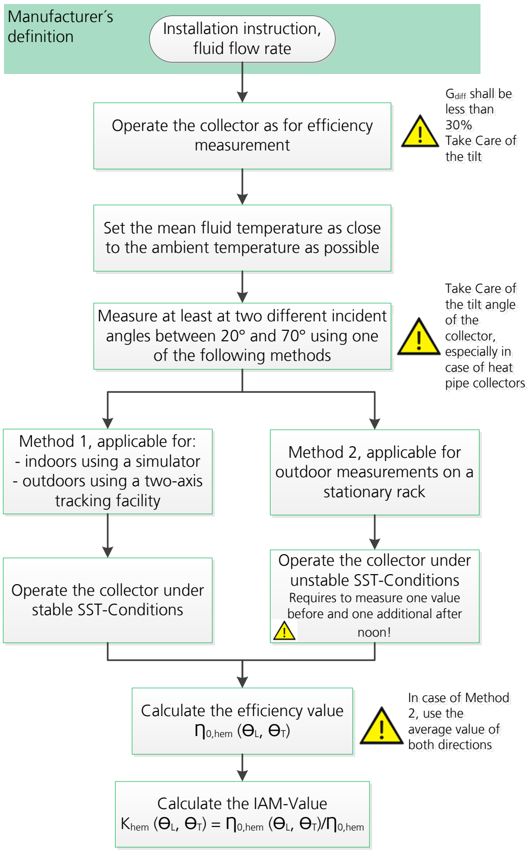


Figure 1: Graph of temperature difference between inlet and outlet of collector (ϑ_e-ϑ_a) versus time

26 Determination of the Incident Angle Modifier

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. Determination of collector incidence angle modifier helps to give an accurate representation of collector output over a wide range of climate conditions when solar irradiance is not near normal incidence. This collector characteristic is for instance used in ScenoCalc when simulating collector energy yield throughout an entire year under varying climate conditions.

Test Procedure



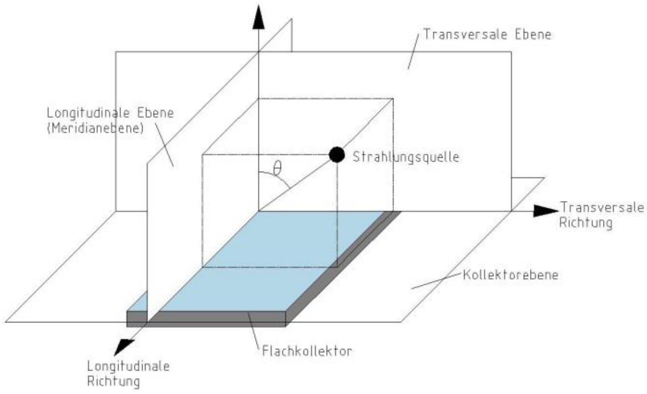


Figure 1: Longitudinal and transversal plane as reference for IAM description; Fraunhofer ISE

Boundary Conditions

The determination of the IAM is only necessary if the efficiency measurement has been done by SST. In case of QDT the IAM is an integral result of the collector model.

The knowledge about the IAM behavior is important. Or else the results from the different collector models are not comparable to each other.

"Tips and Tricks"

Since the inlet temperature of open to ambient SAHCs cannot be varied from the working temperature range of the collector, the determination of the optical efficiencies $\eta_{0,hem}$ and $\eta_{0,hem}(\Theta_L,\Theta_T)$ is not possible. Further the calculation of the IAM-value $K_{hem}(\Theta_L,\Theta_T)$ is also not possible. In case of open to ambient SAHCs, it is recommended to estimate the IAM on the basis of a calculation or simulation and to try and validate the result by an efficiency measurement at the same incident angle.

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.

For collectors with more complex optical properties, values at 20, 40 and 60° might be required to have an accurate determination of the complete incidence angle modifier. Collectors with non-symmetrical behaviour around normal incidence require separate measurements before and after solar noon for a proper determination of its behaviour.

Unlike former standards the calculation of IAM values on the basis of the Ambrosetti function is permitted. Thus the measurement at one incident angle would be sufficient to calculate the values in a range of 0° up to 90°. Nevertheless the standard requires measuring at least at two different incident angles.

Manufacturers Information Box

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 onto the longitudinal and transversal planes.

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. For conventional flat plate collectors it is enough to measure the incidence angle modifier at 50° incidence angle in one plane.

Exemplary Results

For conventional flat plate collectors the IAM can be given either as a constant value for 50°. It can also be given as constant values at e.g. 10°, 20°, 30°, 40°, 50°, 60°, 70°, and 80° without distinguishing between longitudinal and transversal. For collectors with non-symmetric optical characteristics it is necessary to distinguish between longitudinal and transversal for these angles (i.e. bi-axial IAM) and it can also be necessary to determine individual IAMs for each of the four quarter spheres (i.e. multi axial IAM) .
IAMs at high incidence angles have a higher uncertainty but on the other hand they normally have a low influence on the annual energy output.

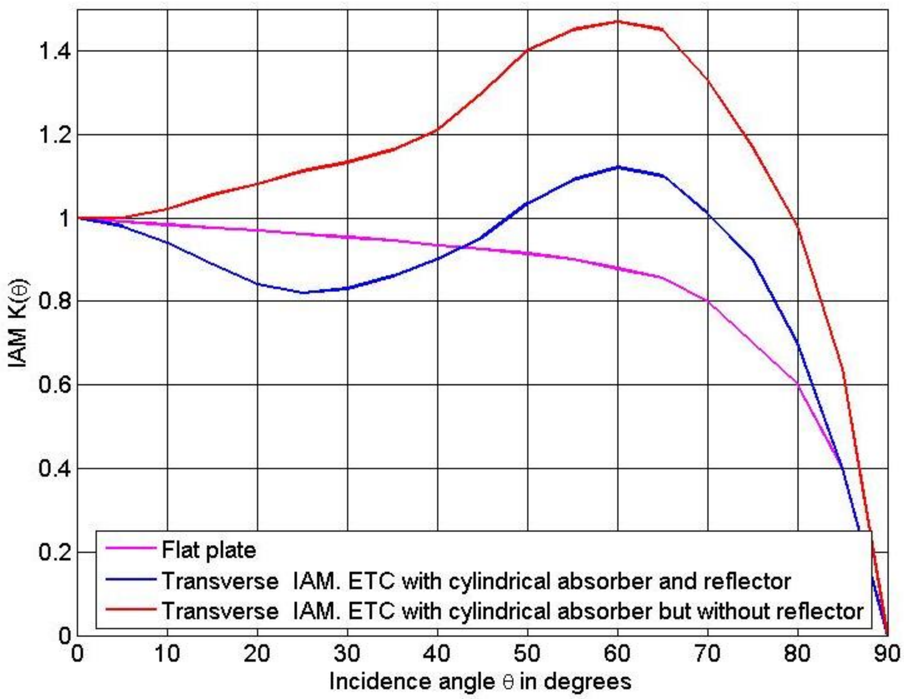


Figure 2: Graph of IAM K(Θ) versus Incidence angle Θ; Fraunhofer ISE

27 Determination of Pressure Drop

For designers of solar collector systems, the pressure drop across a collector maybe of importance (e.g. for sizing of pumps).

Test Setup

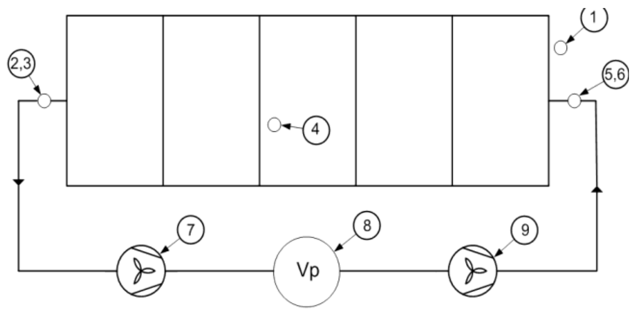


Figure 1: Test setup for determination of pressure drop; Fraunhofer ISE

Key

1	Pyranometer
2	Outlet temperature (T_{out})
3,6	Pressure gauge
4	Ambient Temperature (T_{amb})
5	Inlet temperature (T_{in})
7,9	Ventilator
8	Volumetric flow meter

Test Procedure

Manufacturer´s definition

Mass flow range, flow direction

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Place the collector indoors. It shall not be heated up by irradiation while testing

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Install:
- temperature sensor at inlet
- differential pressure sensor at inlet and outlet
- fluid flow meter

↓

Measure the pressure drop across the collector over its mass flow range

↓

Determine the function of the pressure drop curve by fitting the measurement points. Additional pressure drop caused by your measurement equipment (e.g. connectors) shall be substracted from the collectors pressure drop

↓

Present the results as a table and graphically as a function

Boundary Conditions

The following data shall be measured:
- fluid temperature at the collector inlet;
- fluid flow rate;
- 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.

The following test conditions are given during the test:
- the fluid flow rate shall be held constant within ±1% of the nominal value;
- temperature of the fluid shall be 20 ± 2°C;
- at least five measurements shall be made at values equally spaced over the flow rate range. The zero levels for flow rate and pressure drop shall be also checked;
- the pressure drop of the fittings has to be subtracted from the measured values after the test (e.g. determination through a short circuit test using only the fittings).

"Tips and Tricks"

- As different heat transfer fluids result in different pressure drop characteristics and thus give different curves, the pressure drop should preferably be measured using a fluid with similar properties as the one to be used in practical applications. In particular if the results are to be used by system designers and not only for relative comparisons;
- 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;
- For unglazed collectors flow rates from 0.02 kg/s to 0.1 kg/s per square meter of collector gross area shall be used if the specifications are not given from manufacturer;
- 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;
- Pressure drop tests at other temperatures may be important for oil-based heat transfer fluids;
- Particular attention shall be paid to the selection of appropriate pipe fittings at the collector entry and exit ports;
- The edges of the holes on the inside surface of the duct shall be free of burrs;
- Particular attention shall be paid to the selection of appropriate pipe fittings at the collector entry and exit ports.

Manufacturers Information Box

- The determination of pressure drop is no more an optional test. The manufacturer documents have to show data for pressure drop across the collector. The standard does not state if the test is obligatory or not. It depends on the certification scheme rule;
- The flow direction can have an influence about the pressure drop. Therefore the laboratory needs information about the flow direction;
- Depending on the purpose of testing (for sizing of pumps or for documentation issues) the manufacturer should suggest a specific fluid for the test;
- The manufacturer should recommend the operational specific range of flow rates of the collector.

Exemplary Results

The pressure drop between the collector-inlet and the collector-outlet is shown in the pressure drop curve at different flow rates. The pressure drop curve is normally a quadratic function of the fluid flow rate, which means that the pressure drop increases with the square of the flow rate.

If the collector also operates at low flow rates, e.g. when the flow is laminar, a different relation must be used.

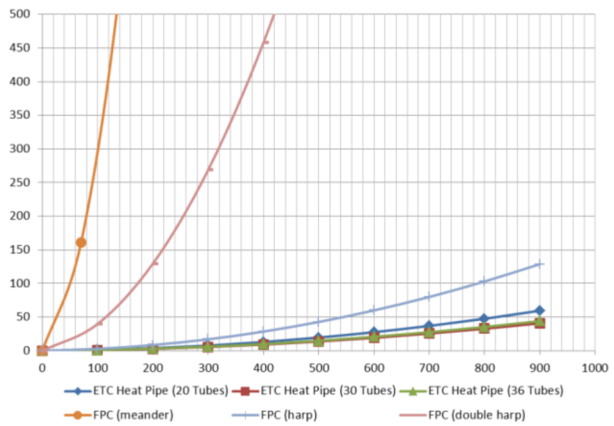

Figure 2: Typical pressure drop values for different SLHCs

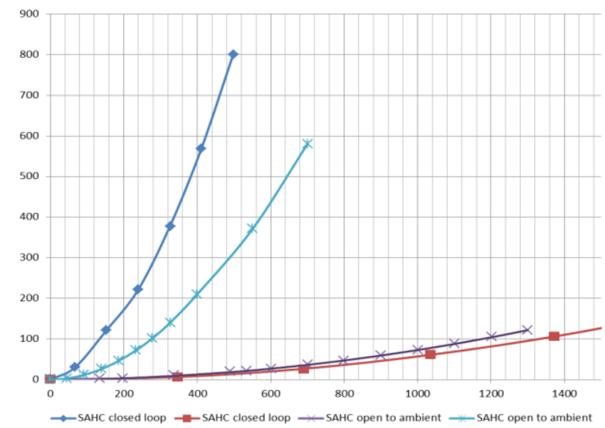

Figure 3: Typical pressure drop values for different SAHCs

Guide to the standard ISO 9806:2017

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