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SOLARTECHNIK

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Test Report No. C1902

Solar thermal collector (liquid heating)
Standards: ISO 9806:2017, EN 12975:2022

Collector model: **HC12**

Test ordered by:

TIGI Ltd.
3 Hamechonai St.
Hod Hasharon, IL-4527712

Manufacturer:

TIGI Ltd.
3 Hamechonai St.
Hod Hasharon, IL-4527712

Remarks:
The content of this test report shall not be modified.
The test methods applied fulfil the requirements of ISO 9806:2017.
The rating of the test results fulfils the requirements of EN 12975:2022.
The results given in this report relate to the tested sample(s) only.
This test report is made according to the requirements of ISO 9806:2017, EN 12975:2022.
This test report fulfils the requirements of ISO 17025.

Rapperswil, 07. July 2024

Dr. Andreas Bohren
Head of SPF Testing

The validity and authenticity of this report can be checked anytime
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1 Summary and main results

Clause in ISO 9806:2017 / Test		Date	Results/Observations	
--	Random sampling	15.09.2022	- - -	
--	Delivery of test sample(s)	08.11.2022	- - -	
--	Initial visual inspection	08.11.2022	- - -	0
6	Maximum operating pressure	26.07.2023	6 bar	0
9	Standard stagnation temperature	09.02.2023	160 °C	0
10	Exposure or half-exposure	10.12.2022 - 03.06.2022	Climate class A	0
11	External thermal shock 1 / 2	-- / --	NR	0
12	Internal thermal shock 1 / 2	04.05.2023 / 04.05.2023	Climate class A	0
13	Rain penetration	24.07.2023	- - -	0
14	Freeze resistance	- - -	NR	-
15	Mechanical load (positive)	10.07.2023	3000 Pa	0
15	Mechanical load (negative)	14.07.2023	3000 Pa	0
16	Impact Resistance	27.02.2023	45 mm	0
27	Pressure drop	16.02.2023	- - -	-
19	Thermal performance	06.12.2022 – 09.02.2023	- - -	0
	A_G Collector gross area		2.54 m^2	-
	$\eta_{0,hem}$ Collector efficiency based on hemispherical irradiance		0.734	-
	$\eta_{0,b}$ Peak collector efficiency based on beam irradiance		0.750	-
	K_d Incidence angle modifier for diffuse solar radiation		0.86	-
	a_1 Heat loss coefficient		1.53 $Wm^{-2}K^{-1}$	-
	a_2 Temperature dependence of the heat loss coefficient		0.015 $Wm^{-2}K^{-2}$	-
	a_3 Wind speed dependence of the heat loss coefficient		0.000 $Wsm^{-3}K^{-1}$	-
	a_4 Sky temperature dependence of the heat loss coefficient		0.00	-
	a_5 Effective thermal capacity incl. fluid (C/A_G)		5630 $Wsm^{-2}K^{-1}$	-
	a_6 Wind speed dependence of the zero-loss efficiency		0.000 sm^{-1}	-
	a_7 Wind speed dependence of IR radiation exchange		0.000 sm^{-1}	-
	a_8 Radiation losses		0.000 $Wm^{-2}K^{-4}$	-
	Average flowrate during the measurement		0.02 kgs^{-1}	-

26	Incidence angle	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	
26	$K_b(\theta_T,0)$	1.00	1.00	1.00	0.98	0.95	0.91	0.80	0.61	0.33	0.00	-
26	$K_b(0,\theta_L)$	1.00	1.00	1.00	0.98	0.95	0.91	0.80	0.61	0.33	0.00	-

25	Time constant	09.02.2023	137 s	-
17	Final inspection	27.07.2023	- - -	0

Table 1: Summary of results

Content

2 Introduction

2.1 Remarks on the test sequence

The collector is equipped with a passive overheating protection system (OPD). A secondary hydraulic system filled with water (or water-glycol mixture, if necessary) is mounted on the underside of the absorber (see Figure 1). This secondary system is connected to a heat exchanger at the rear of the collector box (see Figure 7). In the event of overheating, the fluid in the secondary system evaporates and the heat is dissipated to the ambient air via this heat exchanger. The temperature at which the OPD kicks in is about 100°C (evaporation temperature of water). The measured thermal performance parameters are therefore valid for operating temperatures up to about 100°C (See clause 4.13). The thermal behaviour of the collector at temperatures above the OPD threshold is approximated by a measurement of the thermal losses (See clause 4.13.4.2).

All durability and safety tests can be carried out as for any other collector because the OPD system is passive and does not require any external control or power source.

The stagnation temperature (Clause 4.4) is determined using the thermal performance parameters as reported in clause 4.13.

2.2 Test standards

The collector was tested according to the standards
- ISO 9806:2017
- EN 12975:2022
and in full compliance with the Solar Keymark scheme rules.

The results are presented in this report.
Complementary information which is not required by these standards is specifically marked.

2.3 Manufacturer information

All manufacturer information in this report was plausibility checked by the test laboratory and is not specifically marked anymore.

2.4 Specific abbreviations and formats used in the report

NR	Not required, not relevant	NS	Not specified
NA	Not applicable	NT	Not tested

--	No result as test was not performed
0	No problem (description see 4.19)
1	Minor problem (description see 4.19)
2	Major failure (description see 4.19)

Date and time are always indicated in the format (if applicable) DD.MM.YYYY HH:MM:SS

Indications about tilt angle and collector inclination are always measured from horizontal.

Length always denotes the distance in vertical (south-north) direction as tested
Width always denotes the distance in horizontal (east-west) direction as tested

Some of the thermal performance parameters may be set to zero as described in the ISO 9806:2017: In this case a result of 0 is indicated with the number of trailing zeros as required for this parameter.

The term “water-glycol” is used for a 33.3 Vol-% ethylene glycol mixture with water.

2.5 Test location, instrumentation and test devices

All tests are performed in the premises and on the testing field of the SPF Institute for Solar Technology of the Eastern Switzerland University of Applied Sciences (OST) in CH-8640 Rapperswil

The instrument types, specifications, serial numbers and calibration status of the instruments and test devices which were used to make the measurements and tests for this test report are filed in an internal database at the test laboratory. Upon request all this information can be made available as required by the ISO 17025.

3 Collector descriptions

3.1 Sample identification

Name of manufacturer	TIGI Ltd.
Collector name	HC12
Additional brand names (if applicable)	See Annex D
Collector type	Flat plate collector
Serial No of test sample(s)	Pre-serial production, no serial No.
Serial product	Yes
Photograph(s) of the collector(s)	See Figure 6
Remarks	None
Specific comments on the collector design:	None

3.2 Collector mounting possibilities

On tilted roof	Yes
On flat roof	No
In tilted roof	No
Façade	No
On Stand	Yes
Schematic diagram of collector mounting	See Figure 9

3.3 Protection mechanisms and integrated electrical components

Description and technical details of integrated electrical components	NA
Self-protecting collector as defined in ISO 9806:2017 Clause 5.2.2	Yes
Freeze resistant collector as defined in ISO 9806:2017 Clause 14.2	No
Freeze resistant heat pipes as defined in ISO 9806:2017 Clause 14.3	No
Description of protection mechanism(s)	See Clause 2.1

3.4 Operational range

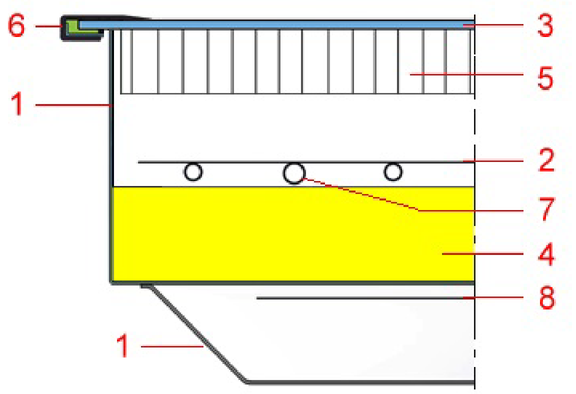
Minimum / Maximum operation temperature	depending on the glycol concentration / 120 °C
Maximum operation pressure (at maximum temperature of operation)	6 x10^5 Pa (6 bar)
Minimum / Maximum installation inclination	15° / 75°
Recommended heat transfer fluid(s)	water / water-glycol
Additional remarks concerning the heat transfer fluid(s)	See Installation manual
Flow rate minimum / recommended / maximum	100 / 150 / 300 lh^{-1}
Other limitations	None

3.5 Dimensions and general information

Gross length (length from bottom to top, orientation as tested)	2110 mm
Gross width (width from left to right, orientation as tested)	1205 mm
Gross height	259 mm
Gross area, A_G (as defined in ISO 9488)	2.54 m^2
Aperture area, A_{Ap} (as defined in ISO 9488)	2.41 m^2
Absorber area, A_{Abs} (as defined in ISO 9488)	2.32 m^2
Weight empty	72 kg
Fluid content	1.8 l

3.6 Specifications on elements

3.6.1 Collector cross section



Legend
1 Casing
2 Absorber
3 Glazing
4 Thermal insulation
5 Transparent insulation
6 Glass fixing
7 Overheating protection
8 Expansion air bag

Figure 1: Collector cross section

3.6.2 Frame, enclosure, casing

Legend No	1
Construction type	Folded casing
Enclosure material	Stainless steel sheet
Thickness	0.5 mm
Joining method	glued and riveted with corner joints

3.6.3 Absorber

Legend No	2
Material	Aluminium
Number of absorber elements (fins, tubes, etc.)	1
Distance between absorber elements	--
Absorber element length / width	2044 / 1135 mm
Absorber total length / width	2044 / 1135 mm
Absorber thickness	0.5 mm
Absorber coating	selective coating
Absorber coating trade name	Alanod Mirotherm
Solar absorptance α / hemispherical emittance ε	95%±1% / 5%±2%
Bond between riser and fin/plate	laser welding

3.6.4 Hydraulic system

Flow pattern	parallel harp, See Figure 8
Number of risers	12
Riser material	Copper
Riser length	1940 mm
Riser diameter outer / inner	8.0 / 7.2 mm
Distance between risers	87 mm
Manifold material	Copper
Manifold length	1195 mm
Manifold diameter outer / inner	22.0 / 20.4 mm
Collector hydraulic connector type/size	G 3/4”
Hydraulic designation code	12-V-1234S-A:7.2,1940-C:20.4,1195

3.6.5 Transparent cover(s)

Legend No	3
Material	Tempered glass
Number of serial glazing	1
Thickness	3.2 mm
Diameter (for tube collectors only) outer / inner	-- / -- mm
Solar transmittance	>95 %
Glazing surface characteristics	Clear

3.6.6 Insulation(s)

Legend No	4
Material	Rock wool
Cover	Aluminium foil
Thickness	50 mm
Thermal conductivity (50°C)	0.0035 W/mK

3.6.7 Insulation(s)

Legend No	5
Material	Transparent honeycomb insulation
Cover	--
Thickness	40 mm
Thermal conductivity (50°C)	NS

3.6.8 Overheating protection device (OPD)

Legend No	7
Flow pattern	parallel harp, welded to the backside of the absorber, See Figure 8
Number of risers	11
Riser material	Copper
Riser length	1870 mm
Riser diameter outer / inner	10.0 / 8.8 mm
Distance between risers	87 mm
Manifold material	Copper
Manifold length	995 mm
Manifold diameter outer / inner	18.0 / 16.4 mm

3.6.9 Other elements

Expansion air bag (Legend No. 8)	Filled with zeolite-type material
Glass fixation (Legend No. 6)	Profile with silicone glue

3.7 Technical documentation and safety requirements (EN 12975:2022)

3.7.1 Labelling

The collector carries a visible and durable label.	Yes

3.7.1.1 Mandatory information on the label

Name of manufacturer	Yes
Model	Yes
Serial number	Yes
Year of production (can be included in the serial number)	Yes
Peak power	Yes
Maximum operating pressure	Yes
Weight of empty collector	Yes
Volume of heat transfer fluid	Yes

3.7.2 Safety

The collector provides for safe installation and mounting. It has no sharp edges, no loose connections, and no other potentially dangerous features	Yes
If the weight of the empty collector exceeds 60 kg an anchorage for a lifting device is included, except for collectors that are assembled on the roof	Yes
If the collector is made to be filled with a heat transfer fluid that is irritant to human skin or eyes or that is toxic, the collector carries a warning label	Yes

3.7.3 Installer instruction manual and/or technical datasheet

The collector is accompanied by an installer instruction manual	Yes

3.7.3.1 Information included in the installer instruction manual

Dimensions	Yes
Weight of the collector	Yes
Instructions about the transport and handling	Yes
Stagnation temperature at 1000 W/m^2 and 30 °C	Yes
Description of the mounting procedure	Yes
Recommendations about lightning protection	Yes
Instructions about the coupling of the solar collectors to one another	Yes
Instruction on the connection of the solar collector field to the heat transfer circuit	Yes
Instruction on dimensions of pipe connections for solar collector arrays	Yes
Reminder to follow the national requirements for the thermal insulation of the piping	Yes
Instructions about the heat transfer media which shall be used	Yes
Instructions and precautions which shall be taken during filling, operation and service	Yes
Pressure drop	Yes
Maximum and minimum tilt angle	Yes
Maximum operating pressure	Yes
Maximum operating temperature	Yes
Permissible positive and negative mechanical load	Yes
Maintenance requirements, including specific cleaning procedures if required	Yes
Indications about the requirements concerning free airflow on the backside of the collector	Yes
Indication on the impact resistance	Yes
Declaration of the climate class for testing	Yes

3.7.3.2 Information for building integrated collectors only

The collector can be used in building integrated systems as part of the building shell	No

If the collector can be integrated in the roof or in the building shell, the following recommendations shall be included in the instruction manual, to be considered when the collector is integrated in the roof or in the building shell.

Permanent stagnation over longer periods shall be avoided.	NA
The stagnation time between installation and commissioning of the system shall be less than one month.	NA
Ventilation behind the collector casing shall be sufficient and in accordance with national regulations and building codes.	NA
No additional isolation shall be added to the rear side of the collector.	NA
Piping near the collector shall be installed and isolated such that they are not in contact with wood or other inflammable materials.	NA
Preventive measures shall be taken to avoid that a leaking connection may lead to ingress of heat transfer fluid into the collector.	NA

3.7.4 Drawings and specifications

A complete set of technical drawings and datasheets has been submitted	Yes
Technical drawings and specifications	See Annex C

4 Test conditions and results

4.1 General remarks

Description of self-protection mechanism and description of adapted test procedure (for self-protecting collectors only, ISO 9806:2017, clause 5.2.2.3):	See Clause 2.1

4.2 Sampling

Sampling of the collector	Solar Keymark, SRCC

4.3 Internal pressure test for fluid channels

4.3.1 General remarks

Test performed	Yes

4.3.2 Test condition

Test fluid	Water
Test temperature	20 °C ± 15 °C
Maximum test pressure (1.5x maximum operating pressure)	9 bar
Test duration	≥15 min

4.3.3 Test results

Any evident problems, damages and failures according to ISO 9806:2017 Clause 17	None
Other observations and remarks	None

4.4 Determination of standard stagnation temperature

4.4.1 General remarks

Test performed	Yes

4.4.2 If measured according to ISO 9806:2017 Clause 9.3

Test location	--
Collector inclination	-- °
Average ambient temperature	-- °C
Average hemispherical irradiance	-- Wm^{-2}
Location for temperature sensor	--
Fluid specifications, flow rate, fluid temperature (if a fluid was circulated)	--
Any evident problems, damages and failures according to ISO 9806:2017 Clause 17	None
Observations and remarks:	None

4.4.3 If determined according to ISO 9806:2017 Clause 9.4

Maximum relative power output (Q/Q_{peak})	< 0
Irradiance at maximum relative power output	> 800 Wm^{-2}
Calculated temperature where $\vartheta_m - \vartheta_a = 0$ °K for $\vartheta_a = 30$ °C and G=1000 Wm^{-2}	115.43 °C

4.4.4 Test results

Calculated stagnation temperature (ϑ_{stag} = 115.43 + 30 °K)	145.43 °C
Standard stagnation temperature at 1000 W/m^2 and 30 °C	150 °C

4.5 Exposure test

4.5.1 General remarks

Test performed	Yes
Test type	Full exposure

4.5.2 Test conditions

Climate class	A
Irradiance G	≥1000 Wm^{-2}
Ambient air temperature ϑ_a	≥20 °C
Irradiation on collector H_x	≥600 MJ/m^2

4.5.2.1 Outdoor exposure

Location for initial outdoor exposure	CH-8640 Rapperswil, 47.2 °N / 8.8 °O, 417 MAMSL
Collector tilt angle during initial outdoor exposure	45°
Collector azimuth angle during initial outdoor exposure (measured from due south)	tracked
Test date	10.12.2022 – 23.02.2023
Collector tested as façade collector	No
Test date in vertical position	None
Number of days in vertical position	None
Location of temperature measurement	No sensor
Total days of outdoor exposure	> 30 days
Total Hemispherical irradiation on collector	> 600 MJm^{-2}
Total time with conditions resulting in absorber temperature of the selected climate class	> 32.0 h

4.5.2.2 Additional exposure test using a fluid loop

Remark	Method not used
Fluid used	--
Flow rate	-- kgh^{-1}
Fluid temperature	-- °C
Test date	--
Location of temperature measurement	--
Total time with conditions resulting in absorber temperature of the selected climate class	-- h

4.5.2.3 Additional exposure test using a solar simulator

Remark	Method not used
Average radiation on collector plane	-- Wm^{-2}
Average ambient temperature	-- °C
Test date	--
Location of temperature measurement:	--
Total hemispherical irradiation on collector	-- MJm^{-2}
Total time with conditions resulting in absorber temperature of the selected climate class	-- h

4.5.3 Test results

Any evident problems, damages and failures according to ISO 9806:2017 Clause 17	None
Other observations and remarks	None

4.6 Extended exposure test

4.6.1 General remarks

To verify the long-term function of the overheating protection device, one collector was exposed in stagnation for a much longer period than required by the standard. This test was made in addition to the requirement of the ISO 9806.
The collector was exposed from 09 November 2022 (date of receipt) until 05 July 2024 (date of this report) in stagnation on the roof of the testing laboratory under the following conditions:

4.6.1.1 Outdoor exposure

Location for initial outdoor exposure	CH-8640 Rapperswil, 47.2 °N / 8.8 °O, 417 MAMSL
Collector tilt angle during outdoor exposure	45°
Test date	09.11.2022 – 05.07.2024
Location of temperature measurement	No sensor
Total days of outdoor exposure (30 days required by ISO 9806)	> 606 days
Total hemispherical irradiation on collector (600 MJm^{-2} required by ISO 9806)	> 7175 MJm^{-2}

4.6.1.2 Test results

The collector was kept in stagnation more than 20 times longer than necessary and the irradiation was more than 10 times higher than required. Furthermore, the collector was also exposed to freezing temperatures several times.
A visual inspection of the collector after this extended exposure test does not show any degradation of the honeycomb structure, thus proofing that the OPD is operational.

4.7 External thermal shock test

4.7.1 General Remarks

Testing is not required for collectors using toughened glass.

Test performed	No

4.8 Internal thermal shock test

4.8.1 General remarks

Test performed	Yes

4.8.2 Test conditions

Climate class tested	A
Irradiance G	≥1000 Wm^{-2}
Ambient air temperature ϑ_a	≥20 °C

4.8.2.1 Shock (1)

Test method	Collector under stagnation conditions for ≥ 1 h
Collector tilt angle	32.3 °
Irradiance during test average / minimum	968.5 / 844.5 Wm^{-2}
Ambient air temperature average / minimum	22.5 / 17.1 °C

4.8.2.2 Shock (2)

Test method	Collector under stagnation conditions for ≥ 1 h
Collector tilt angle	35.2 °
Irradiance during test average / minimum	999.2 / 892.9 Wm^{-2}
Ambient air temperature average / minimum	22.3 / 21.3 °C

4.8.3 Test results

Any evident problems, damages and failures according to ISO 9806:2017 Clause 17	None
Observations and remarks	None

4.9 Rain penetration test

4.9.1 General remarks

Test performed	Yes

4.9.2 Test conditions

Collector tilt angle	25°

Number and position(s) of spray nozzles as defined in Fig. 2 and Fig. 3 of the ISO 9806:2017

4.9.3 Test results

Any evident problems, damages and failures according to ISO 9806:2017 Clause 17	None
Observations and remarks	None

4.10 Freeze resistance test

4.10.1 General remarks

Test performed	No

4.11 Mechanical load test

4.11.1 Positive pressure test

4.11.1.1 General remarks

Test performed	Yes

4.11.1.2 Test conditions

Description of the collector mounting kit used in the test	See Annex A
Test method used to apply positive pressure	Pneumatic actuators with suction cups

4.11.1.3 Test results

Maximum test load without damage	3000 Pa
Any evident problems, damages and failures according to ISO 9806:2017 Clause 17	None
Observations and remarks	None

4.11.2 Negative pressure test

4.11.2.1 General remark

Test performed	Yes

4.11.2.2 Test conditions

Description of the collector mounting kit used in the test	See Annex A
Test method used to apply negative pressure	Pneumatic actuators with suction cups

4.11.2.3 Test results

Maximum negative test load without damage	3000 Pa
Any evident problems, damages and failures according to ISO 9806:2017 Clause 17	None
Observations and remarks	None

4.12 Impact resistance test

4.12.1 General remarks

Test performed	Yes

4.12.2 Test conditions

Test method	Ice balls
Impact direction	Horizontally

4.12.3 Test results

Maximum ball diameter without damage (if ice ball testing)	45 mm
Maximum drop height (1 digit precision) without damage (if steel ball testing)	N/A
Any evident problems, damages and failures according to ISO 9806:2017 Clause 17	None
Observations and remarks	None

4.13 Performance test results

4.13.1 General remarks

Parameters measured | Yes

4.13.2 Collectors using external power sources (ISO 9806:2017 Clause 5.2.2.2)

Description of the required external power source | N/A
Estimation of the energy consumption under normal operation: | N/A

4.13.3 Thermal output measurements

4.13.3.1 Test conditions

Preconditioning	Yes
Test method	Steady state
Heat transfer fluid for testing	Water-glycol
Wind generator	Yes
Orientation of the collector during test	Portrait

4.13.3.2 Outdoor testing

Test location	CH-8640 Rapperswil, 47.2 °N / 8.8 °O, 417 MAMSL
Collector orientation	Tracked

4.13.3.3 Indoor testing (if applicable)

Type of lamps	NR
Irradiance* minimum / mean / maximum	-- / -- / -- Wm^{-2}
Grid spacing for measuring irradiance data	-- mm
Collimation* minimum / mean / maximum	-- / -- / -- Wm^{-2}
Thermal irradiance* minimum / mean / maximum	-- / -- / -- Wm^{-2}

4.13.4 Thermal performance reporting

4.13.4.1 Collector performance coefficients (based on gross area A_G)

The following collector coefficients shall be used for all thermal output calculations.

Collector performance coefficients (valid for $\vartheta_m \leq 100°C$)	**Result**	**Unit**
A_g Collector gross area	2.54	m^2
$\eta_{0,hem}$ Collector efficiency based on hemispherical irradiance	0.734	- - -
$\eta_{0,b}$ Peak collector efficiency based on beam irradiance	0.750	- - -
K_d Incidence angle modifier for diffuse solar radiation	0.86	- - -
a_1 Heat loss coefficient	1.53	$Wm^{-2}K^{-1}$
a_2 Temperature dependence of the heat loss coefficient	0.015	$Wm^{-2}K^{-2}$
a_3 Wind speed dependence of the heat loss coefficient	0.000	$Wsm^{-3}K^{-1}$
a_4 Sky temperature dependence of the heat loss coefficient	0.00	- - -
a_5 Effective thermal capacity incl. fluid (C/A_G)	5630	$Wsm^{-2}K^{-1}$
a_6 Wind speed dependence of the zero-loss efficiency	0.000	sm^{-1}
a_7 Wind speed dependence of IR radiation exchange	0.000	sm^{-1}
a_8 Radiation losses	0.000	$Wm^{-2}K^{-4}$
Average flowrate during the measurement	0.02	kgs^{-1}

Where $\eta_{0,hem} = \eta_{0,b}\,(0.85 + 0.15\,K_d)$ according to ISO 9806:2017 Annex B.

4.13.4.2 Collector performance for temperatures above the OPD threshold.
The thermal performance was measured for operating temperatures ϑ_m up to about 114°C and for temperature differences of $\vartheta_m - \vartheta_a$ > 103°K. To determine the thermal performance only measured data are considered where the absorber temperature ϑ_m > 100°C. From these measurements a heat loss coefficient $a_{1,OPD}$ = 30.08 WK^{-1} is determined.

4.13.4.3 Power output per collector unit under SRC
The thermal output (Table 3) under standard reporting conditions (SRC) for the tested collector at operating temperatures ϑ_m < 100°C is calculated using formula:

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

and for operating temperatures ϑ_m > 100°C (OPD in operation).

$$\dot{Q}_{OPD}(\vartheta_m) = \dot{Q}(100°C - \vartheta_a) - a_{1,OPD}(\vartheta_m - 100)$$

where u' = u – 3 ms^{-1} and

Climatic conditions	**Blue sky**	**Hazy sky**	**Grey sky**
G_b	850 Wm^{-2}	440 Wm^{-2}	0 Wm^{-2}
G_d	150 Wm^{-2}	260 Wm^{-2}	400 Wm^{-2}
ϑ_a	20 °C	20 °C	20 °C
$E_L - \sigma \cdot \vartheta_a^4$	−100 Wm^{-2}	−50 Wm^{-2}	0 Wm^{-2}
u	1,3 ms^{-1}	1,3 ms^{-1}	1,3 ms^{-1}

Table 2: Standard rating conditions (SRC)

$\vartheta_m - \vartheta_a$ [K]	**ϑ_m [°C]**	**Blue sky [W]**	**Hazy sky [W]**	**Grey sky [W]**
-10	10	1900	1299	690
0	20	1865	1264	655
10	30	1822	1221	613
20	40	1772	1171	562
30	50	1714	1113	504
40	60	1649	1048	439
50	70	1575	975	366
60	80	1495	894	285
70	90	1406	805	197
80	100	1310	709	101
90	*110*	*1009*	*409*	-
100	*120*	*709*	*108*	-
110	*130*	*408*	-	-
120	*140*	*107*	-	-

Table 3: Power output under standard rating conditions (SRC). Data at temperatures above OPD are indicated in italic.

Maximum measured temperature difference	114 K
Power output data are valid for the maximum temperature difference	144 K
Peak Power per unit	1865 W

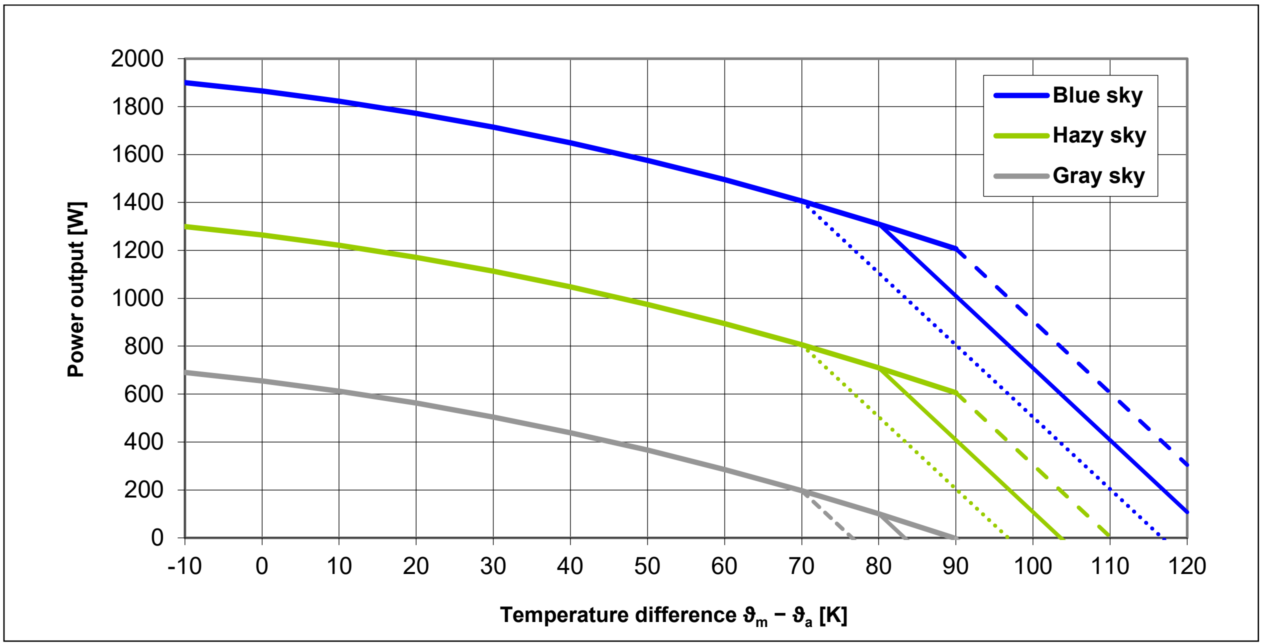


Figure 2: Power output per collector at SRC indicated as a function of the difference between medium collector temperature and ambient air temperature $\vartheta_m - \vartheta_a$.
ϑ_a = 20°C: plain lines, ϑ_a = 10°C: dashed lines, ϑ_a = 30°C: dotted line.

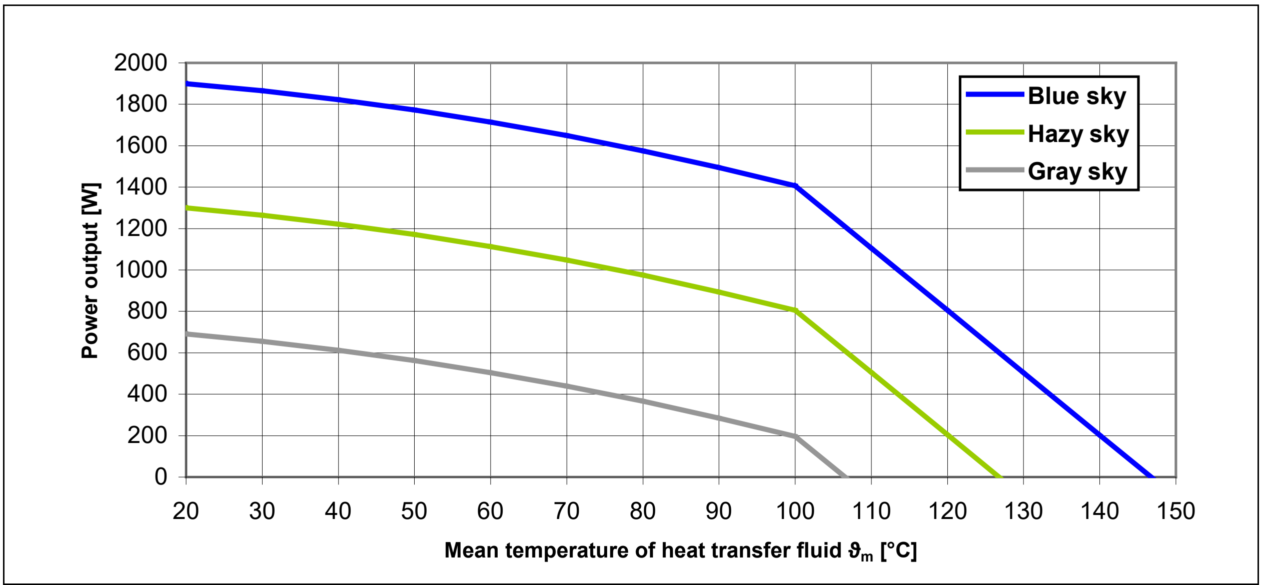


Figure 3: Power output per collector at ambient temperature of ϑ_a = 30°C as a function of the mean fluid temperature ϑ_m.

4.14 Incidence angle modifier

4.14.1 General remarks

Parameters measured — Yes

4.14.2 Test conditions

Test method — tracked steady state
Location — outdoor

4.14.2.1 Additional information for indoor testing only

Type of lamps — NR
Irradiance* minimum / mean / maximum — -- / -- / -- Wm^{-2}
Grid spacing for measuring irradiance, collimation and thermal irradiance — -- mm
Collimation* minimum / mean / maximum — -- / -- / -- Wm^{-2}
Thermal irradiance* minimum / mean / maximum — -- / -- / -- Wm^{-2}
* measured over the collector

4.14.3 Test results

Mathematical model for the transversal incidence angle modifier $K_T(\theta)$: — Cubic spline function
Mathematical model for the longitudinal incidence angle modifier $K_L(\theta)$: — Cubic spline function
Diffuse incidence angle modifier constant K_d (see ISO 9806:2017 Annex B) — 0.86

	0	10	20	30	40	50	60	70	80	90
$K_b(\theta_T,0)$	1.00	1.00	1.00	0.98	0.95	0.91	0.80	0.61	0.33	0.00
$K_b(0,\theta_L)$	1.00	1.00	1.00	0.98	0.95	0.91	0.80	0.61	0.33	0.00

Table 4: table of incidence angle modifiers

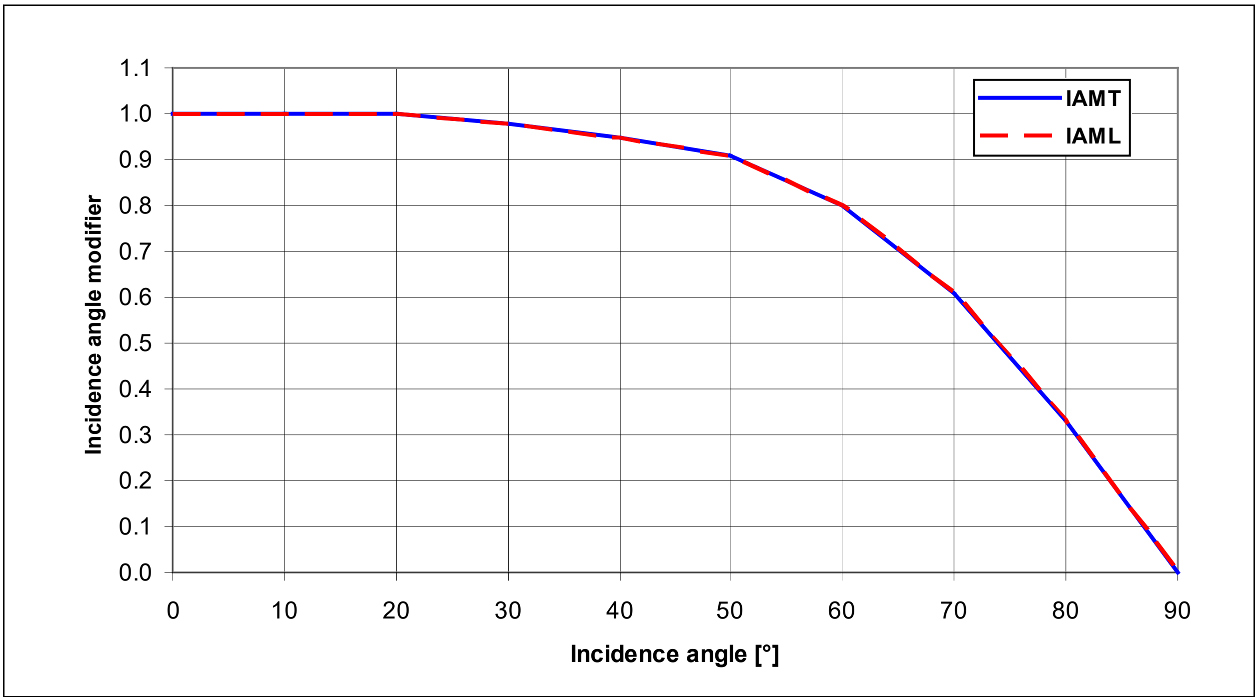


Figure 4: Incidence angle modifier

4.15 Effective thermal capacity

4.15.1 General remarks

Parameters measured — Yes

The effective thermal capacity is determined using two different methods of the ISO 9806:2017. In general the lower of the two values is used for further performance calculations. The difference between the two methods is strongly depending on the collector type.

4.15.2 Measurement of the effective thermal capacity with irradiance

4.15.2.1 Test conditions

Test method — Measured according to ISO 9806:2017 Clause 25.2

4.15.2.2 Test results

Effective heat capacity (including fluid)	7260 $Wsm^{-2}K^{-1}$
Fluid	water-glycol
Effective heat capacity (without fluid)	4545 $Wsm^{-2}K^{-1}$

4.15.3 Calculation method for the determination of the effective thermal capacity

4.15.3.1 Test conditions

Test method — Calculated according to ISO 9806:2017 Clause 25.4

4.15.3.2 Test results

Effective heat capacity (including fluid)	5630 $Wsm^{-2}K^{-1}$
Fluid	water-glycol
Effective heat capacity (without fluid)	2915 $Wsm^{-2}K^{-1}$

4.16 Time constant

4.16.1 General remarks

Parameter measured — Yes

4.16.2 Test conditions

Test method — ISO 9806:2017 Clause 25.1, Heating up

4.16.3 Test results

Time constant, τ_c — 137 s

4.17 Gross Thermal Yield (GTY)

The gross thermal yield of the collector is calculated at the indicated mean fluid temperature ϑ_m for the standard locations Athens, Davos, Stockholm and Würzburg.

	Athens			Davos			Stockholm			Würzburg		
Annual irradiation on collector plane	1765 kWh/m²			1630 kWh/m²			1166 kWh/m²			1244 kWh/m²		
Mean annual ambient air temp.	18.5°C			3.2°C			7.5°C			9.0°C		
Orientation	South, 25°			South, 30°			South, 45°			South, 35°		
ϑ_m	25°C	50°C	75°C	25°C	50°C	75°C	25°C	50°C	75°C	25°C	50°C	75°C
GTY (kWh/coll)	2955	2469	1921	2475	1987	1493	1779	1386	1011	1914	1495	1078
GTY/A_G (kWh/m^2)	1163	972	756	974	782	588	700	546	398	754	589	424
ΣGTY/A_G	8647 kWh/m^2											

If the collector is member of a family as defined in C.1.2 of the EN 12975:2022, then the sum ΣGTY/A_G of the GTY's at the operating temperatures 25 °C, 50 °C and 75 °C at the four reference locations Würzburg, Stockholm, Davos and Athens, divided by the gross area of the collector shall be considered when comparing the yield of the members of the family. The performance parameters of the member with the lowest ΣGTY/A_G are considered as representative for the whole family.

4.18 Pressure drop measurements

4.18.1 General remarks

Parameter measured Yes

4.18.2 Test conditions

Fluid used for the measurement water-glycol
Fluid Temperature 20 °C

4.18.3 Test results

Pressure drop coefficient a 1.43952 $Pah l^{-1}$
Pressure drop coefficient b 0.004675 $Pah^2 l^{-2}$

The pressure drop for the tested collector using the test fluid is calculated using formula:

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

Pressure drop - L/h	50	100	150	200	250	300
Pa	84	191	321	475	652	853
bar	1	2	3	5	7	9

Table 5: Table of pressure drop data

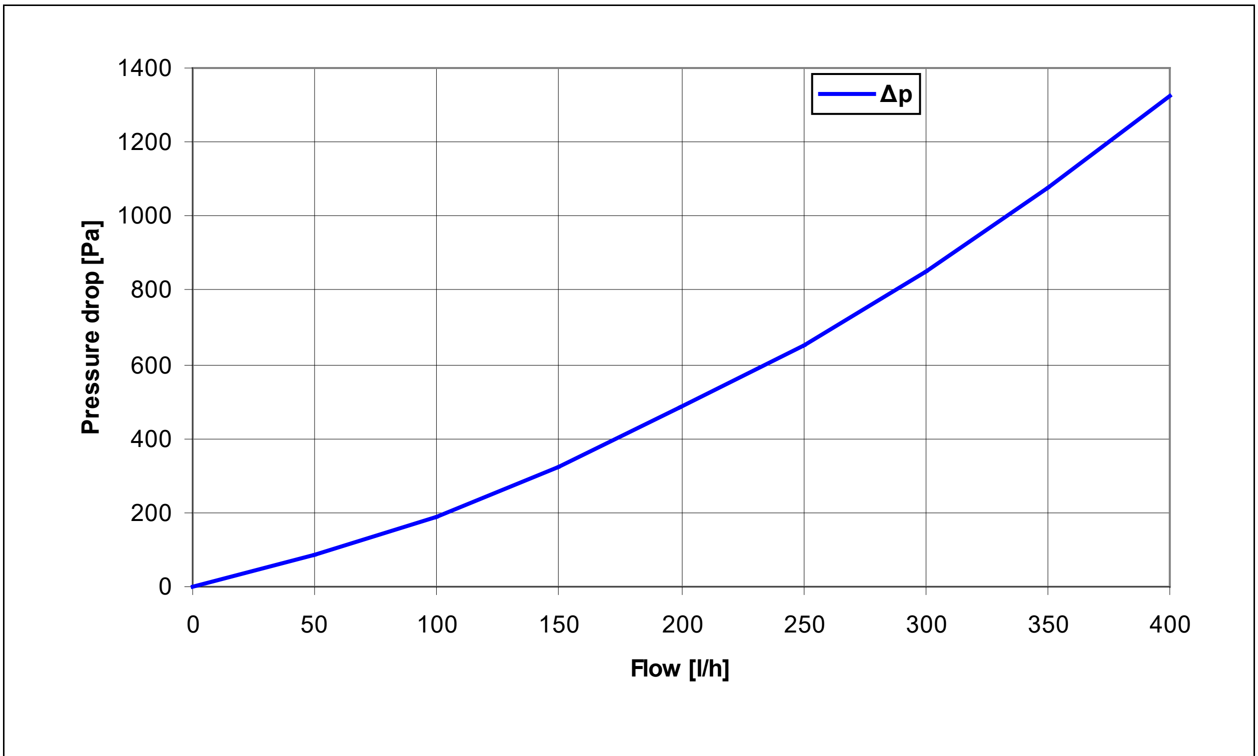


Figure 5: Pressure drop

4.19 Final inspection

The collector was dismantled and inspected completely under laboratory conditions, i.e. in a non-operating condition, shaded from sunlight and at room temperature. Following the list in Table 6 but not limited to, all defects and abnormalities are documented and rated where applicable according to the following key as defined in ISO 9806:2017 Clause 17. Pictures of minor and major failures (if applicable) in Annex A

0 No problem (or element is not existing)

1 Minor problem

2 Major failure

Collector component: Potential problem	Evaluation
a) Collector box/fasteners: Cracking/warping/corrosion/rain penetration/ permanent deformation/Accumulation of humidity/etc.	0
b) Mountings/structure: Strength/safety/loosening/fatiguing/etc.	0
c) Seals/gaskets: Cracking/loss of adhesion/elasticity/brittleness/etc.	0
d) Cover: Cracking/breaking/crazing/buckling/delamination/permanent warping and deformation/outgassing/etc.	0
e) Absorber as a whole: Deformation/corrosion/buckling/etc.	0
f) Absorber coating: Cracking/crazing/blistering/discolouration/peeling/flaking/etc.	0
g) Reflectors: Deformation/cracking/crazing/blistering/discolourtion/buckling/peeling/flaking/etc.	NA
h) Absorber tubes and headers/Flow passages/hoses inside the collector: Deformation/corrosion/leakage/loss of bonding/irreversible swelling/etc.	0
i) Absorber mountings: Permanent deformation/corrosion/rupture/etc.	0
j) Insulation: Water retention/outgassing/swelling/degradation/scorching/singeing/other detrimental changes that could adversely affect collector/performance/fouling/etc.	0
k) Corrosion and other deterioration caused by chemical action. Anywhere in the collector: Corrosion is considered severe if it impairs the function of the collector or if there is evidence that it will progress	0
l) Excessive retention of water anywhere in the collector	0
m) Heat pipes: Loss of fluid/loss of pressure/severe deformation/etc.	NA
n) Self-protection systems: Any problem	0
o) Other components. Any other abnormality resulting in a reduction of thermal performance or service lifetime.	0

Table 6: Final inspection

A “major failure” rating is mandatory in case of (but not limited to):
- breaking or permanent deformation of the cover or the cover fixing;
- liquid channel leakage;
- any deformation such that permanent contact between absorber and cover is established;
- breaking or severe deformation of collector fixing points or of the collector box;
- vacuum loss, loss of gas filling
- dissolution of absorber coating
- accumulation of humidity in form of permanent condensate on the inside of the transparent cover or permanent local retention of water excessing 25 ml anywhere in the collector.

4.20 Statement of conformity with the requirements of the EN 12975:2022

The collector was tested according to clause 5.2 of the EN 12975:2022 and no major failure according to clause 17 of EN ISO 9806:2017 was detected. The collector is accompanied with the documentation as defined in clause 5.3 of the EN 12975:2022 and the performance is reported according to clause 5.4 of the EN 12975:2022.

The tested collector is therefore in full conformity with the requirements of the EN 12975:2022.

4.21 Hydraulic Designation Code

The hydraulic setup and design of the collector is encoded with the hydraulic designation code (See Solar Keymark Annex P5.4 for a detailed description)

The hydraulic designation code for this collector is 12-V-1234S-7.2,1940-20.4,1195-D
were
12: Number of tubes
V: Vertical in test
1234S: connectors in each corner to the side
7.2,1940: 7.2 mm inner diameter of raiser tube with 1940 mm length
20.4,1195: 20.4 mm inner diameter of collector tube with 1195 mm length
D: Drainable

Annex A Illustrations and photographs

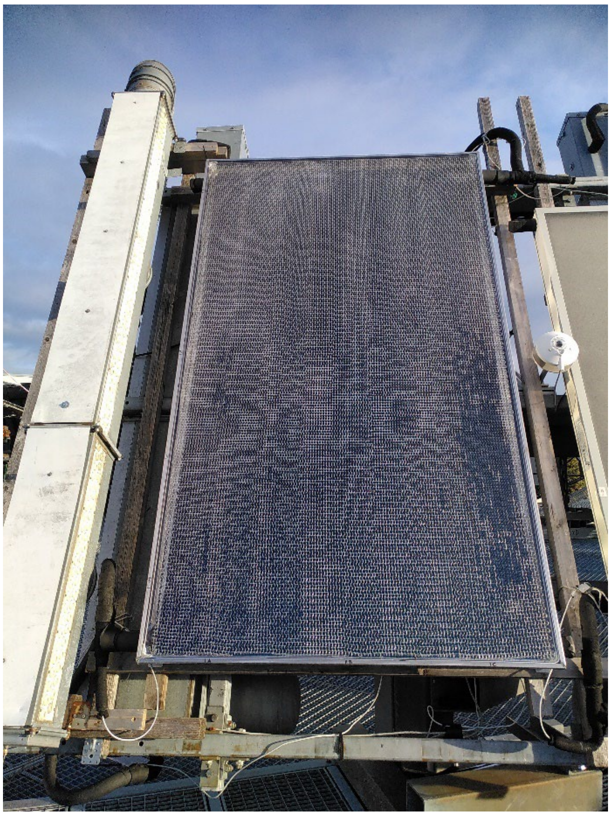


Figure 6: Collector on the test rig

Figure 7: Backside of the collector with heat exchanger for the OPD.

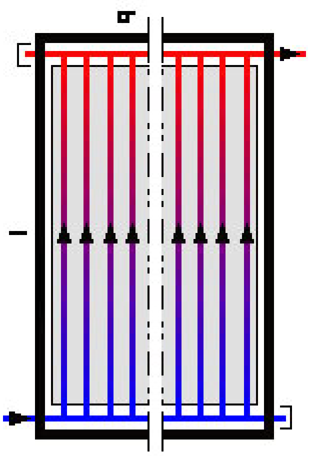


Figure 8: Hydraulic flow scheme

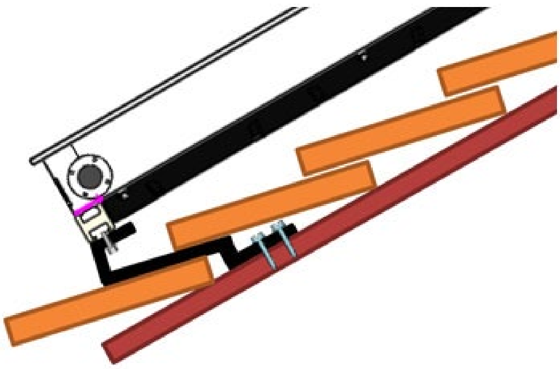


Figure 9: Schematic diagram of collector mounting

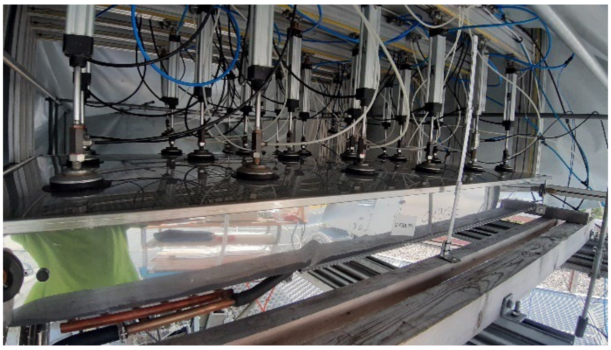


Figure 10: Negative mechanical load test (wind)

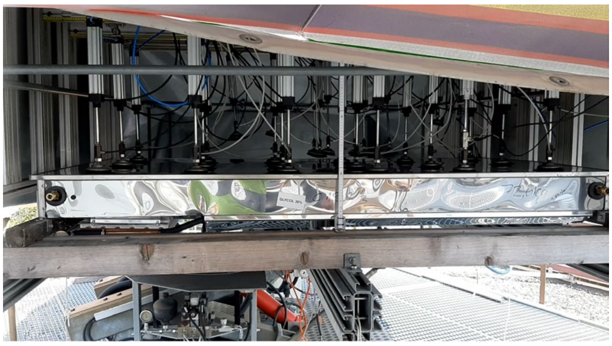


Figure 11: Positive mechanical load test (snow)

Figure 12: Rain test

Annex B Climatic data for exposure

B.1 Exposure to reach minimum H and number of outdoor days

Date	H [MJ/m²]	ϑ_{amb} [°C]	ΣH [MJ/m²]	Day index
10.12.2022	0.4	1.4	0.4	1
11.12.2022	7.0	-0.9	7.4	2
12.12.2022	8.2	-2.7	15.6	3
13.12.2022	1.3	-3.7	16.9	4
14.12.2022	3.6	1.4	20.5	5
15.12.2022	0.5	3.5	21.0	6
16.12.2022	0.5	0.6	21.5	7
17.12.2022	0.8	-0.3	22.3	8
18.12.2022	5.5	-0.1	27.8	9
19.12.2022	5.3	2.9	33.1	10
20.12.2022	4.2	6.1	37.3	11
21.12.2022	0.7	7.4	38.0	12
22.12.2022	6.6	10.1	44.6	13
23.12.2022	0.5	9.4	45.0	14
24.12.2022	0.9	8.1	45.9	15
25.12.2022	8.6	7.7	54.5	16
26.12.2022	3.7	8.2	58.1	17
27.12.2022	4.3	6.9	62.4	18
28.12.2022	15.7	7.5	78.1	19
29.12.2022	3.5	8.8	81.6	20
30.12.2022	8.3	7.5	89.9	21
31.12.2022	8.8	11.4	98.7	22
01.01.2023	15.4	12.1	114.1	23
02.01.2023	3.8	8.7	117.8	24
03.01.2023	0.9	7.9	118.7	25
04.01.2023	2.2	6.7	121.0	26
05.01.2023	2.7	9.5	123.7	27
06.01.2023	4.3	7.2	128.0	28
07.01.2023	11.3	7.4	139.3	29
08.01.2023	1.0	6.2	140.3	30
09.01.2023	6.7	6.7	147.0	31
10.01.2023	13.9	6.9	160.9	32
11.01.2023	1.4	5.4	162.2	33
12.01.2023	2.3	6.3	164.5	34

13.01.2023	3.8	7.5	168.3	35
14.01.2023	5.9	7.2	174.2	36
15.01.2023	0.5	5.8	174.7	37
16.01.2023	3.9	3.2	178.6	38
17.01.2023	1.3	2.7	179.9	39
18.01.2023	1.3	1.3	181.2	40
19.01.2023	11.1	0.4	192.2	41
20.01.2023	6.5	-2.0	198.7	42
21.01.2023	3.2	-1.3	201.9	43
22.01.2023	4.8	0.5	206.7	44
23.01.2023	2.0	0.0	208.7	45
24.01.2023	11.8	0.6	220.4	46
25.01.2023	2.2	1.5	222.7	47
26.01.2023	0.8	0.8	223.5	48
27.01.2023	1.3	0.8	224.8	49
28.01.2023	1.1	1.4	225.9	50
29.01.2023	11.2	1.5	237.2	51
30.01.2023	11.6	2.2	248.8	52
31.01.2023	16.4	4.9	265.2	53
01.02.2023	2.8	4.6	267.9	54
02.02.2023	1.5	6.4	269.5	55
03.02.2023	12.0	7.6	281.5	56
04.02.2023	1.0	5.5	282.5	57
05.02.2023	2.9	3.1	285.4	58
06.02.2023	6.4	3.7	291.8	59
07.02.2023	25.9	3.0	317.7	60
08.02.2023	3.7	-0.3	321.4	61
09.02.2023	23.6	3.1	345.1	62
10.02.2023	26.9	4.0	372.0	63
11.02.2023	18.3	3.9	390.2	64
12.02.2023	26.1	5.7	416.3	65
13.02.2023	13.9	3.2	430.2	66
14.02.2023	11.9	1.2	442.1	67
15.02.2023	12.0	1.2	454.1	68
16.02.2023	25.8	8.4	479.9	69
17.02.2023	3.6	8.8	483.5	70
18.02.2023	23.0	11.4	506.5	71
19.02.2023	2.7	9.0	509.1	72

20.02.2023	28.4	11.0	537.5	73
21.02.2023	28.2	10.3	565.7	74
22.02.2023	20.0	9.9	585.7	75
23.02.2023	16.9	11.0	602.6	76
27.01.2023	1.3	0.8	224.8	49
28.01.2023	1.1	1.4	225.9	50
29.01.2023	11.2	1.5	237.2	51
30.01.2023	11.6	2.2	248.8	52
31.01.2023	16.4	4.9	265.2	53
01.02.2023	2.8	4.6	267.9	54
02.02.2023	1.5	6.4	269.5	55
03.02.2023	12.0	7.6	281.5	56
04.02.2023	1.0	5.5	282.5	57
05.02.2023	2.9	3.1	285.4	58
06.02.2023	6.4	3.7	291.8	59
07.02.2023	25.9	3.0	317.7	60
08.02.2023	3.7	-0.3	321.4	61
09.02.2023	23.6	3.1	345.1	62
10.02.2023	26.9	4.0	372.0	63
11.02.2023	18.3	3.9	390.2	64
12.02.2023	26.1	5.7	416.3	65
13.02.2023	13.9	3.2	430.2	66
14.02.2023	11.9	1.2	442.1	67
15.02.2023	12.0	1.2	454.1	68
16.02.2023	25.8	8.4	479.9	69
17.02.2023	3.6	8.8	483.5	70
18.02.2023	23.0	11.4	506.5	71
19.02.2023	2.7	9.0	509.1	72
20.02.2023	28.4	11.0	537.5	73
21.02.2023	28.2	10.3	565.7	74
22.02.2023	20.0	9.9	585.7	75
23.02.2023	16.9	11.0	602.6	76

Table 7: Climatic conditions for all days during the test

B.2 Exposure time for the selected climate class

Date / Time	G [W/m^2]	ϑ_{amb} [°C]	Δt [min]	Loc.	Sum [min]
29.04.2023 13:12:00-13:57:00	1074.7	21.9	45.0	outdoor	45.0
04.05.2023 14:42:00-15:17:30	1036.5	23.4	35.5	outdoor	80.5
08.05.2023 14:12:00-14:44:00	1170.8	21.8	32.0	outdoor	112.5
22.05.2023 11:32:00-14:57:30	1028.2	25.1	205.5	outdoor	318.0
22.05.2023 15:10:30-16:26:30	1034.4	27.9	76.0	outdoor	394.0
23.05.2023 13:41:30-14:21:30	1025.7	23.2	40.0	outdoor	434.0
23.05.2023 14:24:00-15:18:00	1026.0	24.4	54.0	outdoor	488.0
26.05.2023 12:29:00-13:31:00	1016.8	22.5	62.0	outdoor	550.0
26.05.2023 13:32:00-14:24:30	1015.8	24.3	52.5	outdoor	602.5
26.05.2023 14:31:00-15:07:00	1010.6	25.2	36.0	outdoor	638.5
27.05.2023 11:39:00-13:46:30	1011.0	23.2	127.5	outdoor	766.0
28.05.2023 11:44:00-14:32:00	1020.6	24.0	168.0	outdoor	934.00
28.05.2023 14:33:00-15:30:30	1026.2	26.5	57.5	outdoor	991.5
29.05.2023 11:30:30-14:28:30	1017.5	23.9	178.0	outdoor	1169.5
31.05.2023 11:47:00-14:57:30	1012.0	24.1	190.5	outdoor	1360.0
01.06.2023 11:34:00-13:30:30	1017.6	24.6	116.5	outdoor	1476.5
01.06.2023 13:33:00-15:00:00	1016.9	26.7	87.0	outdoor	1563.5
02.06.2023 11:13:00-14:18:30	1023.0	25.4	185.5	outdoor	1749.0
03.06.2023 11:49:00-14:59:00	1010.6	25.4	190.0	outdoor	1939.0

Table 8: Data record of fulfilled exposure test requirements

Annex C Technical drawings and specifications

C.1 Technical drawings

Drawing number or drawing name	Date of revision
P.N 119040 120028_01 HC12 Case.PDF	04.04.2020
P.N 119013 120022_0 Bushing 8.PDF	25.03.2021
P.N 119041 120021_0 Gromet 8.PDF	30.03.2021
P.N 119042 120019_0 Gromet 22.PDF	25.03.2021
P.N 119044 120026_0 Plug.PDF	30.03.2021
P.N 119048 120027_0 HC12 Front Glass.PDF	31.03.2021
P.N 119049 120013_01 HC12 Absorber Assy.PDF	25.03.2021
P.N 119050 120034_01 HC12 Radiator Assy.PDF	18.04.2021
P.N 119051 120024_0 HC12 Main Air Bag.PDF	30.03.2021
P.N 119057 120035_0 HC12 Air Tube.PDF	25.04.2021
P.N 119058 120012_02 Right Outer Leg.PDF	10.05.2021
P.N 119059 120011_02 Left Outer Leg.PDF	10.05.2021
P.N 119060 120017_0 Bottom Insulation.PDF	25.03.2021
P.N 119065 120036_0 Clamp.PDF	25.03.2021
P.N 119066 120015_0 Side Profile.PDF	25.03.2021
P.N 119067 120016_0 Top Profile.PDF	25.03.2021
P.N 119068 120023_01 HC12 Air Bag Cover.PDF	29.03.2021
P.N 119073 120025_0 Bushing 22 Stationary.PDF	25.03.2021
P.N 119088 120018_0 Honeycomb.PDF	25.03.2012

Table 9: Technical drawings

C.2 Specifications

Document name	Date of revision
P.N 119006 TDS_303_devtec.pdf	01.05.2012
P.N 119016 Desiccant.pdf	undated
P.N 119045 FZ-Butylver-SS_TDS.pdf	22.03.2018
P.N 119046 S02_Super Spacer Premium datasheet_UK 2020 03.pdf	03.2020
P.N 119055 TRAC109.pdf	undated
P.N 119060&119061 KI_DP_501 SDS RMW OEM Israel_en.pdf	25.05.2021
P.N 119063) devtec_tds_Soudaseal-250XF.pdf	30.08.2017
P.N 119075) TDS_316_devtec-.pdf	01.05.2012
P.N 119086) RTV 212 Ver. 2 (1) (1).pdf	02.09.2021
Material specifications are indicated also in the technical drawings (see Annex C.1)	

Table 10: Specifications

C.3 Bill of materials

Document name	Date of revision
HC12 Collector- Bill of materials	27.01.2021

Table 11: Bill of materials

Annex D Additional brand names

The collector is also distributed under the following brands and brand names.

- None