Test Report: KTB Nr. 2006-35-k-j-en

Collector test according to EN 12975-1,2:2006

for:
IMMERGAS S.p.A. , Italia

Brand name:
Series Collettore Solare Piano CP4M
and Collettore Solare Piano CP2M

Responsible for testing:
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Date:
2nd November 2011

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Deutscher Akkreditierungs Rat

Registration No.:
DAP-PL-3926.00

DIN CERTCO
Anerkanntes Prüflaboratorium

Contents

1 Summary

1.1 Preliminary remark

The tests have been passed according to EN 12975-1,2:2006. Main purpose for testing has been, to fulfill all requirements for the SolarKeymark label. All requirements have been met.
The present report is valid for the collector series Collettore Solare Piano CP4M , Collettore Solare Piano CP4L, Collettore Solare Piano CP4XL and the collector series Collettore Solare Piano CP2M , Collettore Solare Piano CP2L, Collettore Solare Piano CP2XL . The tests were performed at the largest collector and at the smallest collector of the series, according to the rules of the SolarKeymark (Version 8.00 of January 2003).
Alike the certificate of the collector minimum gain of 525 kwh/m^{2}a is handed.

1.2 Collector efficiency parameters determined

Results:
The calculated parameters are based on following areas:

aperture area of 1.924 m^2:	absorber area of 1.840 m^2:
η_{0a} = 0.759	η_{0A} = 0.794
a_{1a} = 3.480 W/m^{2}K	a_{1A} = 3.639 W/m^{2}K
a_{2a} = 0.0161 W/m^{2}K^2	a_{2A} = 0.0168 W/m^{2}K^2

1.3 Incidence angle modifier - IAM

θ:	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
K_θ:	**1.00**	1.00	**1.00**	**0.99**	**0.98**	**0.95**	**0.89**	0.76	0.50	0.00

Table 1: Measured **(bold)** and calculated IAM data for Collettore Solare Piano CP4M

1.4 Pressure drop

The pressure drop in mbar can be described by the following function of the mass flow x in kg/h:

$$\Delta p = 0.005 * x + 1.187 * 10^{-5} * x^2 \quad (1)$$

1.5 Effective thermal capacity of the collector

Effective thermal capacity (Collettore Solare Piano CP4M):

11.01 kJ/K

The effective thermal capacity per square meter is (valid for the series):

5.72 kJ/K m^2

1.6 Schedule of tests and callculations

The function test have been passed on the collector Collettore Solare Piano CP4XL and have been adopted for the whole series.

Test	Date	Result
Date of delivery:	March 30th 2006 7th August 2006	
1st internal pressure	9th October 2006	passed
High temperature resistance	23th August 2006	passed
Exposure	7th August 2006 - 13th November 2006	passed
1st external thermal shock	1th September 2006	passed
2nd external thermal shock	17th October 2006	passed
1st internal thermal shock	31th August 2006	passed
2nd internal thermal shock	22th September 2006	passed
Rain penetration	1th September 2006	passed
Freeze resistance		not relevant
2nd internal pressure	9th October 2006	passed
Mechanical load	9th November 2006	passed
Stagnation temperature		234.0 °C
Final inspection	13th November 2006	passed
Determination of collector parameters	18th - 21st April 2006	passed
Determination of IAM	20th April 2006	passed
Effective thermal capacity		performed

1.7 Summary statement

No problems or distinctive observations occured during the measurements.

2 Test Center

Test Center for Thermal Solar Systems of Fraunhofer ISE
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3 Orderer, Expeller, Manufacturer

Orderer:	IMMERGAS S.p.A. Via Cisa Ligure 95 42041 Brescello Italia Tel: +39 522 689450 Fax: +49 522 689178
Expeller and Manufacturer:	see orderer

4 Overview of series Collettore Solare Piano CP

According to the SolarKeymark rules there is a agreement concerning collectors wich differ only in size, so called series. Only the biggest and the smallest collector have to be tested in this case. A complete collector test according to EN 12975-1,2 has to be performed at the biggest collector. The efficiency test only is sufficient at the smallest collector. The SolarKeymark label based on this tests is valid for the whole series.

(MS) = Manufacturer Specification

Brand name	test collector	Size of total area (MS) [m^2]	Size of absorber area (MS) [m^2]
Collettore Solare Piano CP4M	yes	2.025	1.840
Collettore Solare Piano CP4L	no	2.340	2.140
Collettore Solare Piano CP4XL	yes	2.515	2.310
Collettore Solare Piano CP2M	no	2.024	1.840
Collettore Solare Piano CP2L	no	2.340	2.140
Collettore Solare Piano CP2XL	no	2.516	2.310

5 Description of the Collector

	(MS): Manufacturer Spezification
Typ:	Flat-Plate-Collector, Harpe Absorber
Material of the cover:	solar glass (HA)
Number of covers:	1
Transmission of cover:	$\geq$ 90.8 % $\pm$ 2 % (MS)
Thickness of cover:	4 mm (MS)
	3.2 mm (MS)

5.1 Specific data of the smallest collector of the series Collettore Solare Piano CP4M

Brand name:	Collettore Solare Piano CP4M
Serial no.:	06/11001
Year of production:	2006
Number of test collectors:	1
Collector reference no.:	2-KT-50 11 032006
Collector dimensions	
Height, width, depth	1.731 m, 1.170 m, 0.084 m
Total area:	1.731 m * 1.170 m = 2.025 m^2
Aperture area:	1.695 m * 1.135 m = 1.924 m^2
Absorber area:	1.105 m * 1.666 m = 1.840 m^2
Number of absorber pipes	12 (MS)
Weight empty:	37.1 kg
Volume of the fluid:	1.5 l (MS)
Heat transfer fluid	propylene glycol/Water (MS)

5.2 Specific data of the smallest collector of the series Collettore Solare Piano CP2M

Brand name:	Collettore Solare Piano CP2M
Number of test collectors:	0
Collector dimensions	
Height, width, depth	1.730 m, 1.170 m, 0.083 m (MS)
Total area:	1.730 m x 1.170 m = 2.024 m^2 (MS)
Aperture area:	1,91 m^2 (MS)
Absorber area:	1.668 m * 1.105 m = 1.840 m^2 (MS)
Number of absorber pipes	12 (MS)
Weight empty:	no declaration
Volume of the fluid:	1.5 l (MS)
Heat transfer fluid	propylene glycol/Water (MS)

5.3 Specific data of the largest collector of the series Collettore Solare Piano CP4XL

Brand name:	Collettore Solare Piano CP4XL
Serial no.:	0603
Year of production:	2006
Number of test collectors:	1
Collector reference no.:	2-KT-50 20 032006
Collector dimensions	
Height, width, depth	2.151 m, 1.170 m, 0.084 m (MS)
Total area:	2.151 m * 1.170 m = 2.517 m^2
Aperture area:	2.111 m * 1.133 m = 2.392 m^2
Absorber area:	2.090 m * 1.105 m = 2.309 m^2 (MS)
Number of absorber pipes	12 (MS)
Weight empty:	47 kg (MS)
Volume of the fluid:	1.7 l (MS)
Heat transfer fluid	propylene glycol/Water (MS)

5.4 Specific data of the largest collector of the series Collettore Solare Piano CP2XL

Brand name:	Collettore Solare Piano CP2XL
Number of test collectors:	0
Collector dimensions	
Height, width, depth	2.150 m, 1.170 m, 0.083 m (MS)
Total area:	2.150 m * 1.170 m = 2.516 m^2
Aperture area:	2.390 m^2 (MS)
Absorber area:	2.088 m * 1.105 m = 2.310 m^2 (MS)
Number of absorber pipes	12 (MS)
Weight empty:	no declaration
Volume of the fluid:	1.7 l (MS)
Heat transfer fluid	propylene glycol/Water (MS)

5.5 Absorber

Material of the absorber sheet:	Aluminium (MS)
Thickness of the absorber sheets:	0.5 mm (MS)
Kind of the selective coating:	BlueTec; Eta plus (MS)
	Alanod; Mirrotherm (MS)
Absorptivity coefficient α:	94.0 % $\pm$ 2% (MS)
Emissivity coefficient ε:	5 % $\pm$ 2% (MS)
Material of the absorber pipes:	Copper (MS)
Layout of the absorber pipes:	double harpe (MS)
Outer diameter:	8 mm (MS)
Inner diameter:	7 mm (MS)
Distance between the pipes:	96 mm (MS)
Material of the header pipe:	Copper (MS)
Outer diameter of the header pipe:	22 mm (MS)
Inner diameter of the header pipe:	20.4 mm (MS)

5.6 Insulation and Casing

Thickness of the insulation at the back:	40 (MS)
Thickness of the insulation at the sides:	not existent
Material:	mineral rock wool, black glas fleece (MS)
Material of the casing:	Seewater resistant aluminium (MS)
Sealing material:	UV restitant silicon adhasive (MS)

5.7 Limitations

Maximum fluid pressure:	1000 kPa (MS)
Operating fluid pressure:	400 kPa (MS)
Maximum service temperature:	no declaration
Maximum stagnation temperature:	234.0 °C
Maximum wind load:	no declaration
Recommended tilt angle:	45°
Flow range recommendation:	no declaration (MS)

5.8 Kind of mounting

Flat roof - mounted on the roof:	yes (MS)
Tilted roof - mounted on the roof:	yes (MS)
Tilted roof - integrated:	no (MS)
Free mounting:	yes (MS)
Fassade:	no (MS)

5.9 Picture and cut drawing of the collector

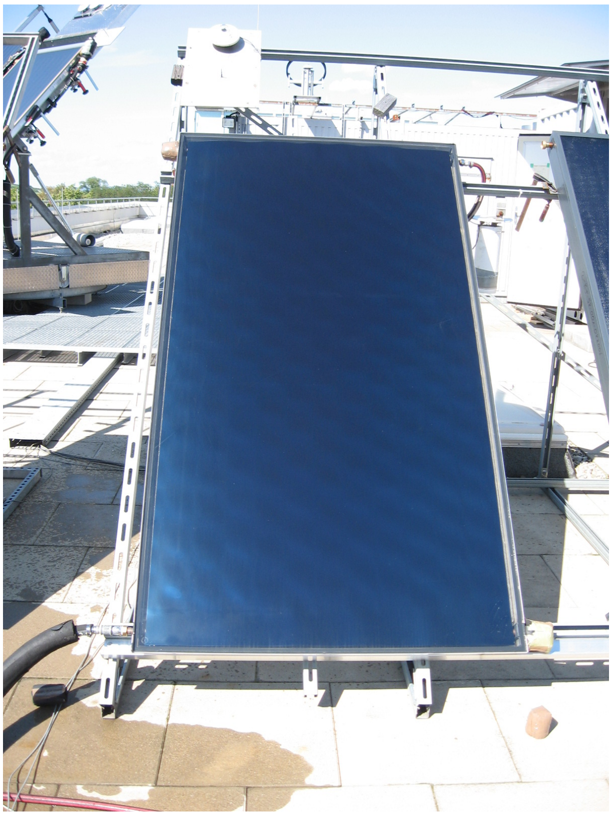

Figure 1: Picture of the collector Collettore Solare Piano CP4M

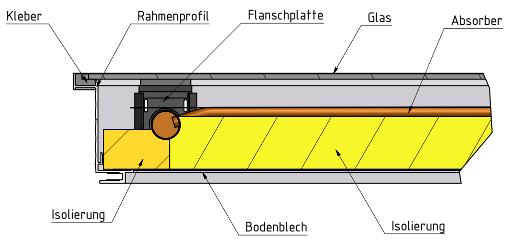

Figure 2: Cut drawing of the collector Collettore Solare Piano CP4M

6 Collector efficiency parameters

6.1 Test method

Outdoor, steady state according to EN 12975-2:2006 (tracker)
Thermal solar systems and components-solar collectors,Part 2: Test methods

6.2 Description of the calculation

The functional dependence of the collector efficiency on the meteorological and system operation values can be represented by the following mathematical equation:

$$\eta_{(G,(t_\mathrm{m}-t_\mathrm{a}))} = \eta_0 - a_{1\mathrm{a}}\frac{t_\mathrm{m}-t_\mathrm{a}}{G} - a_{2\mathrm{a}}\frac{(t_\mathrm{m}-t_\mathrm{a})^2}{G} \quad (2)$$

(based on aperture area)

$$t_m = \frac{t_e+t_{in}}{2}$$

where:
G = global irradiance on the collector area (W/m^2)
t_in = collector inlet temperature ($^\circ$C)
t_e = collector outlet temperture ($^\circ$C)
t_a = ambient temperature ($^\circ$C)

The coefficients $\eta_0,\ a_{1\mathrm{a}}$ and $a_{2\mathrm{a}}$ have the following meaning:

η_0: Efficiency without heat losses, which means that the mean collector fluid temperature is equal to the ambient temperature:

$$t_m = t_a$$

The coefficients $a_{1\mathrm{a}}$ and $a_{2\mathrm{a}}$ describe the heat loss of the collector. The temperature depedency of the collector heat loss is described by:

$$a_{1a} + a_{2a} * (t_m - t_a)$$

6.3 Steady stade efficiency parameters based on the aparture area and fluid mean temperature

Test method:	outdoor, steady state with tracker
Latitude:	48.0°
Longitude:	7.8°
Collector tilt:	tracked between 35°and 55°
Collector azimuth:	tracked
Mean irradiation :	997 W/m^2
Mean wind speed:	3 m/s
Mean flow rate:	140 kg/h
Kind of fluid:	water
Date of measurement	November 2006

Results:

The calculated parameters are based on following areas. They are valid for the whole series.

aperture area of 1.924 m^2:	absorber area of 1.840 m^2:
η_{0a} = 0.759	η_{0A} = 0.794
a_{1a} = 3.480 W/m^2K	a_{1A} = 3.639 W/m^2K
a_{2a} = 0.0161 W/m^2K^2	a_{2A} = 0.0168 W/m^2K^2

The determination for the standard deviation (k=2) was performed according ENV 13025 (GUM). Based on this calculation the uncertainty is less than 2%-points of the efficiency values over the complete measured temperature range (η_{0a} = 0.759 +/- 0.02). Based on our experience with the test facilities the uncertainty is much smaller and in a range of **+/- 1%-point**. The standard deviation of the heat loss parameters resulting from the regression fit curve through the measurement points is:
a_{1a} = 3.480 +/- 0.0772 and a_{2a} = 0.0161 +/- 0.00095 .

For more detailed data and the calculated efficiency curve please see annex E.2.

6.4 Power output per collector unit

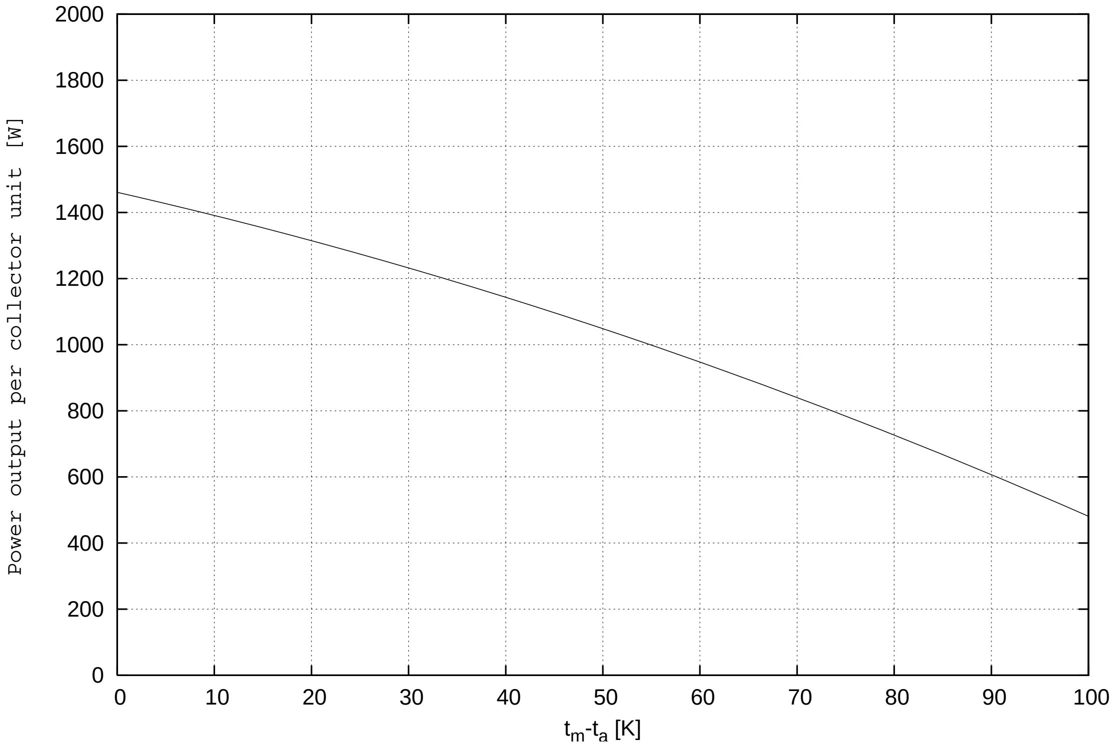

Figure 3: Power output for collector Collettore Solare Piano CP4M based on 1000 W/m^2

Power output per collector unit [W] for collector Collettore Solare Piano CP4M [W]:

$t_m - t_a$ [K]	400 [W/m^2]	700 [W/m^2]	1000 [W/m^2]
10	514	952	1390
30	355	793	1232
50	172	610	1048

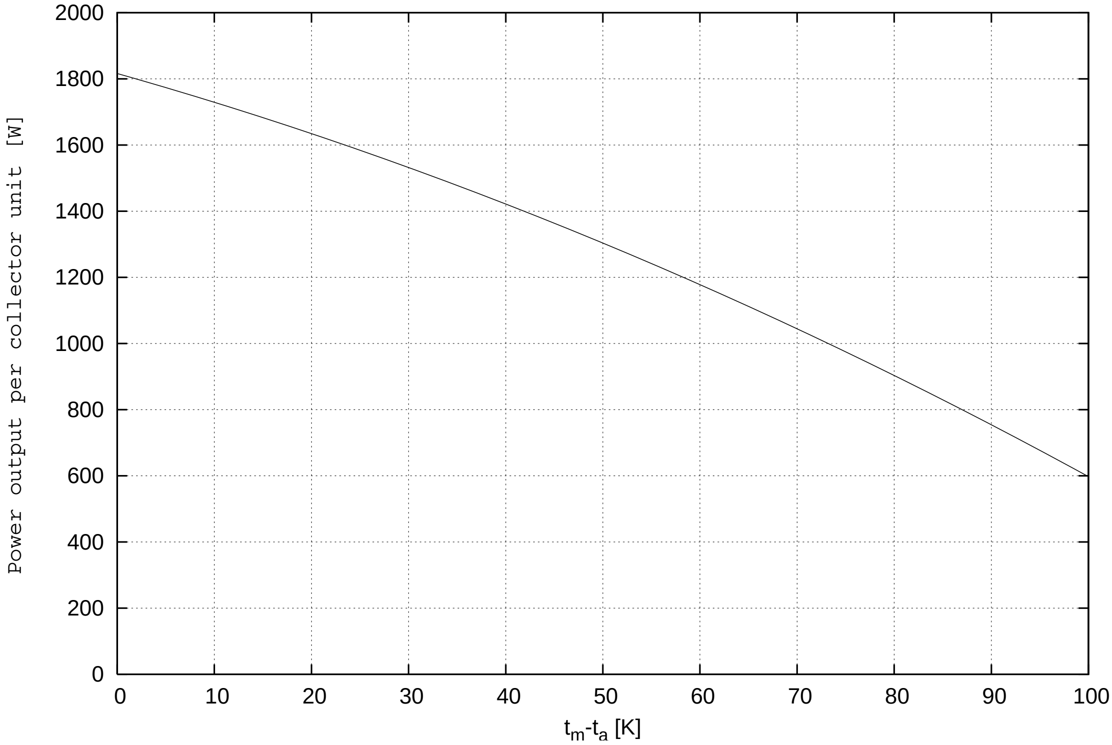

Figure 4: Power output for collector Collettore Solare Piano CP4XL based on 1000 W/m^2

Power output per collector unit [W] for collector Collettore Solare Piano CP4XL [W] :

$t_m - t_a$ [K]	400 [W/m^2]	700 [W/m^2]	1000 [W/m^2]
10	639	1184	1728
30	442	986	1531
50	214	758	1303

The power output per collector unit can be calculated for other collectors of this series according to the follwoing procedure:

$$P = P_{ref} * \frac{A_a}{A_{a,ref}}$$

with:

P	= Collector output for a different collector of the series
P_{ref}	= Collector output for collector Collettore Solare Piano CP4M , (values see table)
A_a	= Aperture area of a different collector of the series
$A_{a,ref}$	= Aperture area of collector Collettore Solare Piano CP4M

7 Incidence angle modifier IAM

The IAM (= Incidence Angle Modifier) is a correction factor representing how the angle of incident radiation affects the performance of a collector.

The IAM of flat plate collector is assumed as rotation-symmetric. Therefor the thermal performance of the collector is only depending on the angle between the incident radiation and the normal of the collector plane.

θ:	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
K_θ:	**1.00**	1.00	1.00	0.99	0.98	**0.95**	0.89	0.76	0.50	0.00

Table 2: Measured **(bold)** and calculated IAM data for Collettore Solare Piano CP4M

The IAM was measured for one angle (θ = 50°). All other angles for the IAM in table 2 were calculated according to Ambrosetti [1](equation 7).

$$K_\theta = 1 - [tan\frac{\theta}{2}]^{\frac{1}{r}} \qquad (3)$$

[1] P.Ambrosetti. Das neue Bruttowärmeertragsmodell für verglaste Sonnenkollektoren, Teil 1 Grundlagen. EIR, Wurenlingen 1983

8 Pressure drop

The measurement of the pressure drop Δp was carried out with water as fluid up to a flow rate of 969 kg/h.The inlet temperature of the water was 20°C. The measurement has been carried out up to the flow rate 969 kg/h. The reason for the high number of measurement points at a low flow rate is given by EN 12975-2:2006. Five measurements of different flow rates in the range of 18 kg/h m^2 to 108 kg/h m^2 are necessary. The measurements were performed up to a much higher value to increase the accuracy of the parameters. Also, these flow rates are closer to flow rates occuring in collector fields.

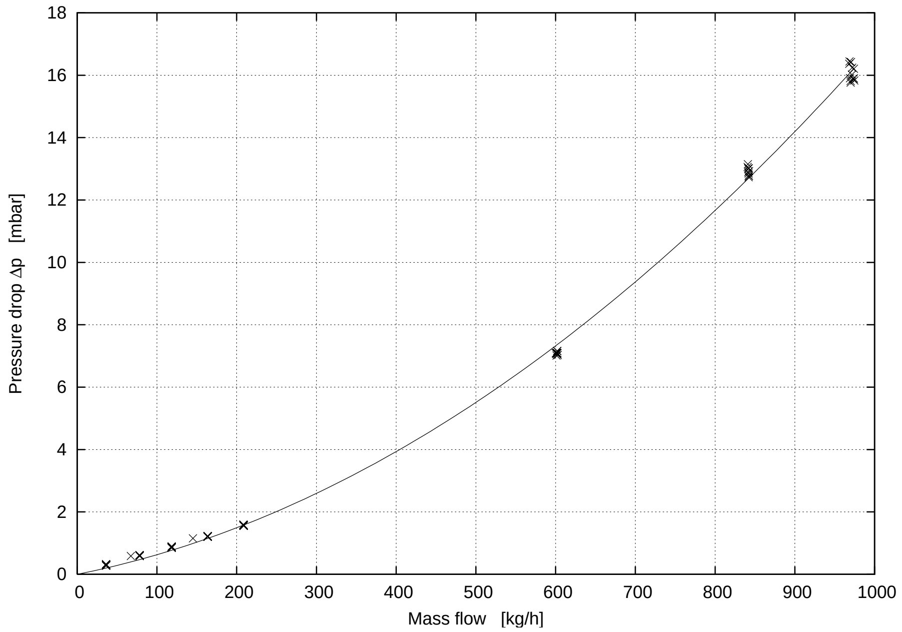

Figure 5: Measured pressure drop of the collector

The pressure drop Δp in mbar can be described by the follwing function of the mass flow x in kg/h:

$$\Delta p = 0.005 \ * x + 1.187 * 10^{-5} \ * x^2$$

Example values from fitted curve:

Mass flow [kg/h]	Pressure drop Δp [mbar]
0	0.0
100	0.6
200	1.5
300	2.6
400	3.9
500	5.5
600	7.3
700	9.3
800	11.6
900	14.1

Table 3: Example values for Δp

9 Effective thermal capacity of the collector

The effective thermal capacity of the collector is calculated according to section 6.1.6.2 of EN 12975-2:2006. For the heat transfer fluid a mixture 2/1 of water/propylen glycol at a temperature of 50°C has been chosen.

Effective thermal capacity (Collettore Solare Piano CP4M):

11.01 kJ/K

The effective thermal capacity per square meter is vadil for the whole series:

5.72 kJ/K m^2

10 Internal pressure test

Maximum pressure:	1000 kPa (MS)
Test temperature:	21.2 °C
Test pressure:	1500 kPa (1.5 times the maximum pressure)
Test duration:	15 min

Result:
During and after the test no leakage, swelling or distortion was observed or measured.

11 High temperature resistance test

Method:	Outdoor testing
Collector tilt angle:	45°
Average irradiance during test:	1015 W/m^2
Average surrounding air temperature:	23.5 °C
Average surrounding air speed:	< 0.5 m/s
Average absorber temperature:	230.6 °C
Duration of test:	1 h

Result:
No degradation, distortion, shrinkage or outgassing was observed or measured at the collector.

12 Exposure test

The collector tilt angle was 45° facing south. Annex G shows all test days of the exposure test.

Result:
The number of days when the daily global irradiance was more than 14 MJ/m^{2}d was 50 . The periods when the global irradiance G was higher than 850 W/m^2 and the surrounding air temperature t_a was higher than 10 °C was 112.5 h.

The evaluation of the exposure test is described in the chapter 20 "Final inspection".

13 External thermal shock tests

Test conditions	1st test	2nd test
Outdoors:	yes	yes
Combined with exposure test:	yes	yes
Combined with high temperatur resistance test:	no	no
Collector tilt angle:	45°	45°
Average irradiance:	1010 W/m^2	924 W/m^2
Average surrounding air temperature:	22.2 °C	15.6 °C
Period during which the required operating conditions were maintained prior to external thermal shock:	1 h	1 h
Flowrate of water spray:	0.05 l/m^2 s	0.05 l/m^2 s
Temperature of water spray:	16.8 °C	17.6 °C
Duration of water spray:	15 min	15 min
Absorber temperature immediately prior to water spray:	194.5 °C	204.1 °C

Result:
No cracking, distortion, condensation or water penetration was observed or measured at the collector.

14 Rain penetration test

Collector mounted on:	Open frame
Method to keep the absorber warm:	Exposure of collector to solar radiation
Flowrate of water spray:	0.05 l/m^2 s
Duration of water spray:	4 h

Result:
No water penetration was observed or measured at the collector.

15 Freeze resistance test

The freeze resistance test is not relevant, because the manufacturer suggestst a application of the collector only with a freeze resistance fluid.

16 Internal thermal shock tests

Test conditions	1st test	2nd test
Outdoors:	yes	yes
Combined with exposure test:	yes	yes
Combined with high temperature resistance test:	no	no
Collector tilt angle:	45°	45°
Average irradiance:	888 W/m^2	950 W/m^2
Average surrounding air temperature:	22.0 °C	25.2 °C
Period during which the required operating conditions were maintained prior to internal thermal shock:	1 h	1 h
Flowrate of heat transfer fluid:	0.02 l/m^2 s	0.02 l/m^2 s
Temperature of heat transfer fluid:	20.4 °C	23.0 °C
Duration of heat transfer fluid flow:	5 min	5 min
Absorber temperature immediately prior to heat transfer fluid flow:	176.7 °C	180.0 °C

No cracking, distortion or condensation was observed or measured at the collector.

17 Internal pressure test (retest)

Maximum pressure specified by the manufacturer:	1000 kPa
Test temperature:	17.3 °C
Test pressure:	1500 kPa (1.5 times the maximum pressure)
Test duration:	15 min

Result:
During and after the test no leakage, swelling or distortion was observed or measured.

18 Mechanical load test

18.1 Positive pressure test of the collector cover

The positive pressure (according to a positive pressure load caused by snow or wind) was increased in steps of 250 Pa up to the maximum pressure load.

Method used to apply pressure:	suction cups, pressed
Maximum pressure load:	1000 Pa

Result:
During and after the test no damage at the cover of the collector was observed.

18.2 Negative pressure test of fixings between the cover and the collector box

The negative pressure (according to a negative pressure load caused by wind) was increased in steps of 250 Pa up to the maximum pressure load.

Method used to apply pressure:	suction cups
Maximum pressure load:	1000 Pa

Result:
During and after the test no damage at the cover or at the cover fixings of the collector was observed.

18.3 Negative pressure test of mountings

The negative pressure (according to a negative pressure load caused by wind) was increased in steps of 250 Pa up to the maximum pressure load.

Method used to apply pressure:	suction cups
Maximum pressure load:	1000 Pa

Result:
During and after the test no damage at the collector mounting fixtures or fixing points was observed.

19 Stagnation temperature

The stagnation temperature was measured outdoors. The measured data are shown in the table below. To determine the stagnation temperature, these data were extrapolated to an irradiance of 1000 W/m^2 and an ambient temperatur of 30 °C. The calculation is as follows:

$$t_\mathrm{s} = t_\mathrm{as} + \frac{G_\mathrm{s}}{G_\mathrm{m}} * (t_\mathrm{sm} - t_\mathrm{am}) \tag{4}$$

t_s: Stagnation temperature
t_as: 30 °C
G_s: 1000 W/m^2
G_m: Solar irradiance on collector plane
t_sm: Absorber temperature
t_am: Surrounding air temperature

Measurement	Irradiance	Surrounding air temperature	Absorber temperature
	[W/m^2]	[°C]	[°C]
1	959	27.3	232.0
2	933	27.3	239.8
3	965	28.3	216.4
4	959	28.6	214.1
5	1033	20.1	227.8
6	1052	20.3	223.7

The resulting stagnation temperature is:

234.0 °C

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20 Final inspection

The following table shows an overview of the result of the final inspection.

Collector component	Potential problem	Evaluation
Collector box/ fasteners	Cracking/ wraping/ corrosion/ rain penetration	0
Mountings/ structure	Strength/ safety	0
Seals/ gaskets	Cracking/ adhesion/ elasticity	0
Cover/ reflector	Cracking/ crazing/ buckling/ delamination/ wraping/ outgassing	0
Absorber coating	Cracking/ crazing/ blistering	0
Absorber tubes and headers	Deformation/ corrosion/ leakage/ loss of bonding	0
Absorber mountings	Deformation/ corrosion	0
Insulation	Water retention/ outgassing/ degradation	0

0: No problem
1: Minor problem
2: Severe problem
x: Inspection to establish the condition was not possible

21 Collector identification

The collector identification/documentation according EN 12975-1 chapter 7 was complete, see the following items:

- Drawings and data sheet
- Labeling of the collector
- Installer instruction manual
- List of used materials

22 Summary statement

The measurements were carried out from April 2006 - November 2006 .

No problems or distinctive observations occured during the measurements.

23 Annotation to the test report

The results described in this test report refer to the test collector. They are also valid for the whole collector series. It is not allowed to make extract copies of this test report.

Test report: KTB Nr. 2006-35-k-j-en

Freiburg, 2nd November 2011
Fraunhofer-Institute for Solar Energy Systems ISE

Dipl.-Ing. (FH) K. Kramer Director of the PZTS	Dipl.-Ing. (FH) S. Mehnert Deputy Director of the PZTS

A Drawing of absorber layout Collettore Solare Piano CP4M

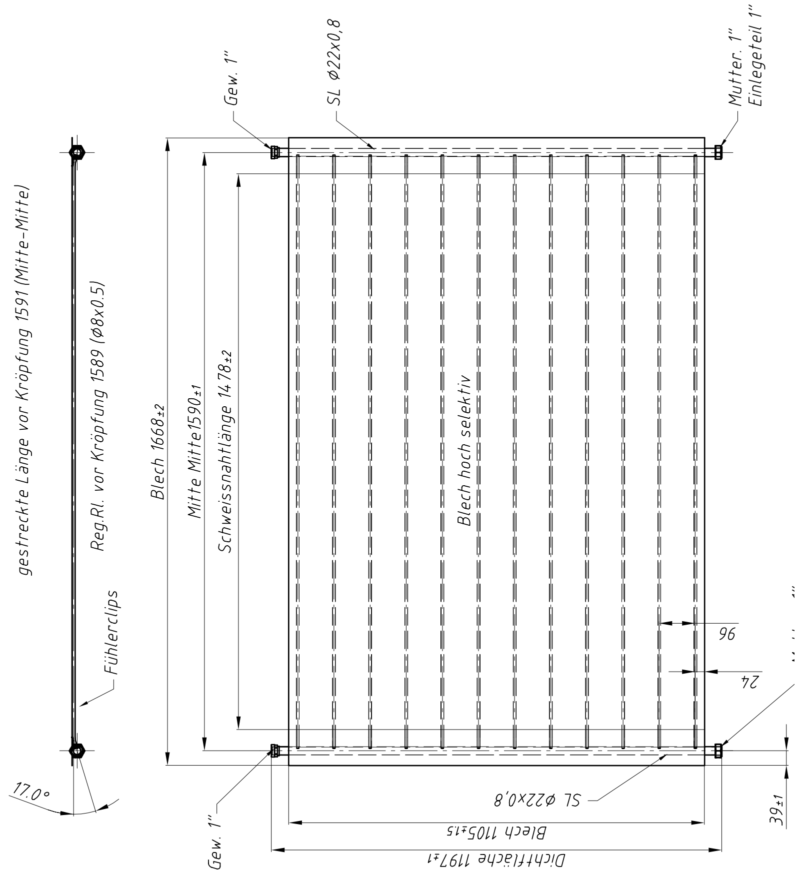

Figure 6: Drawing of absorber layout Collettore Solare Piano CP4M

B Drawing of absorber layout Collettore Solare Piano CP4XL

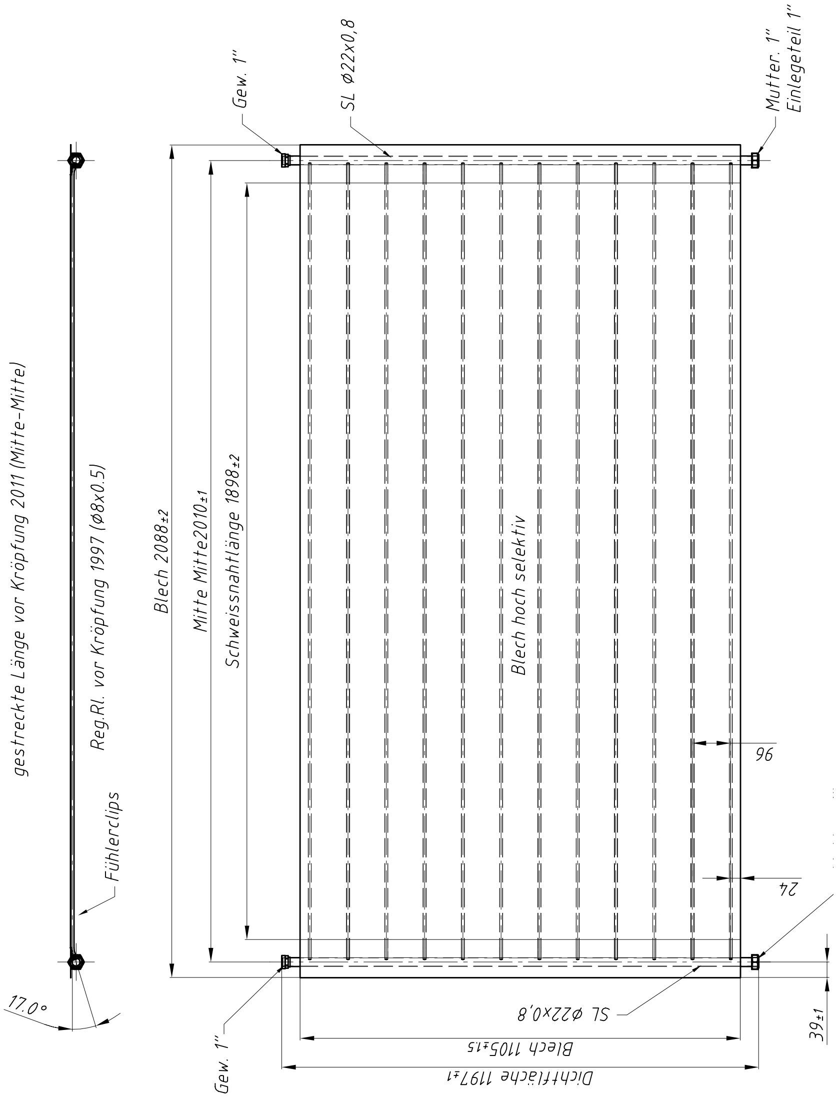

Figure 7: Drawing of absorber layout Collettore Solare Piano CP4XL

C Drawing of absorber layout Collettore Solare Piano CP2L

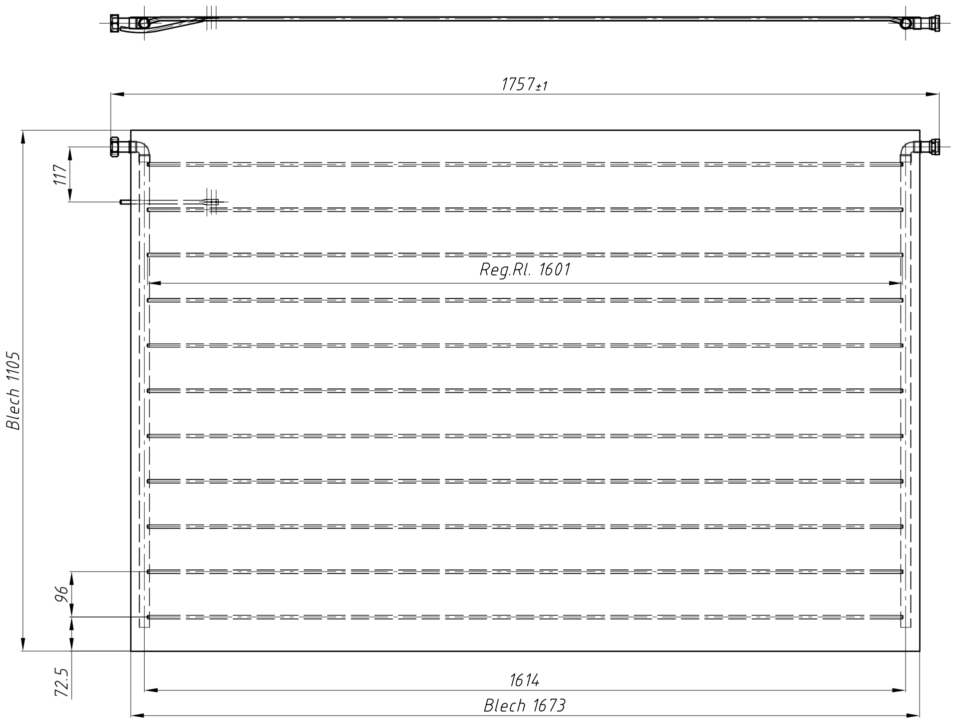

Figure 8: Drawing of absorber layout Collettore Solare Piano CP2M

D Drawing of absorber layout Series Collettore Solare Piano CP2XL

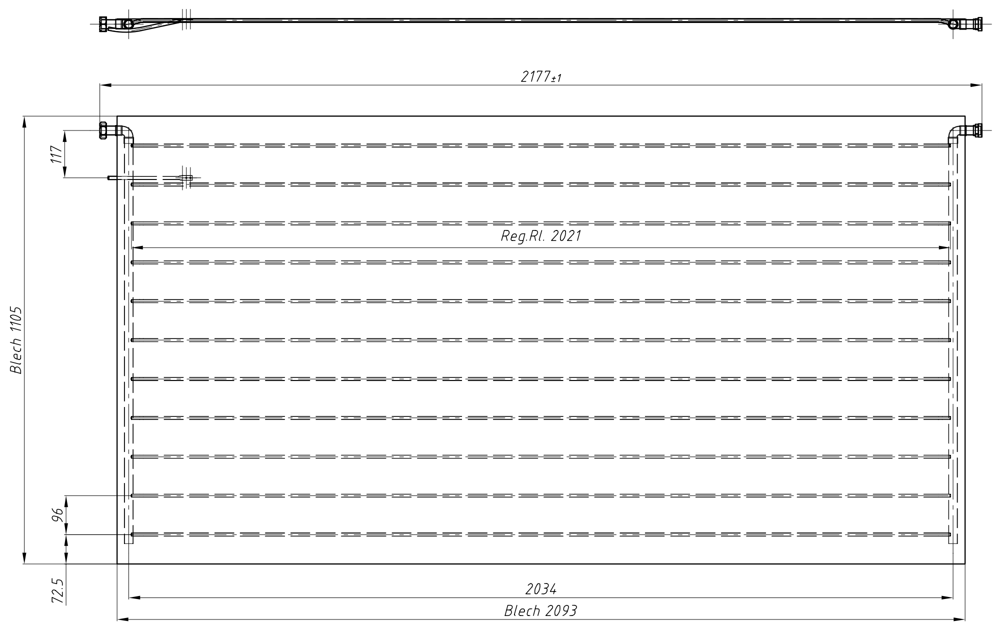

Figure 9: Drawing of absorber layout Collettore Solare Piano CP2XL

E Efficiency curve and measurement points

E.1 Measured data for efficiency curve

[W/m²]	[-]	[kg/h]	[°C]	[°C]	[K]	[°C]	[°C]	[K]	[K m²/W]	[-]
998	0.17	132.7	15.61	25.05	9.44	20.33	20.05	0.28	0.0003	0.758
987	0.18	132.7	15.58	24.91	9.33	20.25	19.67	0.58	0.0006	0.758
984	0.17	132.6	15.57	24.90	9.33	20.24	20.38	-0.14	-0.0001	0.760
983	0.16	132.6	15.58	24.94	9.36	20.26	21.23	-0.97	-0.0010	0.763
989	0.16	147.8	34.93	42.23	7.29	38.58	13.08	25.50	0.0258	0.658
988	0.16	147.8	34.94	42.24	7.30	38.59	13.17	25.42	0.0257	0.659
995	0.16	147.8	34.96	42.33	7.36	38.65	13.54	25.10	0.0252	0.660
1000	0.16	147.8	34.95	42.35	7.40	38.65	13.23	25.42	0.0254	0.660
985	0.14	139.1	63.01	69.47	6.46	66.24	17.76	48.48	0.0492	0.552
987	0.14	139.0	63.04	69.54	6.50	66.29	17.98	48.31	0.0490	0.554
990	0.14	139.1	63.04	69.56	6.52	66.30	18.19	48.11	0.0486	0.553
995	0.14	139.2	63.07	69.63	6.56	66.35	18.93	47.41	0.0477	0.555
997	0.19	139.2	91.06	95.76	4.70	93.41	17.99	75.43	0.0756	0.399
1002	0.19	139.2	91.10	95.86	4.77	93.48	17.92	75.56	0.0754	0.402
1009	0.18	139.1	91.07	95.95	4.88	93.51	18.07	75.44	0.0748	0.409
1010	0.18	139.1	91.06	95.97	4.91	93.51	17.86	75.65	0.0749	0.411
1017	0.18	139.2	91.09	96.04	4.95	93.56	18.41	75.15	0.0739	0.411
1021	0.17	139.2	91.08	96.15	5.07	93.61	18.62	74.99	0.0734	0.420

Table 4: Daten der am Außenprüfstand ermittelten Wirkungsgradpunkte

E.2 Efficiency curve

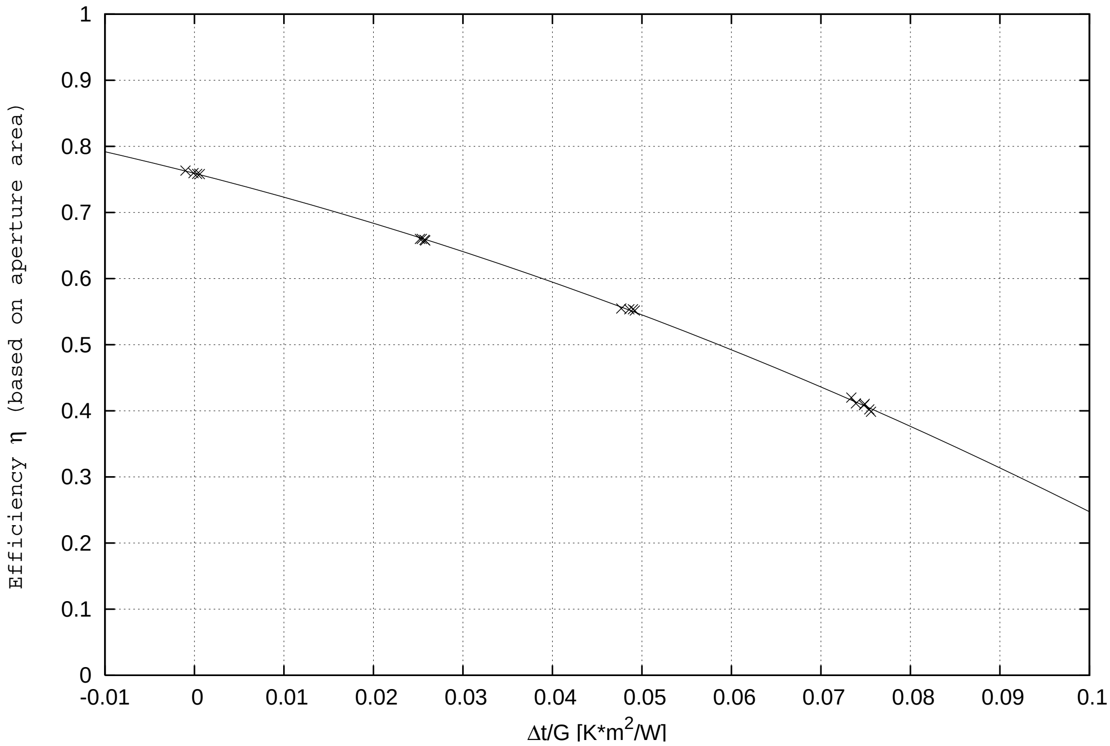

Figure 10: Efficiency curve with measurement points based on aperture area 1.924 m^2

Results:

The calculated parameters are based on following areas:

aperture area of 1.924 m^2:	absorber area of 1.840 m^2:
η_{0a} = 0.759	η_{0A} = 0.794
a_{1a} = 3.480 W/m^2K	a_{1A} = 3.639 W/m^2K
a_{2a} = 0.0161 W/m^2K^2	a_{2A} = 0.0168 W/m^2K^2

E.3 Efficiency curve for the determined coefficients and for an assumed irradiation of 800 W/m^2 based on aperture area

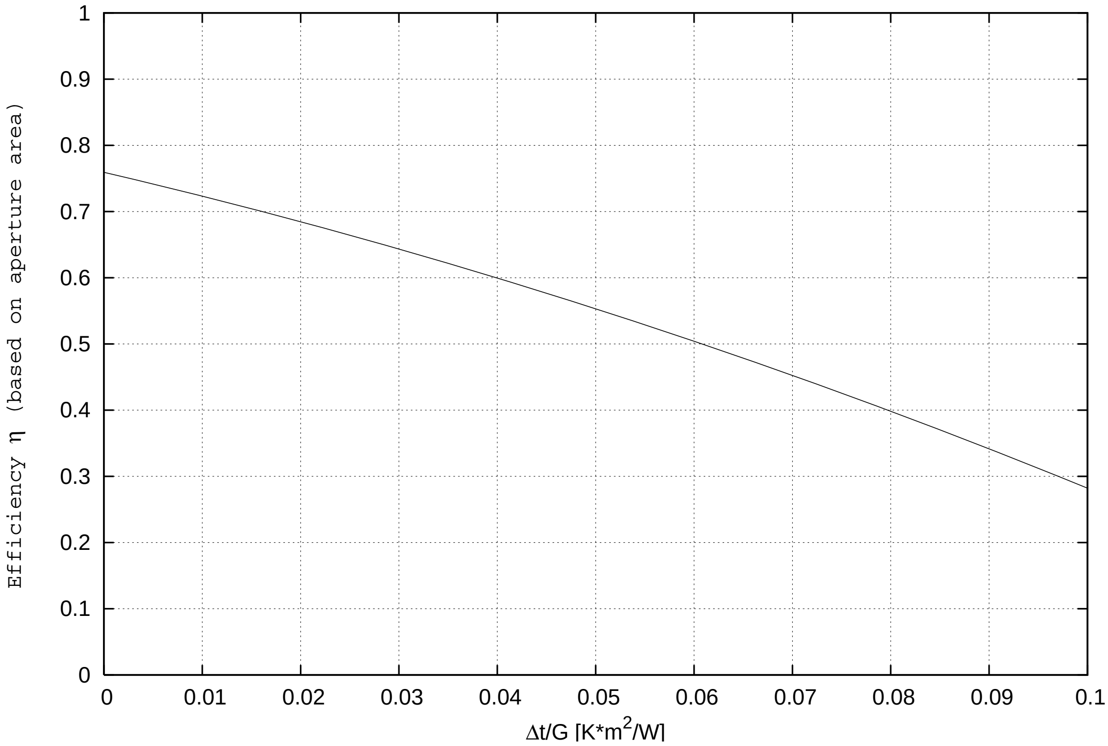

Figure 11: Efficiency curve scaled to 800 W/m^2 based on aperture area 1.924 m^2

The calculated parameters are based on following areas:

aperture area:	absorber area:
$\eta_{0.05a}$ = 0.553	$\eta_{0.05A}$ = 0.578

$\eta_{0.05}$ is the efficiency of the collector for typical conditions of solar domestic hot water systems:
irradiation of 800 W/m^2,
ambient temperature of 20 °C
mean collector temperture of 60 °C.

F Measured data for IAM determination

Table 5 shows the determined efficiency points for the incidence angle modifier IAM. For the calculation of the IAM, the efficiency value (last column) was extrapolated to $(t_{\text{m}} - t_{\text{a}})/G$ = 0. To accomplish this, the heat loss values of the collector $a_{1\text{a}}$ = 3.480 W/m^{2}K and $a_{2\text{a}}$ = 0.0161 W/m^{2}K^2 were used.

G [W/m^2]	G_{d}/G [-]	m [kg/h]	t_{in} [°C]	t_{e} [°C]	$t_{\text{e}} - t_{\text{in}}$ [K]	t_{m} [°C]	t_{a} [°C]	$t_{\text{m}} - t_{\text{a}}$ [K]	$(t_{\text{m}} - t_{\text{a}})/G$ [Km^2/W]	η_{a} [-]
50°										
998	0.17	132.7	15.61	25.05	9.44	20.33	20.05	0.28	0.0003	0.758
987	0.18	132.7	15.58	24.91	9.33	20.25	19.67	0.58	0.0006	0.758
984	0.17	132.6	15.57	24.90	9.33	20.24	20.38	-0.14	-0.0001	0.760
983	0.16	132.6	15.58	24.94	9.36	20.26	21.23	-0.97	-0.0010	0.763
604	0.28	132.7	15.59	21.10	5.51	18.34	20.69	-2.35	-0.0039	0.731
593	0.27	132.6	15.58	21.02	5.43	18.30	20.38	-2.08	-0.0035	0.734
573	0.26	132.7	15.58	20.83	5.24	18.21	21.11	-2.90	-0.0051	0.734
565	0.25	132.7	15.58	20.77	5.18	18.18	20.97	-2.80	-0.0050	0.735
557	0.24	132.6	15.57	20.71	5.13	18.14	20.72	-2.58	-0.0046	0.739
558	0.23	132.7	15.57	20.71	5.14	18.14	20.95	-2.81	-0.0050	0.738
545	0.22	132.6	15.56	20.61	5.04	18.08	20.02	-1.94	-0.0036	0.742
472	0.19	132.8	15.58	19.97	4.39	17.78	20.59	-2.81	-0.0060	0.746
473	0.17	132.8	15.60	20.01	4.41	17.80	20.41	-2.61	-0.0055	0.748

Table 5: Data of measured efficiency points for IAM

G Data of the exposure test

H:	daily global irradiation
$valid\ period$:	periods when the global irradiance G is higher than 850 W/m^2 and the surrounding air temperature t_a is higher than 10 °C
t_a:	surrounding air temperature
$rain$:	daily rain [mm]

$Date$	H [MJ/m^2]	$valid\ period$ [h]	t_a [°C]	$rain$ [mm]
20060808	15.5	0.6	18.0	1
20060809	22.7	2.7	18.3	4
20060810	12.2	0.7	16.0	12
20060811	4.6	0.0	13.7	9
20060812	16.3	1.8	14.2	8
20060813	5.8	0.0	13.1	12
20060814	6.1	0.0	13.8	20
20060815	25.1	4.1	19.3	6
20060816	17.6	2.0	19.0	4
20060817	10.8	0.2	20.2	15
20060818	25.0	4.4	20.2	1
20060819	20.6	2.9	20.7	1
20060820	18.3	1.6	18.7	2
20060821	12.4	0.5	18.6	4
20060822	18.6	2.3	18.0	0
20060823	26.7	4.1	18.5	0
20060824	16.1	1.7	17.8	2
20060825	13.3	1.4	17.6	5
20060826	14.5	1.1	16.2	6
20060827	11.1	1.0	16.2	8
20060828	2.4	0.0	14.6	14
20060829	5.8	0.0	12.7	6
20060830	11.0	1.0	12.7	10
20060831	26.7	4.0	16.5	0
20060901	26.6	4.0	18.4	0
20060902	15.3	1.5	21.1	0
20060903	7.3	0.3	22.0	0
20060904	16.1	1.1	24.2	0
20060905	25.2	3.8	22.8	0
20060906	14.1	1.0	20.8	0
20060907	20.9	3.1	21.8	12

see also next page

Datum	H [MJ/m^2]	*gueltiger Abschnitt* [h]	t_a [°C]	*Regen* [mm]
20060908	27.0	4.3	16.8	0
20060909	26.6	4.0	16.7	0
20060910	16.6	0.6	20.3	1
20060911	19.5	0.5	22.2	1
20060912	20.4	2.4	21.9	0
20060913	24.1	3.1	21.6	0
20060914	8.4	0.0	19.5	0
20060915	3.0	0.0	16.8	0
20060916	9.0	0.2	17.4	0
20060917	1.1	0.0	16.3	35
20060918	2.2	0.0	15.8	28
20060919	12.2	1.3	17.9	0
20060920	23.4	3.0	18.2	0
20060921	24.8	3.6	19.2	0
20060922	23.1	3.3	19.6	0
20060923	19.4	0.6	20.0	0
20060924	15.3	0.6	19.9	0
20060925	1.4	0.0	14.8	0
20060926	5.9	0.2	14.5	0
20060927	14.5	0.6	15.6	0
20060928	17.2	1.6	15.4	0
20060929	21.3	2.7	18.1	42
20060930	14.8	1.8	18.2	0
20061001	3.5	0.0	17.3	0
20061002	7.3	0.0	18.1	0
20061003	1.3	0.0	15.0	0
20061004	9.3	0.1	12.7	0
20061005	23.1	4.0	13.6	35
20061006	8.6	0.5	15.8	0
20061007	12.1	1.2	14.6	0
20061008	23.7	2.8	12.3	0
20061009	21.7	2.3	14.6	10
20061010	16.7	0.3	14.8	1
20061011	14.1	0.1	14.7	0
20061012	19.3	0.8	16.5	0
20061013	12.1	0.2	14.1	0

see also next page

Datum	*H* [MJ/m^2]	*gueltiger Abschnitt* [h]	t_a [°C]	*Regen* [mm]
20061014	2.2	0.0	12.8	0
20061015	10.0	0.1	12.0	0
20061016	2.7	0.0	8.5	0
20061017	19.1	2.9	10.6	0
20061018	8.7	0.0	12.2	0
20061019	7.9	0.1	13.8	1
20061020	16.2	2.8	16.4	0
20061021	9.9	0.6	16.3	0
20061022	19.1	0.4	17.8	5
20061023	1.9	0.0	16.5	22
20061024	11.3	0.4	16.4	0
20061025	7.9	0.0	12.1	0
20061026	20.0	1.6	16.8	0
20061027	3.5	0.0	19.7	0
20061028	7.0	0.3	16.2	0
20061029	1.3	0.0	15.4	5
20061030	16.2	1.6	11.2	0
20061031	8.3	0.1	12.7	2
20061101	10.7	0.8	9.6	0
20061102	20.3	0.0	4.2	0
20061103	10.1	0.0	3.7	0
20061104	14.9	0.1	5.0	0
20061105	9.2	0.0	4.1	0
20061106	16.6	0.2	5.2	0
20061107	17.4	0.8	5.3	0
20061108	3.4	0.0	12.5	0
20061109	1.9	0.0	12.7	1
20061110	16.8	0.1	6.1	0
20061111	1.0	0.0	8.0	5
20061112	5.1	0.0	8.8	5
20061113	2.3	0.0	9.1	1