



Fraunhofer Institut
Solare Energiesysteme

Test Report: KTB Nr. 2006-43-a-en

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

for:

Roth Werke , Germany

Brand name:

Roth Röhrenkollektor R1

Responsible for testing:

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Date:

January 25th 2007

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Accredited according to DIN EN ISO/IEC 17025:2005



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1 Summary

1.1 Preliminary remark

The collector test was performed with the purpose of the European quality label SolarKeymark. All relevant tests have been passed with success.

The present report is valid for the collector Roth Röhrenkollektor R1 of the company Roth Werke . This collector is identically with VacoSol CPC 7 of the company European Solar Engineering SA . The present report is valid for the series of the collector type VacoSol CPC of the company European Solar Engineering SA with the collectors

VacoSol CPC 21 , VacoSol CPC 14 and VacoSol CPC 7 .

The tests were performed at the largest collector and at the smallest collector of the series, according the rules of the SolarKeymark.

The tests were performed considering all requirements of the standard EN 12975-1,2:2006.

1.2 Collector efficiency parameters determined

Results:

The calculated parameters are based on following areas of the collector VacoSol CPC 21 . These parameters are valid for the complete series.

aperture area of 3.289 m ² :	absorber area of 1,098 m ² :
$\eta_{0a} = 0.601$	$\eta_{0A} = 1.800$
$a_{1a} = 0.767 \text{ W/m}^2\text{K}$	$a_{1A} = 2.298 \text{ W/m}^2\text{K}$
$a_{2a} = 0.0038 \text{ W/m}^2\text{K}^2$	$a_{2A} = 0.0114 \text{ W/m}^2\text{K}^2$

1.3 Incidence angle modifier - IAM

θ :	0°	10°	20°	30°	40°	50°	60°	65°	70°	80°	90°
$K_{\theta T}$:	1.00	1.02	1.03	1.04	1.03	1.07	1.12	1.14	1.13	0.98	0.05
$K_{\theta L}$:	1.00	1.00	1.00	0.99	0.98	0.95	0.88	0.83	0.75	0.50	0.00

Table 1: Measured (**bold**) and calculated IAM data

1.4 Pressure drop

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

$$\Delta p = 0.035 * x + 0.0011 * x^2$$

1.5 Effective thermal capacity of the collector

Effective thermal capacity (VacoSol CPC 21):

28.31 kJ/K

The effective thermal capacity per square meter is:

8.61 kJ/K m²

1.6 Tests on function and efficiency

Test	Date	Result
Date of delivery:	24th May 2006	
Internal pressure	21st September 2006	passed
High temperature resistance	11th June 2006	passed
Exposure	20th September 2006 - 17th Dezember 2006	passed
1st external thermal shock	13th June 2006	passed
2nd external thermal shock	20th June 2006	passed
1st internal thermal shock	21st September 2006	passed
2nd internal thermal shock	22nd September 2006	passed
Rain penetration	31st Oktober 2006	passed
Freeze resistance		not relevant
Mechanical load	21st Dezember 2006	passed
Stagnation temperature	Oktober - November 2006	244°C
Final inspection	21st Dezember 2006	passed
Determination of collector parameters	7th November - 16th November 2006	passed
Determination of IAM	11th July 2006	passed
Effective thermal capacity	calculated	performed

1.7 Summary statement

No problems or distinctive observations occurred during the measurements.



2 Test Center

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3 Orderer, Expeller, Manufacturer

Orderer:	Roth Werke Am Seerain 3 35232 Dautphetal Germany Tel: 0049-6466-922-324 Fax: 0049-6466-922-5324 E-mail: christian.dersch@roth- werke.de
Expeller and Manufacturer:	see orderer

4 Overview of series collectors

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

Brand name	test collector	number of tubes
VacoSol CPC 7	yes	7
Vacosol CPC 14	no	14
VacoSol CPC 21	yes	21

4.1 Specific data of the largest collector of the series (VacoSol CPC 21)

Brand name:	VacoSol CPC 21
Serial no.:	0206006102114
Year of production:	2006
Number of test collectors:	2
Collector reference no.:	2 KT 12 012 092006 (efficiency tests)
Collector reference no. 2:	2 KT 12 009 052006 (function tests)
Total area:	1.610 m x 2.360 m = 3.800 m ²
Collector depth:	0.140 m
Aperture area:	2.278 m x 1.444 m = 3.289 m ² (projected area of the mirror dimensions)
Absorber area:	0.036 m x 1.444 m x 21 tubes = 1.098 m ² (projected area of the absorber tubes)
Number of tubes:	21
Length of the tubes:	1500 mm (MS)
Weight empty:	75 kg
Volume of the fluid:	2.94 l (MS)

4.2 Specific data of the smallest collector of the series (VacoSol CPC 7)

Brand name:	VacoSol CPC 7
Serial no.:	0201006130120
Year of production:	2006
Number of test collectors:	1
Collector reference no.:	2 KT 12 014 092006
Total area:	0.830 m x 1.610 m = 1.336 m ²
Collector depth:	0.140 m
Aperture area:	0.755 m x 1.444 m = 1.090 m ² (projected area of the mirror dimensions)
Absorber area:	1.444 m x 0.036 m x 7 tubes = 0.360 m ² (projected area of the absorber tubes)
Number of tubes:	7
Length of the tubes:	1500 mm (MS)
Weight empty:	22.5 kg
Volume of the fluid:	0.98 l (MS)

4.3 Collector data in common

	(MS) = Manufacturer Specification
Type:	vacuum tube collector,u-tube, CPC reflector
Material of the cover tube:	borosilicate glass (MS)
Transmission of the cover tube:	90 %
Outer diameter of the cover tube:	47 mm (MS)
Thickness of the cover tube:	1.6 mm (MS)
Outer diameter of the inner tube	36.2 mm (MS)
Thickness of the inner tube:	1.6 mm (MS)
Distance from tube to tube:	110 mm (MS)
Mirror construction:	CPC
Material of the mirror:	coated aluminium

4.4 Absorber

Material of the absorber:	borosilicate glass (MS)
Kind/Brand of selective coating:	selective coating (MS)
Absorptivity coefficient α :	> 92 % (MS)
Emissivity coefficient ε :	< 7 % (MS)
Material of the header pipe:	copper (MS)
Outer diameter of the header pipe:	12 mm (MS)
Inner diameter of the header pipe:	10 mm (MS)
Layout of the absorber:	clusters of 7 parallel u-tubes, serially connected
Material of the contact sheets:	aluminium (MS)
Thickness of the contact sheets:	0.3 mm (MS)
Material of the U-pipes:	copper (MS)
Outer U-pipe diameter:	8 mm (MS)
Inner U-pipe diameter:	7 mm (MS)

4.5 Insulation and Casing

Medium between the inner and outer tubes of the vacuum flask:	high vacuum (MS)
Thickness of the insulation in the header:	40 mm (MS)
Material:	rockwool (MS)
Material of the casing:	aluminium (MS)
Sealing material:	EPDM (MS)



4.6 Limitations

Maximum pressure:	3000 kPa (MS)
Operating pressure:	600 kPa (MS)
Maximum service temperature:	not specified
Maximum stagnation temperature:	244°C
Maximum wind load:	150 km/h (MS)
Recommended tilt angle:	15 - 45 °(MS)
Flow range recommendation:	25 - 30 l/m ² h (MS)

4.7 Kind of mounting

Flat roof - mounted on the roof:	Yes (MS)
Tilted roof - mounted on the roof:	No (MS)
Tilted roof - integrated:	No (MS)
Free mounting:	Yes (MS)
Fassade:	Yes (MS)

4.8 Picture and cut drawing of the collector



Figure 1: Picture of the collector VacoSol CPC 21 mounted on the test facility of Fraunhofer ISE

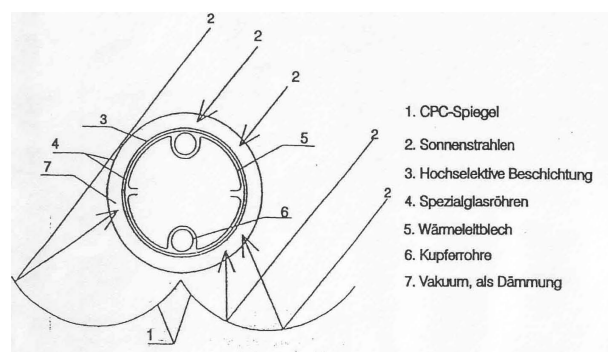


Figure 2: Cut drawing of the collector VacoSol CPC 21

5 Collector efficiency parameters

5.1 Test method

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

5.2 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:

$$\eta_{(G,(t_m-t_a))} = \eta_0 - a_{1a} \frac{t_m - t_a}{G} - a_{2a} \frac{(t_m - t_a)^2}{G} \quad (1)$$

(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 ($^{\circ}\text{C}$)
 t_e = collector outlet temperature ($^{\circ}\text{C}$)
 t_a = ambient temperature ($^{\circ}\text{C}$)

The coefficients η_0 , a_{1a} und a_{2a} 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_{1a} and a_{2a} describe the heat loss of the collector. The temperature dependency of the collector heat loss is described by:

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

5.3 Efficiency parameters

Boundary conditions:

Test method:	outdoor, steady state
Latitude:	48.0°
Longitude:	7.8°
Collector tilt:	tracked between 40° and 50°
Collector azimuth:	tracked
Mean irradiation :	883 W/m ²
Mean wind speed:	3 m/s
Mean flow rate:	238 kg/h
Kind of fluid:	water

Results:

The calculated parameters are based on following areas of the collector VacoSol CPC 21 .

These values are also valid for the complete series.¹:

aperture area of 3.289 m ² :	absorber area of 1,098 m ² :
$\eta_{0a} = 0.601$	$\eta_{0A} = 1.800$
$a_{1a} = 0.767 \text{ W/m}^2\text{K}$	$a_{1A} = 2.298 \text{ W/m}^2\text{K}$
$a_{2a} = 0.0038 \text{ W/m}^2\text{K}^2$	$a_{2A} = 0.0114 \text{ W/m}^2\text{K}^2$

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 ($\eta_{0a} = 0.601 \pm 0.02$). 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 measurements points is: $a_{1a} = 0.767 \pm 0.047$ and $a_{2a} = 0.0038 \pm 0.0005$.

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

¹ absorber area - projected area of absorber tube,
aperture area - mirror dimensions

5.4 Power output per collector unit

The power output per collector unit will be documented for the largest collector of the series VacoSol CPC 21 with the highest output per collector unit and for the smallest collector of the series VacoSol CPC 7 with the lowest output per collector unit.

Power output per collector unit [W] for collector VacoSol CPC 21 (aperture area of 3.289 m²):

$t_m - t_a$ [K]	400 [W/m ²]	700 [W/m ²]	1000 [W/m ²]
10	764	1357	1950
30	704	1297	1890
50	633	1226	1819

Power output per collector unit [W] for collector VacoSol CPC 7 (aperture area of 1.090 m²):

$t_m - t_a$ [K]	400 [W/m ²]	700 [W/m ²]	1000 [W/m ²]
10	261	465	669
30	238	442	646
50	212	416	620

The power output per collector unit can be calculated for other collectors of this series according the following 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 VacoSol CPC 21 , (values see table)
- A_a = Aperture area of a different collector of the series
- $A_{a,ref}$ = Aperture area of collector VacoSol CPC 21 = 1.090 m²

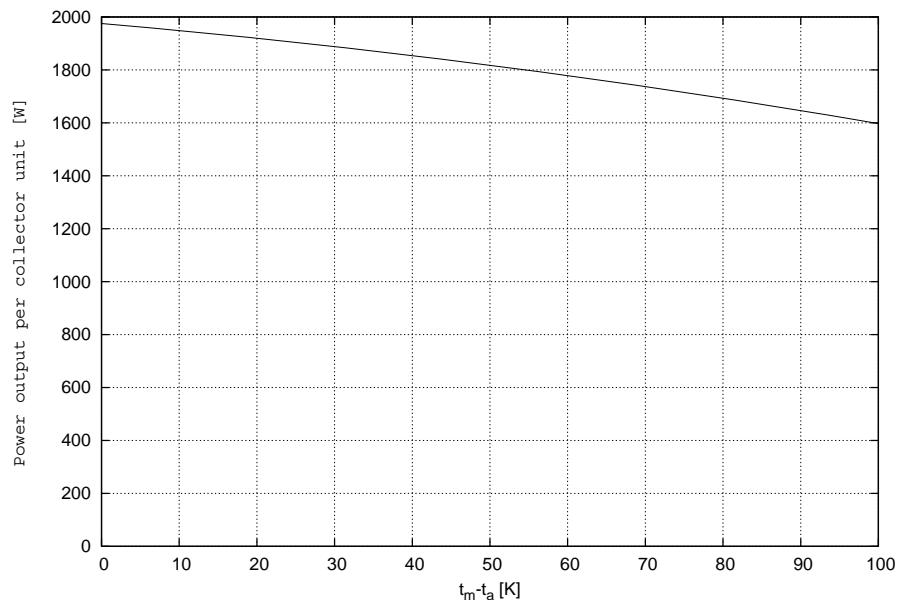


Figure 3: Power output for collector VacoSol CPC 21 based on 1000 W/m^2

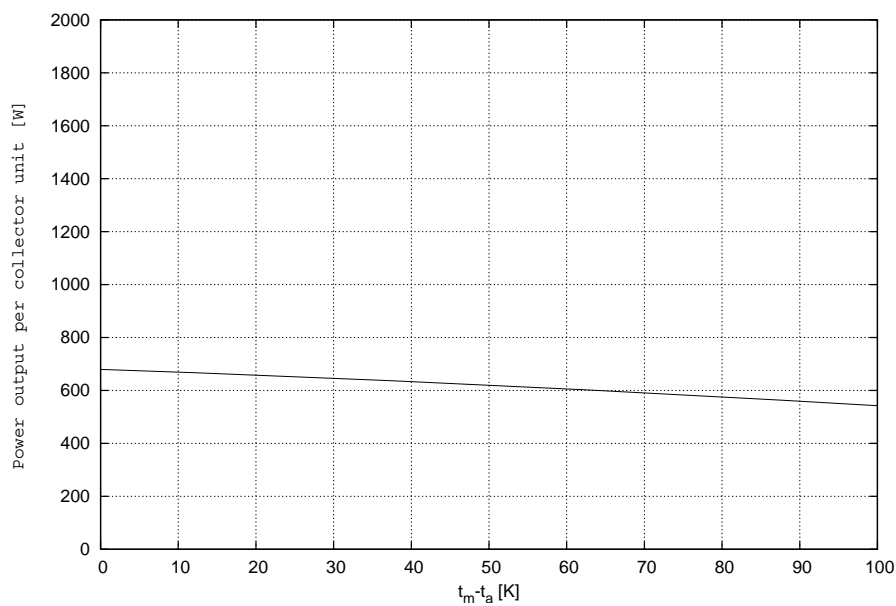


Figure 4: Power output per collector unit based on an irradiance of 1000 W/m^2

6 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.

For collectors which have a direction-depending IAM behaviour (for example vakuum tube collectors and cpc collectors), it is necessary to measure the IAM for more than one direction, to have a proper determination of the IAM.

The complex IAM can be estimated by calculating it as the product of both separately measured incidence angle modifiers $K_{\theta L}$ and $K_{\theta T}$ of two orthogonal planes (equation 2).

$$K_{\theta} = K_{\theta L} * K_{\theta T} \quad (2)$$

The longitudinal plane (index L) is orientated parallelly to the optical axis of the collector. The transversal plane is orientated orthogonally to the optical axis of the collector. The angles θT and θL are the projection of the incidence angle of the radiation on the transversal or longitudinal plane.

The transversal measurement was performed dynamically, what means that the orientation of the tracker was fixed, just the tilt angle was tracked. So the sun is turning around the collector and there is no longitudinal influence. The incident angle is changing during the day. The resulting values for the incident angle θ are the mean values between the east and the west measurement.

For the measurement of the IAM longitudinal the orientation and the tilt angle of the tracker were tracked, which means a steady state measurement.

Test method:	outdoor
Latitude:	48.0°
Longitude:	7.8°

θ :	0°	10°	20°	30°	40°	50°	60°	65°	70°	80°	90°
$K_{\theta T}$:	1.00	1.02	1.03	1.04	1.03	1.07	1.12	1.14	1.13	0.98	0.05
$K_{\theta L}$:	1.00	1.00	1.00	0.99	0.98	0.95	0.88	0.83	0.75	0.50	0.00

Table 2: Measured (**bold**) and calculated IAM data

The IAM longitudinal was measured for one angle ($\theta = 50^\circ$). All other angles for the IAM longitudinal in table 2 were calculated according to Ambrosetti ¹(equation 3).

$$K_{\theta} = 1 - \left[\tan \frac{\theta}{2} \right]^{\frac{1}{2}} \quad (3)$$

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

7 Pressure drop

The measurement of the pressure drop Δp was carried out with water as fluid up to a flow rate of 275 kg/h. The inlet temperature of the water was 20°C. 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 m² to 108 kg/h m² 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 occurring in collector fields.

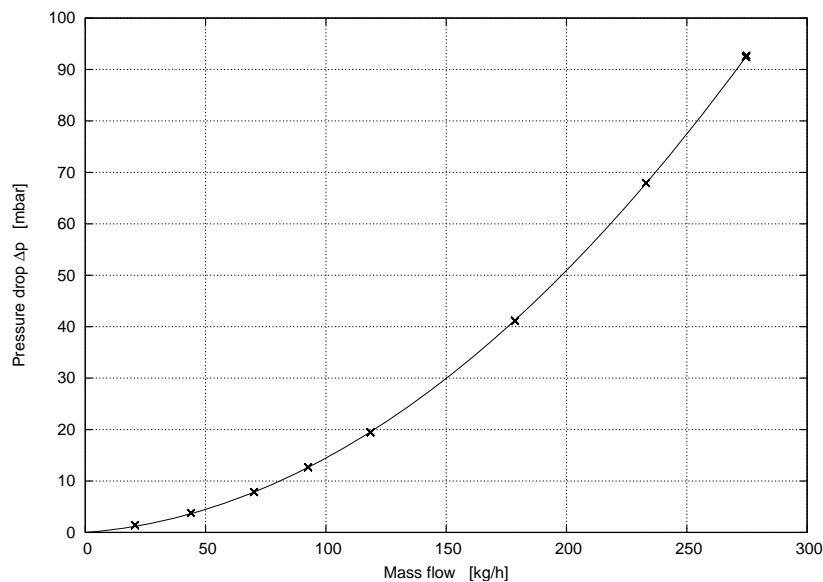


Figure 5: Measured pressure drop of the collector VacoSol CPC 7

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

$$\Delta p = 0.035 * x + 0.0011 * x^2$$

Example values from fitted curve:

Mass flow [kg/h]	Pressure drop Δp [mbar]
0	0.0
100	14.5
200	51.0
300	109.5
400	190.0
500	292.5
600	417.0
700	563.5
800	732.0
900	922.5

Table 3: Example values for Δp

8 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: For the heat transfer fluid a mixture 2/1 of water/propylenglycol at a temperature of 50°C has been chosen.

28.31 kJ/K

The effective thermal capacity per square meter is:

8.61 kJ/K m²

9 Internal pressure test

Maximum pressure:	3000 kPa (MS)
Test temperature:	9.3 °C
Test pressure:	4500 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.

10 High temperature resistance test

Method:	Outdoor testing
Collector tilt angle:	45°
Average irradiance during test:	1010 W/m ²
Average surrounding air temperature:	30.5 °C
Average surrounding air speed:	< 0.5 m/s
Average absorber temperature:	246 °C
Duration of test:	1 h

Result:

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

11 Exposure test

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

Result:

The number of days when the daily global irradiance was more than 14 MJ/m²d was 33 . The periods when the global irradiance G was higher than 850 W/m² and the surrounding air temperature t_a was higher than 10 °C was 44.4 h.

The evaluation of the exposure test is described in the chapter 18 "Final inspection".

12 External 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:	937 W/m ²	985 W/m ²
Average surrounding air temperature:	29.2 °C	30.4 °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:	22.0 °C	23.1 °C
Duration of water spray:	15 min	15 min
Absorber temperature immediately prior to water spray:	229 °C	241 °C

Result:

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

13 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:	960 W/m ²	963 W/m ²
Average surrounding air temperature:	22.4 °C	23.5 °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:	23.5 °C	21.3 °C
Duration of heat transfer fluid flow:	5 min	5 min
Absorber temperature immediately prior to heat transfer fluid flow:	227 °C	229 °C

No cracking, distortion or condensation 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 suggests a application of the collector only with a freeze resistance fluid.

16 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/m² and an ambient temperature of 30 °C. The calculation is as follows:

$$t_s = t_{as} + \frac{G_s}{G_m} * (t_{sm} - t_{am}) \quad (4)$$

t_s : Stagnation temperature
 t_{as} : 30 °C
 G_s : 1000 W/m²
 G_m : Solar irradiance on collector plane
 t_{sm} : Absorber temperature
 t_{am} : Surrounding air temperature

Measurement	Irradiance [W/m ²]	Surrounding air temperature [°C]	Absorber temperature [°C]
1	917	9.9	204.9
2	915	9.5	205.1
3	926	9.0	205.2
4	907	9.8	205.4
5	912	10.2	205.3

The resulting stagnation temperature is: 244°C

17 Mechanical load test

17.1 Positive pressure test of the collector cover

The positive pressure (according to a positive pressure load caused by snow or wind) was not performed because it is not reasonable at this collector construction.

17.2 Negative pressure test of fixings of the header casing and the collector frame

The negative pressure (according to a negative pressure load caused by wind) was increased in steps of 100 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 header casing or at the fixings of the header casing and the collector frame was observed.

17.3 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.

18 Final inspection

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

Collector component	Potential problem	Evaluation
Collector box/ fasteners	Cracking/ wrapping/ corrosion/ rain penetration	0
Mountings/ structure	Strength/ safety	0
Seals/ gaskets	Cracking/ adhesion/ elasticity	0
Cover/ reflector	Cracking/ crazing/ buckling/ de- lamination/ wrapping/ outgassing	0
Absorber coating	Cracking/ crazing/ blistering	0
Absorber tubes and headers	Deformation/ corrosion/ leak- age/ 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

19 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



20 Summary statement

The measurements were carried out from Oktober - November .

No problems or distinctive observations occurred during the measurements.

21 Annotation to the test report

The results described in this test report refer only to the test collector. It is not allowed to make extract copies of this test report.

Test report: KTB Nr. 2006-43-a-en

Freiburg, January 25th 2007

Fraunhofer-Institute for Solar Energy Systems ISE

Dipl.-Phys. M. Rommel
Head of the Test Center for
Thermal Solar Systems

Dipl.-Ing. (FH) A. Schäfer
Responsible for testing

A Drawing of absorber layout

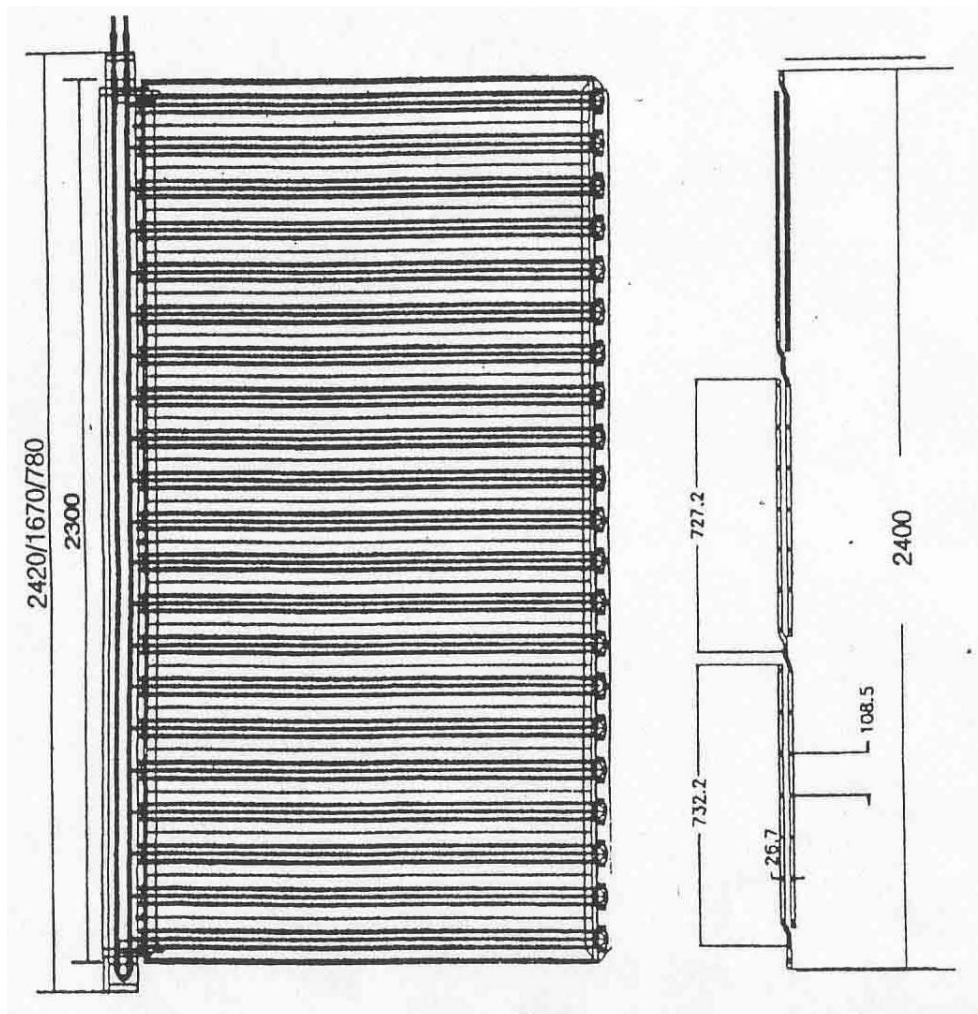


Figure 6: Drawing of absorber layout VacoSol CPC 21

B Efficiency curve

B.1 Efficiency curve with measurement points based on aperture area 1.090 m²

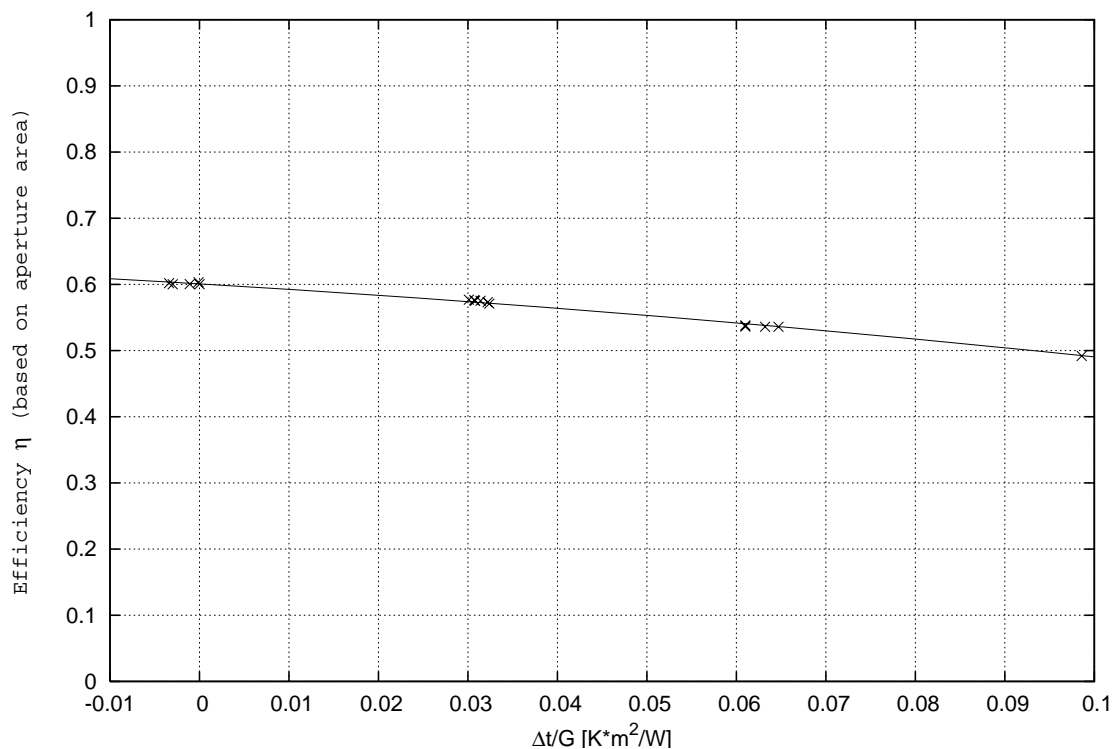


Figure 7: Efficiency curve with measurement points based on aperture area 1.090 m²

Results:

The calculated parameters are based on following areas:

aperture area of 1.090 m²: absorber area of 0.360 m²:

$$\eta_{0a} = 0.601$$

$$\eta_{0A} = 1.800$$

$$a_{1a} = 0.767 \text{ W/m}^2\text{K}$$

$$a_{1A} = 2.298 \text{ W/m}^2\text{K}$$

$$a_{2a} = 0.0038 \text{ W/m}^2\text{K}^2$$

$$a_{2A} = 0.0114 \text{ W/m}^2\text{K}^2$$

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

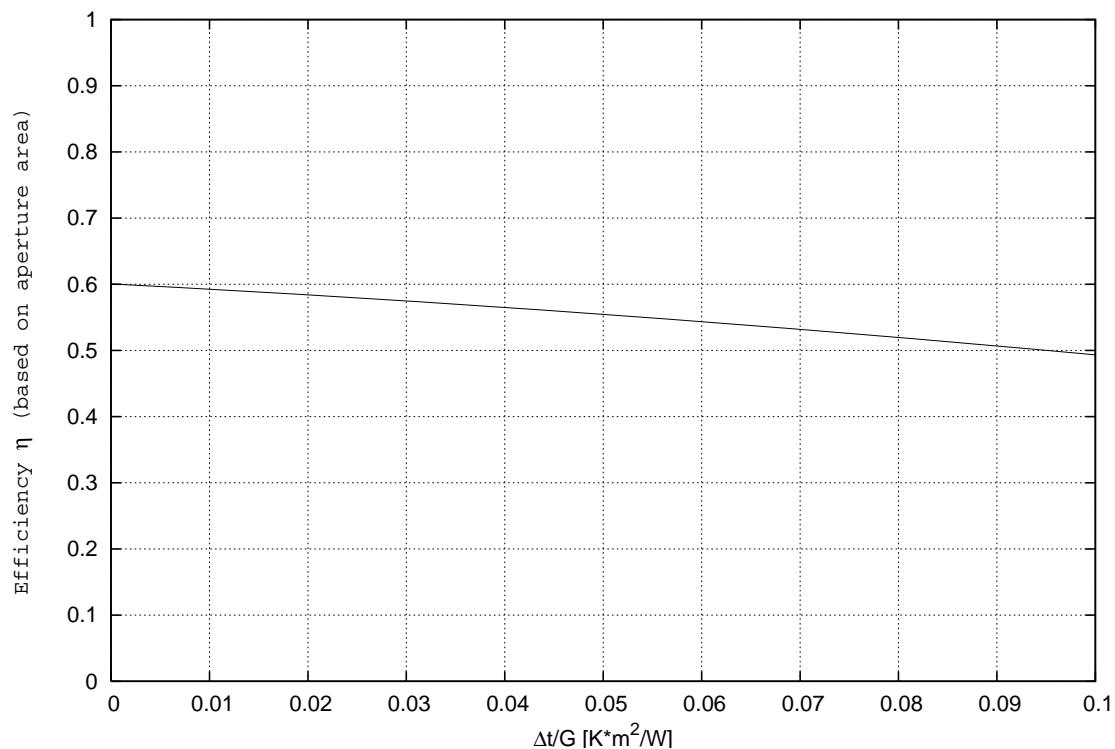


Figure 8: Efficiency curve scaled to 800 W/m^2 based on aperture area 1.090 m^2

The calculated parameters are based on following areas:

aperture area:

$$\eta_{0.05a} = 0.555$$

absorber area:

$$\eta_{0.05A} = 1.663$$

$\eta_{0.05}$ is the efficiency of the collector for typical conditions of solar domestic hot water systems:

irradiation of 800 W/m^2 ,

ambient temperature of $20 \text{ }^\circ\text{C}$

mean collector temperature of $60 \text{ }^\circ\text{C}$.

B.3 Measured data for efficiency curve

G [W/m ²]	G_d/G [-]	m [kg/h]	t_{in} [°C]	t_e [°C]	$t_e - t_{in}$ [K]	t_m [°C]	t_a [°C]	$t_m - t_a$ [K]	$(t_m - t_a)/G$ [K m ² /W]	η_a [-]
899	0.09	236.7	13.16	19.60	6.45	16.38	16.37	0.01	0.0000	0.600
890	0.07	236.5	13.16	19.58	6.42	16.37	16.46	-0.09	-0.0001	0.603
895	0.07	236.4	13.16	19.59	6.43	16.38	17.35	-0.97	-0.0011	0.600
839	0.07	236.5	13.20	19.22	6.02	16.21	18.69	-2.48	-0.0030	0.600
822	0.07	235.8	13.21	19.14	5.94	16.17	18.94	-2.76	-0.0034	0.602
840	0.06	236.2	38.03	43.78	5.75	40.90	13.69	27.21	0.0324	0.571
852	0.06	236.3	38.03	43.88	5.85	40.96	13.52	27.44	0.0322	0.573
862	0.06	236.4	38.04	43.98	5.94	41.01	13.97	27.04	0.0314	0.575
870	0.06	236.4	38.05	44.06	6.00	41.06	14.25	26.81	0.0308	0.575
874	0.06	236.3	38.05	44.10	6.04	41.08	14.25	26.83	0.0307	0.576
878	0.06	236.3	38.06	44.13	6.07	41.09	14.71	26.39	0.0301	0.577
922	0.09	239.7	63.77	69.60	5.83	66.69	7.04	59.64	0.0647	0.536
936	0.09	239.8	63.80	69.71	5.91	66.76	7.67	59.09	0.0632	0.536
942	0.09	240.1	63.87	69.82	5.95	66.84	9.40	57.44	0.0610	0.536
946	0.09	240.2	63.84	69.83	5.99	66.83	9.09	57.74	0.0610	0.538
850	0.09	240.0	92.45	97.28	4.83	94.87	4.71	90.16	0.1060	0.485
870	0.09	240.3	92.45	97.42	4.96	94.94	5.10	89.83	0.1033	0.487
872	0.10	240.4	92.45	97.44	4.99	94.95	5.05	89.89	0.1030	0.488
891	0.10	240.7	92.52	97.58	5.06	95.05	5.70	89.35	0.1003	0.486
901	0.10	240.5	92.54	97.73	5.18	95.13	6.36	88.77	0.0986	0.492

Table 4: Data of measured efficiency points

C 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 $10 \text{ }^\circ\text{C}$
t_a: surrounding air temperature
rain: daily rain [mm]

<i>Date</i>	<i>H</i> [MJ/m ²]	<i>valid period</i> [h]	<i>t_a</i> [°C]	<i>rain</i> [mm]
20060920	23.4	3.0	18.2	0.0
20060921	24.8	3.6	19.2	0.0
20060922	23.1	3.3	19.6	0.0
20060923	19.4	0.6	20.0	0.0
20060924	15.3	0.6	19.9	0.0
20060925	1.4	0.0	14.8	0.0
20060926	5.9	0.2	14.5	0.0
20060927	14.5	0.6	15.6	0.0
20060928	17.2	1.6	15.4	42.0
20060929	21.3	2.7	18.1	0.0
20060930	14.8	1.8	18.2	0.0
20061001	3.5	0.0	17.3	0.0
20061002	7.3	0.0	18.1	0.0
20061003	1.3	0.0	15.0	0.0
20061004	9.3	0.1	12.7	0.0
20061005	23.1	4.0	13.6	35.0
20061006	8.6	0.5	15.8	0.0
20061007	12.1	1.2	14.6	0.0
20061008	23.7	2.8	12.3	0.0
20061009	21.7	2.3	14.6	10.0
20061010	16.7	0.3	14.8	0.5
20061011	14.1	0.1	14.7	0.0
20061012	19.3	0.8	16.5	0.0
20061013	12.1	0.2	14.1	0.0
20061014	2.2	0.0	12.8	0.0
20061015	10.0	0.1	12.0	0.0
20061016	2.7	0.0	8.5	0.0
20061017	19.1	2.9	10.6	0.0
20061018	8.7	0.0	12.2	0.0
20061019	7.9	0.1	13.8	1.0
20061020	16.2	2.8	16.4	0.0
20061021	9.9	0.6	16.3	0.0
20061022	19.1	0.4	17.8	5.0
20061023	1.9	0.0	16.5	22.0
20061024	11.3	0.4	16.4	0.0
20061025	7.9	0.0	12.1	0.0

Continuation, see next page:



<i>Date</i>	<i>H</i> [MJ/m ²]	<i>valid period</i> [h]	<i>t_a</i> [°C]	<i>rain</i> [mm]
20061026	20.0	1.6	16.8	0.0
20061027	3.5	0.0	19.7	0.0
20061028	7.0	0.3	16.2	0.0
20061029	1.3	0.0	15.4	5.0
20061030	16.2	1.6	11.2	0.0
20061031	8.3	0.1	12.7	1.5
20061101	10.7	0.8	9.6	0.0
20061102	20.3	0.0	4.2	0.0
20061103	10.1	0.0	3.7	0.0
20061104	14.9	0.1	5.0	0.0
20061105	9.2	0.0	4.1	0.0
20061106	16.6	0.2	5.2	0.0
20061107	17.4	0.8	5.3	0.0
20061108	3.4	0.0	12.5	0.0
20061109	1.9	0.0	12.7	1.0
20061110	16.8	0.1	6.1	0.0
20061111	1.0	0.0	8.0	4.5
20061112	5.1	0.0	8.8	4.5
20061113	2.3	0.0	9.1	1.0
20061114	2.1	0.0	12.9	0.0
20061115	17.8	0.0	14.1	0.0
20061116	16.1	0.2	13.2	1.0
20061117	1.8	0.0	13.8	0.0
20061118	16.1	0.4	12.1	0.0
20061119	3.1	0.0	9.6	10.0
20061120	13.3	0.2	7.7	3.0
20061121	2.5	0.0	10.1	11.0
20061122	7.9	0.0	5.8	0.0
20061123	2.8	0.0	12.3	1.0
20061124	6.8	0.1	14.1	0.0
20061125	4.8	0.0	14.4	0.0
20061126	7.0	0.0	11.9	0.0
20061127	7.2	0.0	11.0	0.0
20061128	14.4	0.0	8.4	3.0
20061129	1.2	0.0	8.9	4.0
20061130	1.3	0.0	6.9	0.0

Continuation, see next page:



<i>Date</i>	<i>H</i> [MJ/m ²]	<i>valid period</i> [h]	<i>t_a</i> [°C]	<i>rain</i> [mm]
20061201	14.8	0.0	7.0	0.0
20061202	9.0	0.1	7.8	0.0
20061203	8.2	0.0	13.7	0.0
20061204	3.5	0.0	11.6	4.0
20061205	4.1	0.1	15.3	12.0
20061206	0.9	0.0	9.9	4.0
20061207	11.5	0.1	8.6	1.0
20061208	1.3	0.0	9.2	20.0
20061209	1.3	0.0	6.2	6.0
20061210	7.3	0.0	4.9	0.0
20061211	1.7	0.0	4.4	2.5
20061212	1.5	0.0	7.2	0.0
20061213	15.4	0.0	6.2	0.0
20061214	14.9	0.0	3.9	0.0
20061215	16.1	0.0	5.5	0.0
20061216	6.2	0.0	10.4	0.0
20061217	1.8	0.0	5.8	4.0