Fraunhofer Institut
Solare Energiesysteme

Test Report: KTB Nr. 2003-18-b-en

Collector test according to EN 12975-1,2:2002

for:
RM Solar Ltd

Brand Name:
S-Class

Responsible for Testing:
Dipl.-Ing. (FH) A. Schäfer

Date:
17th July 2006

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Deutscher Akkreditierungs Rat

Registration No.:
DAP-PL-3926.00

DIN CERTCO
Anerkanntes Prüflaboratorium

Contents

1 Summary

1.1 Preliminary remark

All test results were taken from KTB 2003-18-en from 4th of August 2003.

1.2 Boundary conditions for the efficiency curve

Test method:	indoor, steady state
Collector tilt:	45 °
Mean wind speed:	3 m/s
Kind of fluid:	Water
Period:	Abril 2003
Mean flow rate:	124 kg/h
Mean irradiation G:	975 W/m^2

Test conditions:

Mean irradiation :	975 W/m^2
Mean wind speed:	3 m/s
Mean flow rate:	124 kg/h
Kind of fluid:	water
Period:	Abril 2003

1.3 Collector parameters determined

The following parameters are based on the aperture area of 1.740 m^2:

η_{0a} = 0.814
a_{1a} = 4.954 W/m^{2}K
a_{2a} = 0.0189 W/m^{2}K^2

The following parameters are based on the absorber area of 1.780 m^2:

η_{0A} = 0.796
a_{1A} = 4.843 W/m^{2}K
a_{2A} = 0.0185 W/m^{2}K^2

1.4 Pressure drop

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

$$\Delta p = 0.374 * x + 0.0131 * x^2$$

1.5 Incidence angle modifier - IAM (measured at the outdoor test facility (tracker))

Test method:	outdoor, steady state
Latitude:	48.0°
Longitude:	7.8°
Collector tilt:	tracked
Collector azimuth:	tracked

$IAM_{\theta=50°}$ = 0.938

1.6 Effective thermal capacity

Effective thermal capacity:

19,29 kJ/K

The effective thermal capacity based on the aperture area 1.740 m^2:

11,09 kJ/K m^2

1.7 Functional tests

Test	Date	Result
1st internal pressure	23rd Abril 2003	succeeded
High temperature resistance	23rd May 2003	succeeded
Exposure	24th Abril 2003- 09th June 2003	succeeded
1st external thermal shock	28th Abril 2003	succeeded
2nd external thermal shock	04th June .06.2003	succeeded
1st internal thermal shock	01st May 2003	succeeded
2nd internal thermal shock	03rd June 2003	succeeded
Rain penetration	02nd June 2003	succeeded
Freeze resistance	-	not necessary
2nd internal pressure	09th June 2003	succeeded
Mechanical load	05th June 2003	succeeded
Stagnation temperature	23rd May 2003- 01st June 2003	170 °C
Final inspection	10th June 2003	succeeded

1.8 Summary statement

No problems or distinctive observations occured during the measurements. All tests and measurements are based on test report KTB 2003-17-en of 17th July 2006 (Genersys 1000-10). The difference between the collector types is, that collector Genersys 1000-10 has four connections (possible usage, parallel) and S-Class has two connections (only seriel usage).

2 Test Center

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3 Orderer

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4 Description of the Collector

Distributer and Manufacturer:	see orderer

4.1 Collector

(MS):	Manufacturer Specification
Type:	Flat plat collector
Brand name:	S-Class
Serial no.:	-
Year of construction:	2003
Number of test collectors:	1
Collector reference number:	2 KT 18 005 042003
Total area:	2,008 m * 1,010 m = 2,028 m^2
Aperture area:	1,910 m * 0,911 m = 1.740 m^2
Absorber area:	1.780 m^2 (MS)
Material of the cover:	ESG white glass
Number of covers:	1
Transmission of the cover:	90,5 %
Thickness of the cover:	4 mm
Weight empty:	36,5 kg
Volume of the fluid:	1,15 l (MS)
Heat transfer fluid:	Propylenglykol (MS)

4.2 Absorber

Material of the absorber sheet:	Aluminium (MS)
Thickness of the absorber sheets:	0,4 mm (MS)
Kind of the selective coating:	Galvanic selectiv (MS)
Absorptivity coefficient α:	95 % (MS)
Emissivity coefficient ε	16 % (MS)
Material of the absorber pipes:	Copper (MS)
Layout of the absorber pipes:	Meander (MS)
Number of absorber pipes:	1 (MS)
Outer diameter:	10 mm (MS)
Inner diameter:	0,7 mm (MS)
Distance between the pipes:	87 mm (MS)
Material of the header pipe:	V2A steel (MS)
Outer diameter of the header pipe:	18 mm (MS)
Wall thickness of the header pipe:	1 mm (MS)

4.3 Insulation and Casing

Collector dimensions Height, width, depth:	2,008 m; 1,010 m; 0,072 m
Thickness of the insulation at the back:	40 mm
Thickness of the insulation at the sides:	15 mm
Material:	Mineral wool (MS)
Material of the casing:	Aluminium (MS)

4.4 Limitations

Maximum pressure:	20 bar (MS)
Operating pressure:	4,5 bar(MS)
Maximum temperature:	170 °C
Flow range recommendation:	30 l/m^2h (MS)

4.5 Kind of mounting

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

4.6 Picture of the collector

Figure 1: Picture of the collector S-Class

4.7 Drawing of the collector

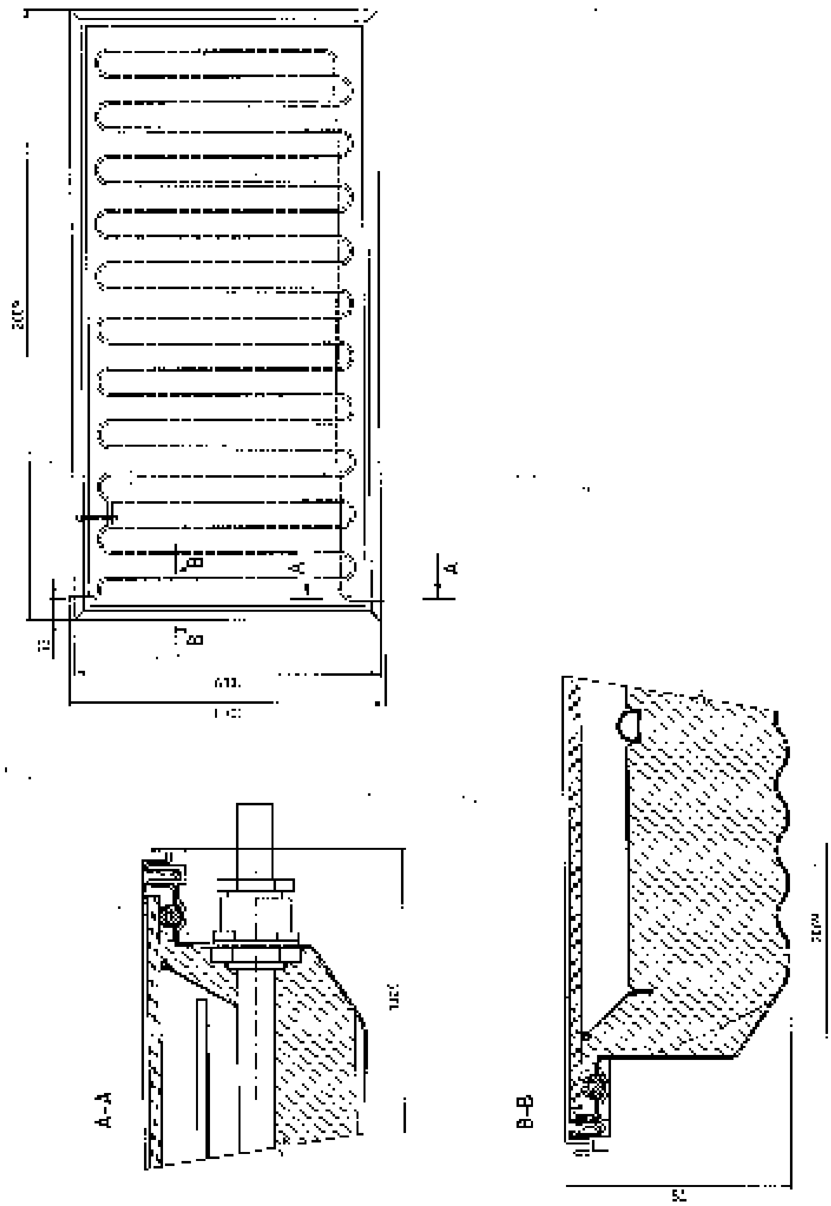

Figure 2: Drawing of the collector-S-Class

5 Collector efficiency curve

5.1 Test method

Outdoor, steady state according to EN 12975-2:
Thermal solar systems and components, solar collectors, 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)

with: $t_m = \frac{(t_e + t_{in})}{2}$

where: G = global irradiance on the collector area (W/m^2)
t_{in} = collector inlet temperature (°C)
t_e = collector outlet temperture (°C)
t_a = ambient temperature (°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:

$$\frac{(t_{in} + t_e)}{2} = t_a$$

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

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

5.3 Instantaneous efficiency curve based on aperture and absorber area and mean temperature of heat transfer fluid

Boundary conditions:

Test method:	indoor, steady state
Collector tilt:	45 °
Mean wind speed:	3 m/s
Kind of fluid:	Water
Period:	Abril 2003
Mean flow rate:	124 kg/h
Mean irradiation G:	975 W/m^2

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_a} [-]
121.32	23.04	32.94	9.90	27.99	29.58	-1.59	-0.0016	0.822
121.40	23.05	32.95	9.90	28.00	29.64	-1.64	-0.0017	0.822
121.34	23.05	32.96	9.91	28.00	29.72	-1.72	-0.0018	0.823
124.87	46.16	54.38	8.22	50.27	29.72	20.55	0.0211	0.702
124.76	46.18	54.42	8.24	50.30	29.97	20.33	0.0208	0.703
124.74	46.20	54.45	8.25	50.32	29.98	20.34	0.0209	0.704
126.02	69.29	75.85	6.56	72.57	30.75	41.81	0.0429	0.567
125.97	69.30	75.87	6.56	72.58	30.73	41.85	0.0429	0.567
126.04	69.32	75.88	6.56	72.60	30.71	41.89	0.0429	0.567
123.59	92.14	96.99	4.85	94.56	30.94	63.62	0.0652	0.413
123.65	92.16	97.01	4.86	94.59	31.10	63.49	0.0651	0.413
123.68	92.18	97.04	4.86	94.61	31.12	63.49	0.0651	0.414

Table 1: Data of determined efficiency points

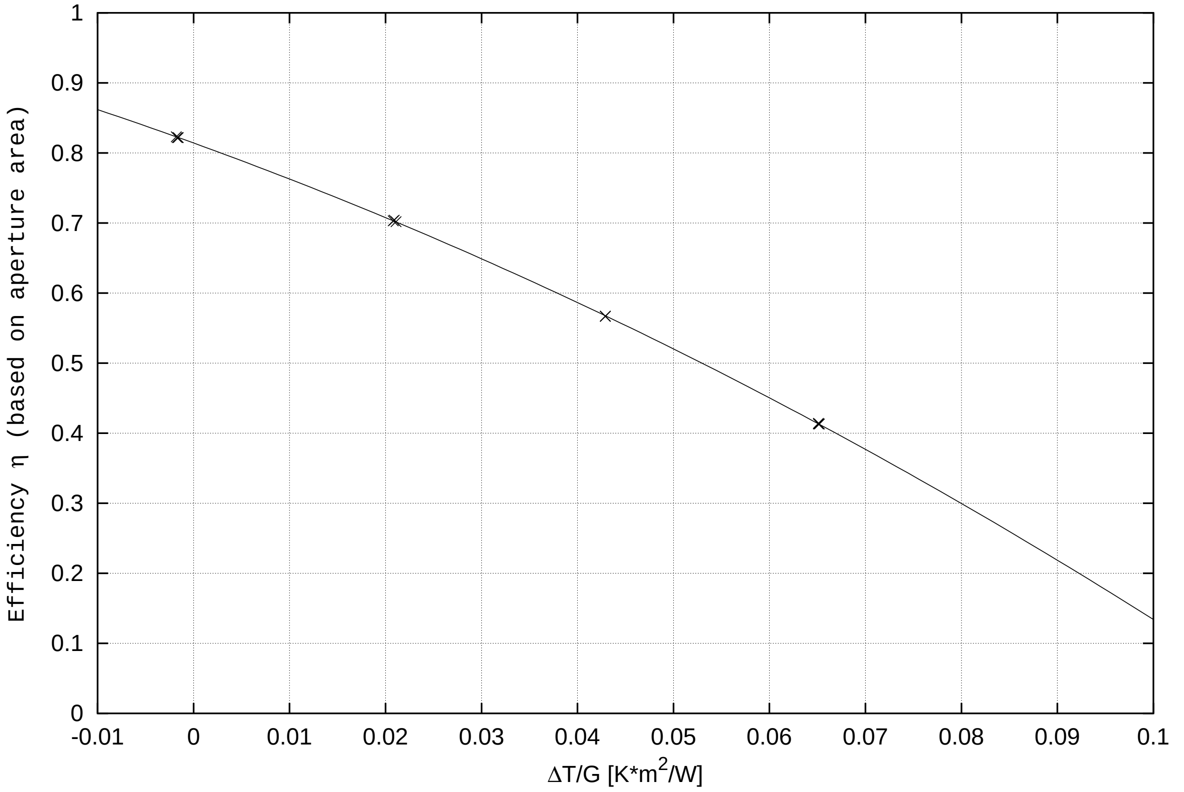

Figure 3: Efficiency curve with measurement points based on aperture area 1.740 m^2

Results:

based on aperture area (1.740 m^2):		based on absorber area (1.780 m^2):	
η_{0a}	= 0.814	η_{0A}	= 0.796
a_{1a}	= 4.954 W/m^2K	a_{1A}	= 4.843 W/m^2K
a_{2a}	= 0.0189 W/m^2K^2	a_{2A}	= 0.0185 W/m^2K^2

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

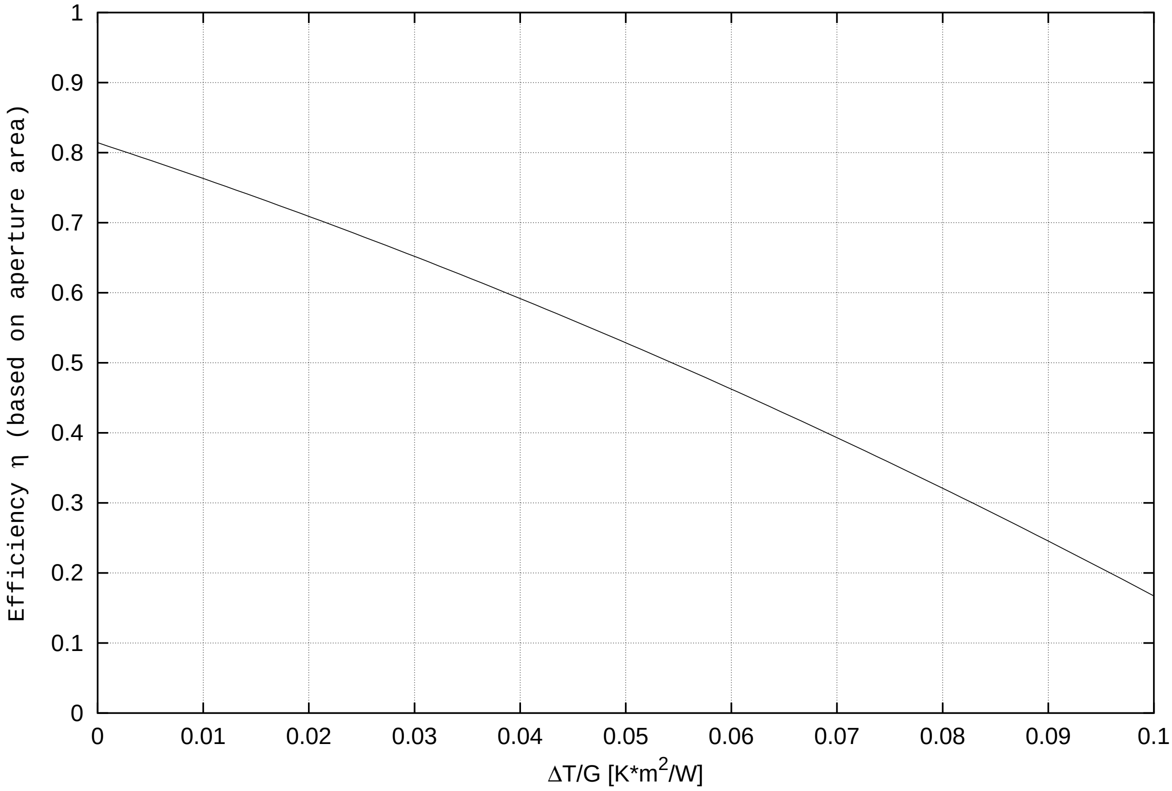

Figure 4: Efficiency curve scaled to 800 W/m^2 based on aperture area 1.740 m^2

based on aperture area:
$\eta_{0.05a}$ = 0.529

based on absorber area:
$\eta_{0.05A}$ = 0.517

$\eta_{0.05}$ is the efficiency of the collector for the follwing conditons (for example):
an irradiation of 800 W/m^2, an ambient temperature of 20°C and a mean collector temperture of 60°C. These are typical conditions for solar domestic hot water systems.

6 Incidence angle modifier IAM

The incidence angle modifier IAM was measured at the outdoor test facility (tracker) of Fraunhofer ISE.

Test method:	outdoor, steady state
Latitude:	48.0°
Longitude:	7.8°
Collector tilt:	tracked
Collector azimuth:	tracked

$IAM_{\theta=50°}$ = 0.938

Table 2 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 $(t_m - t_a)/G$ = 0. To accomplish this, the heat loss values of the collector a_{1a} = 4.954 W/m^{2}K and a_{2a} = 0.0189 W/m^{2}K^2 were used.

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]	$(t_m - t_a)/G$ [Km^2/W]	η_a [-]
0°										
924	0.134	120.5	20.53	29.77	9.24	25.15	24.08	1.07	0.00116	0.811
928	0.133	120.5	20.50	29.77	9.26	25.13	24.45	0.69	0.00074	0.806
924	0.134	120.6	20.52	29.77	9.25	25.14	24.42	0.72	0.00078	0.810
50°										
590	0.184	119.9	20.47	26.12	5.65	23.29	23.84	-0.55	-0.00094	0.762
585	0.182	120.0	20.47	26.05	5.58	23.26	23.73	-0.47	-0.00081	0.760
584	0.176	119.9	20.46	26.03	5.56	23.25	23.79	-0.54	-0.00092	0.758
590	0.172	119.9	20.48	26.06	5.58	23.27	23.37	-0.10	-0.00017	0.756

Table 2: Data of determined efficiency points for IAM

7 Pressure drop

The measurement of the pressure drop Δp was carried out with water as fluid until a flow rate of 73 kg/h. The inlet temperature of the water was 20°C.

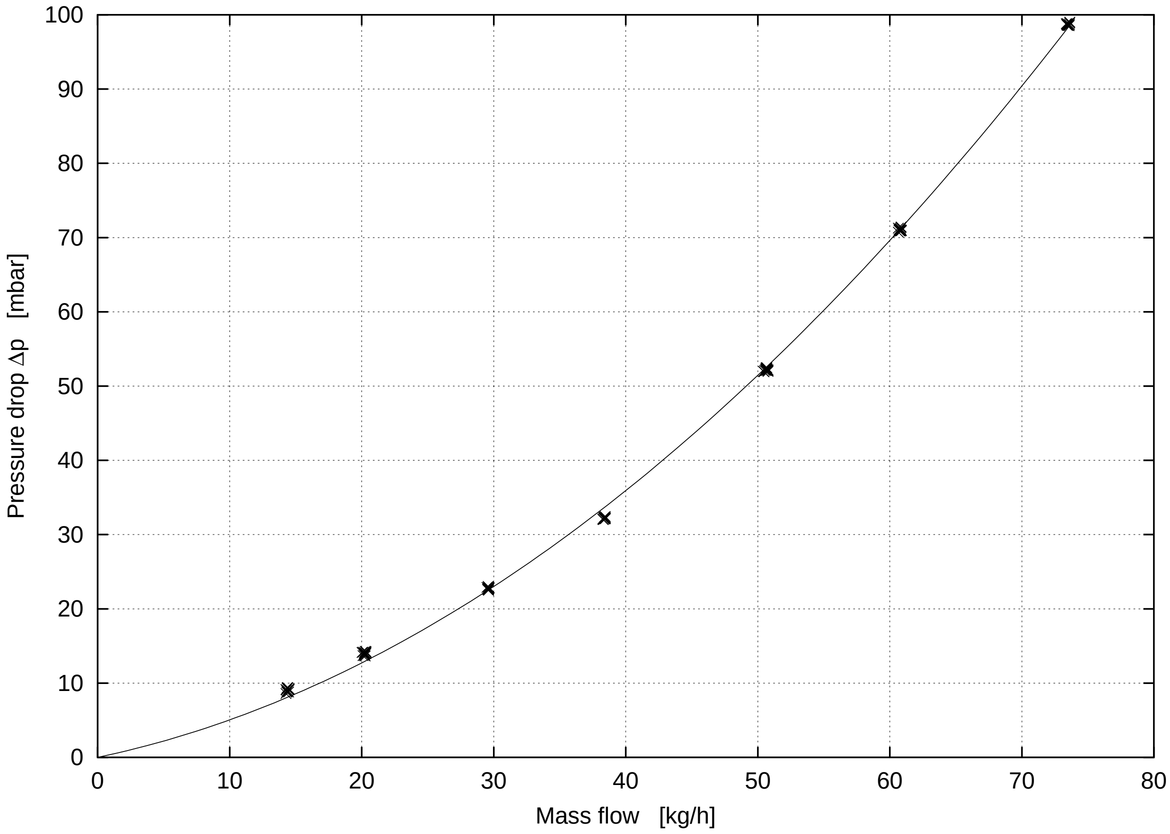

Figure 5: Measured pressure drop of the collector S-Class

The pressure drop in mbar can be approached to the follwing function of the mass flow x in kg/h:

$$\Delta p = 0.374 * x + 0.0131 * x^2$$

Example values from fitted curve:

Mass flow [kg/h]	Pressure drop Δp [mbar]
0	0.0
20	12.7
40	35.9
60	69.6
80	113.8
100	168.5
120	233.6
140	309.2
160	395.4
180	492.0
200	599.1

Table 3: Example values for Δp

8 Effective thermal capacity

The effective thermal capacity was determined out of the step response. Therefore the collector was shaded and a stepwise change to the full sun was proceeded. The calculation was done according to EN 12975-2, Annex J3:

19,29 kJ/K

The effective thermal capacity based on the aperture area 1.740 m^2 is:

11,09 kJ/K m^2

9 Internal pressure test

Maximum pressure specified by the manufacturer:	2000 kPa
Test temperature:	15,6 °C
Test pressure:	3000 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:	1014 W/m^2
Average surrounding air temperature:	24,0 °C
Average surrounding air speed:	< 0,5 m/s
Average absorber temperature:	164,7 °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. The following table shows all test days 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

Date	H [MJ/m^2]	*valid period* [h]	t_a [°C]	*rain* [mm]
20030424	25.6	3.4	16.2	0.0
20030425	23.0	2.6	18.7	0.0
20030426	4.2	0.0	15.2	82.5
20030427	14.8	0.6	13.9	0.0
20030428	22.9	2.8	19.0	0.0
20030429	10.7	0.4	16.6	3.4
20030430	2.2	0.0	14.1	15.1
20030501	24.6	3.3	14.8	0.1
20030502	12.4	0.2	14.5	0.6
20030503	28.1	5.0	14.6	0.3
20030504	28.2	4.5	18.8	0.0
20030505	15.7	1.4	20.7	0.0
20030506	19.0	0.9	20.2	0.0
20030507	23.6	3.2	18.1	0.0
20030508	20.2	2.1	20.3	27.4
20030509	21.8	3.9	16.9	4.0
20030510	15.5	1.2	14.9	0.0
20030511	15.3	1.0	15.4	0.0
20030512	26.7	3.8	17.8	5.8
20030513	8.0	0.0	11.8	7.2
20030514	18.4	2.5	9.2	1.8
20030515	27.2	4.1	11.3	0.0
20030516	27.1	4.0	14.1	0.0
20030517	7.3	0.0	14.5	0.8
20030518	10.3	0.2	16.8	1.5
20030519	9.3	0.9	17.5	8.6
20030520	15.1	1.0	12.4	2.8
20030521	8.5	0.4	11.0	4.9
20030522	3.9	0.0	12.7	3.3
20030523	26.9	4.0	19.9	0.0
20030524	22.4	2.2	20.5	2.3
20030525	2.7	0.0	12.9	1.0
20030526	4.5	0.0	13.5	0.0

Date	*H* [MJ/m^2]	*valid period* [h]	t_a [°C]	*rain* [mm]
20030527	6.2	0.0	16.5	0.0
20030528	15.4	0.3	18.8	0.0
20030529	17.1	1.6	20.0	0.0
20030530	22.1	2.5	22.4	0.0
20030531	20.0	1.4	23.5	0.0
20030601	26.7	3.1	24.0	0.0
20030602	19.3	1.7	23.7	0.0
20030603	27.3	3.7	24.2	0.0
20030604	24.3	3.4	25.0	2.7
20030605	21.5	1.4	24.6	0.0
20030606	15.7	0.4	22.6	0.0
20030607	23.0	2.2	24.7	0.0
20030608	24.5	2.5	25.4	0.0
20030609	25.9	3.3	22.9	0.0

Result:
The number of days when the daily global irradiance was more than 14 MJ/m^{2}d was 35 . 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 87 h.

The following table gives detailed information about the exposure test.

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

12 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:	1001 W/m^2	963 W/m^2
Average surrounding air temperature:	28,7 °C	31,0 °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:	24,0 °C	19,3 °C
Duration of water spray:	15 min	15 min
Absorber temperature immediately prior to water spray:	158 °C	164 °C

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

13 Internal thermal shock tests

Test conditions	1. Test	2. 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:	878 W/m^2	928 W/m^2
Average surrounding air temperature:	23,4 °C	28,1 °C
Period during which the required operating conditions were maintained prior to internal thermal shock:	1 h	1 h
Flowrate of heat transfer fluid:	0,03 l/m^2 s	0,03 l/m^2 s
Temperature of heat transfer fluid:	22,6 °C	18,3 °C
Duration of heat transfer fluid flow:	5 min	5 min
Absorber temperature immediately prior to heat transfer fluid flow:	154 °C	150 °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 Internal pressure test (retest)

Maximum pressure specified by the manufacturer:	2000 kPa
Test temperature:	24,5 °C
Test pressure:	3000 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.

16 Mechanical load test

16.1 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 100 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.

16.2 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 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 cover or at the cover fixings of the collector was observed.

16.3 Negative pressure test of mountings

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 collector mounting fixtures or fixing points was observed.

17 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:

$$t_{\text{s}} = t_{\text{as}} + \frac{G_{\text{s}}}{G_{\text{m}}} * (t_{\text{sm}} - t_{\text{am}}) \tag{2}$$

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	1002	23.6	164.2
2	998	24.5	165.3
3	937	27.7	164.9
4	963	28.4	168.4
5	948	29.5	169.8

The resulting stagnation temperature is:

170 °C

18 Final inspection

An overview of the result of the final inspection shows the following table.

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

19 Summary statement

The measurements were carried out from Abril to June 2003 .

No problems or distinctive observations occured during the measurements.

20 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. 2003-18-b-en

Freiburg, 17th July 2006
Fraunhofer-Institute for Solar Energy Systems ISE

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