Fraunhofer Institut
Solare Energiesysteme

Test Report: KTB Nr. 2003-28

Efficiency test according to EN 12975-2

for:
Kloben

Brand Name:
Kloben SP14 CPC Diffusion

Responsible for Testing:
Dipl.-Ing. A. Schäfer

Date:
6th October 2003

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Test facility certified by DIN CERTCO

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Fraunhofer Institut Solare Energiesysteme

1 Summary

This test report is also valid for the models Kloben SP 7 CPC Diffusion and Kloben SP 21 CPC Diffusion. The difference is in the total dimensions. The construction is the same like Kloben SP14 CPC Diffusion .

1.1 Boundary conditions for the efficiency curve

Test method:	outdoor, steady state
Latitude:	48.0°
Longitude:	7.8°
Collector tilt:	tracked between 40°and 50°
Collector azimuth:	tracked

Test conditions:

Mean irradiation :	974 W/m^2
Mean wind speed:	3 m/s
Mean flow rate:	156 kg/h
Kind of fluid:	water
Period:	September 2003

1.2 Collector parameters determined

The following parameters are based on the aperture area of 2.202 m^2:

η_{0a} = 0.632
a_{1a} = 0.936 W/m^{2}K
a_{2a} = 0.0076 W/m^{2}K^2

The following parameters are based on the absorber area of 0.751 m^2 (projected area, according to EN 12975:2001):

η_{0A} = 1.853
a_{1A} = 2.744 W/m^{2}K
a_{2A} = 0.0223 W/m^{2}K^2

The following parameters are based on the absorber area of 2.359 m^2 (total area):

η_{0A} = 0.590
a_{1A} = 0.874 W/m^{2}K
a_{2A} = 0.007 W/m^{2}K^2

1.3 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

transversal:	longitudinal:
$IAM_{\theta=20°}$ = 1.019	$IAM_{\theta=50°}$ = 0.957
$IAM_{\theta=40°}$ = 0.985	
$IAM_{\theta=60°}$ = 1.061	

1.4 Pressure drop

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

$$\Delta p = 0.0259 * x + 0.000305 * x^2$$

1.5 Effective thermal capacity

Effective thermal capacity:

87.8 kJ/K

The effective thermal capacity based on the aperture area 2.202 m^2:

39.9 kJ/K m^2

1.6 Summary statement

No problems or distinctive observations occured during the measurements.

2 Test Center

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3 Orderer

Kloben
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Via Rizzotti 1, 37064 Povegliano Veronese , Verona, Italy
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4 Description of the Collector

Manufacturer and Seller:	Kloben Via Rizzotti 1, 37064 Povegliano Veronese Verona, Italy Tel: +39 045 7971966 Fax: +39 045 7971866 E-mail: info@kloben.it

4.1 Collector

	(MS) = Manufacturer Specification
Type:	All-glass evacuated tubular collector with "U" copper pipes
Brand name:	Kloben SP14 CPC Diffusion
Serial no.:	SP 14 2003-01
Year of construction:	2003
Number of test collectors:	1
Collector reference no.:	2 KT 14 003 092003
Total area:	1.605 m * 1.580 m = 2.536 m^2
Aperture area:	1.430 m * 1.540 m = 2.202 m^2
Absorber area:	0.037m*pi*1.45*14 = 2.359 m^2 (Total area of coated inner absorber tube from 14 tubes) 0.037m*1.45m*14 = 0.751 m^2 (projected area of absorber tube (according to EN 12975:2001)
Material of the cover tube:	Borosilicate glass (MS)
Outer diameter of the cover tupe:	47 mm (MS)
Thickness of the cover tube:	1.7 mm (MS)
Outer diameter of the inner tupe	37 mm (MS)
Thickness of the inner tube:	1.7 mm (MS)
Distance between the tubes:	110 mm
Number of tubes:	14 (HA)
Weight empty:	45 kg
Volume of the fluid:	2.05 l (MS)
Heat transfer fluid:	Antifreezing liquid or water (MS)
Mirror construction:	Moulded Aluminium (MS)
Material of the mirror:	Bright finished Aluminium (MS)

4.2 Absorber

Material of the absorber:	Glass(MS)
Kind/Brand of selective coating:	Graded Al-N/Al selective surface (MS)
Absorptivity coefficient α:	> 90% (MS)
Emissivity coefficient ε:	< 8% (MS)
Material of the header pipe:	Copper (MS)
Outer diameter of the header pipe:	14 mm (MS)
Inner diameter of the header pipe:	12 mm(MS)
Function of the absorber:	Contact sheets to the inner glass tube, connected to U-pipes
Material of the contact sheets:	Aluminium
Thickness of the contact sheets:	0.3 mm
Material of the U-pipes:	Copper
Outer U-pipe diameter:	7 mm
Inner U-pipe diameter:	6 mm

4.3 Insulation and Casing

Collector dimensions Height, width, depth:	1.605 m; 1.580 m; 0.141 m
Medium between the inner and outer tubes of the vacuum flask:	High vacuum
Thickness of the insulation in the header:	27 mm
Material:	Mineral wool (MS)
Material of the casing:	Electro-colored Aluminium (MS)

4.4 Limitations

Maximum pressure:	600 kPa (MS)
Operating pressure:	300 kPa(MS)
Maximum temperature:	not measured
Flow range recommendation:	30 l/m^{2}h (MS)

4.5 Kind of mounting

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

4.6 Picture of the collector

Figure 1: Picture of the collector Kloben SP14 CPC Diffusion

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:	outdoor, steady state
Latitude:	48.0°
Longitude:	7.8°
Collector tilt:	tracked between 40°and 50°
Collector azimuth:	tracked

Test conditions:

Mean irradiation :	974 W/m^2
Mean wind speed:	3 m/s
Mean flow rate:	156 kg/h
Kind of fluid:	water
Period:	September 2003

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 [-]
990	0.11	155.1	19.16	26.82	7.66	22.99	22.76	0.23	0.0002	0.633
984	0.11	155.1	19.18	26.79	7.61	22.98	23.23	-0.25	-0.0003	0.633
979	0.11	155.2	19.21	26.77	7.56	22.99	23.45	-0.46	-0.0005	0.633
979	0.11	155.2	19.24	26.76	7.52	23.00	24.10	-1.10	-0.0011	0.629
1048	0.15	155.3	41.99	49.67	7.68	45.83	20.00	25.84	0.0246	0.600
971	0.13	155.0	41.99	49.20	7.21	45.60	19.85	25.74	0.0265	0.607
956	0.13	154.8	42.00	49.12	7.12	45.56	20.15	25.41	0.0266	0.608
946	0.13	155.0	42.01	49.05	7.04	45.53	20.12	25.40	0.0268	0.608
946	0.14	154.9	42.01	48.99	6.99	45.50	20.47	25.03	0.0264	0.603
959	0.11	156.6	66.77	73.33	6.56	70.05	24.04	46.02	0.0480	0.566
954	0.11	156.7	66.79	73.30	6.51	70.04	24.60	45.44	0.0476	0.564
942	0.11	156.6	66.82	73.30	6.47	70.06	24.58	45.48	0.0483	0.569
924	0.11	156.6	66.81	73.19	6.37	70.00	24.88	45.12	0.0488	0.571
917	0.11	156.3	66.82	73.13	6.31	69.98	24.10	45.87	0.0500	0.569
1017	0.12	155.9	91.92	98.35	6.43	95.13	19.99	75.15	0.0739	0.523
1022	0.11	156.1	91.98	98.44	6.47	95.21	21.11	74.10	0.0725	0.524
1025	0.11	156.1	91.97	98.46	6.49	95.21	21.60	73.61	0.0719	0.525

Table 1: Data of determined efficiency points

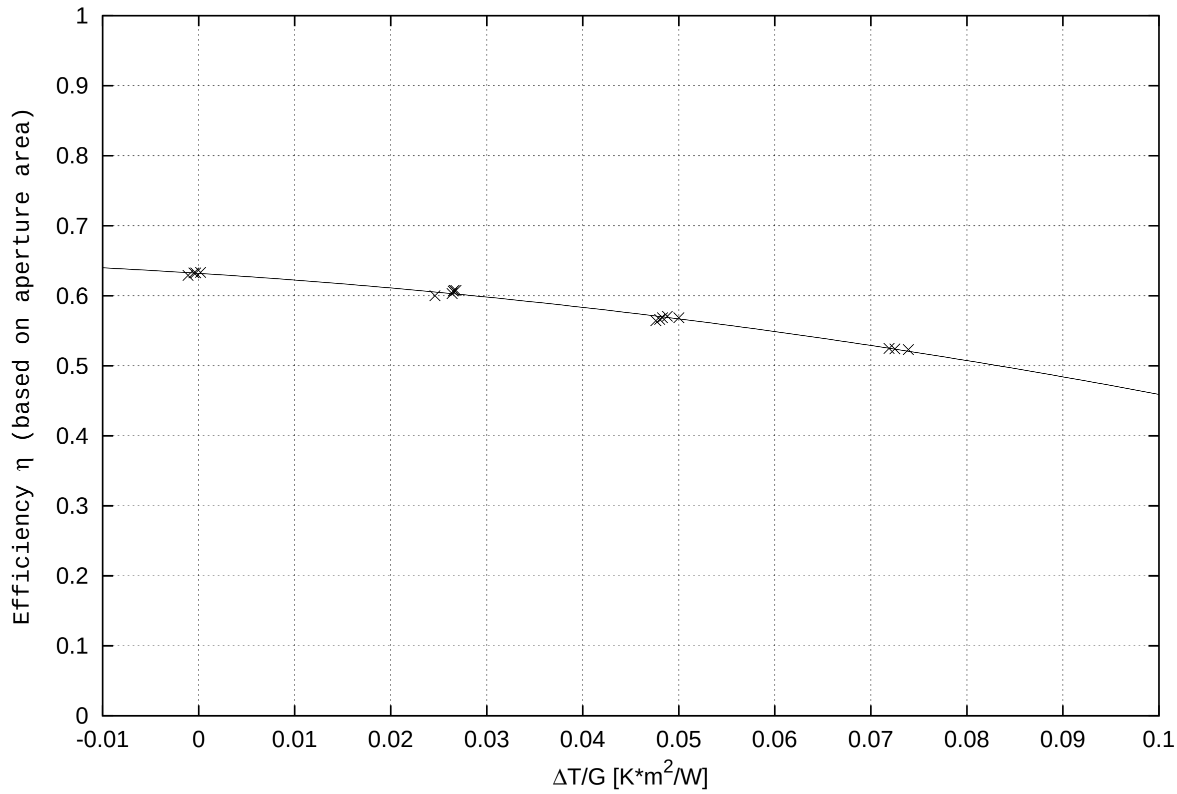

Figure 2: Efficiency curve with measurement points based on aperture area 2.202 m^2

Results:

based on aperture area (2.202 m^2):		based on absorber area (2.359 m^2):	
η_{0a}	= 0.632	η_{0A}	= 0.590
a_{1a}	= 0.936 W/m^2K	a_{1A}	= 0.874 W/m^2K
a_{2a}	= 0.0076 W/m^2K^2	a_{2A}	= 0.007 W/m^2K^2

5.4 Efficiency curve for the determined coefficients and for an assumed irradiation of 800 W/m² based on aperture area

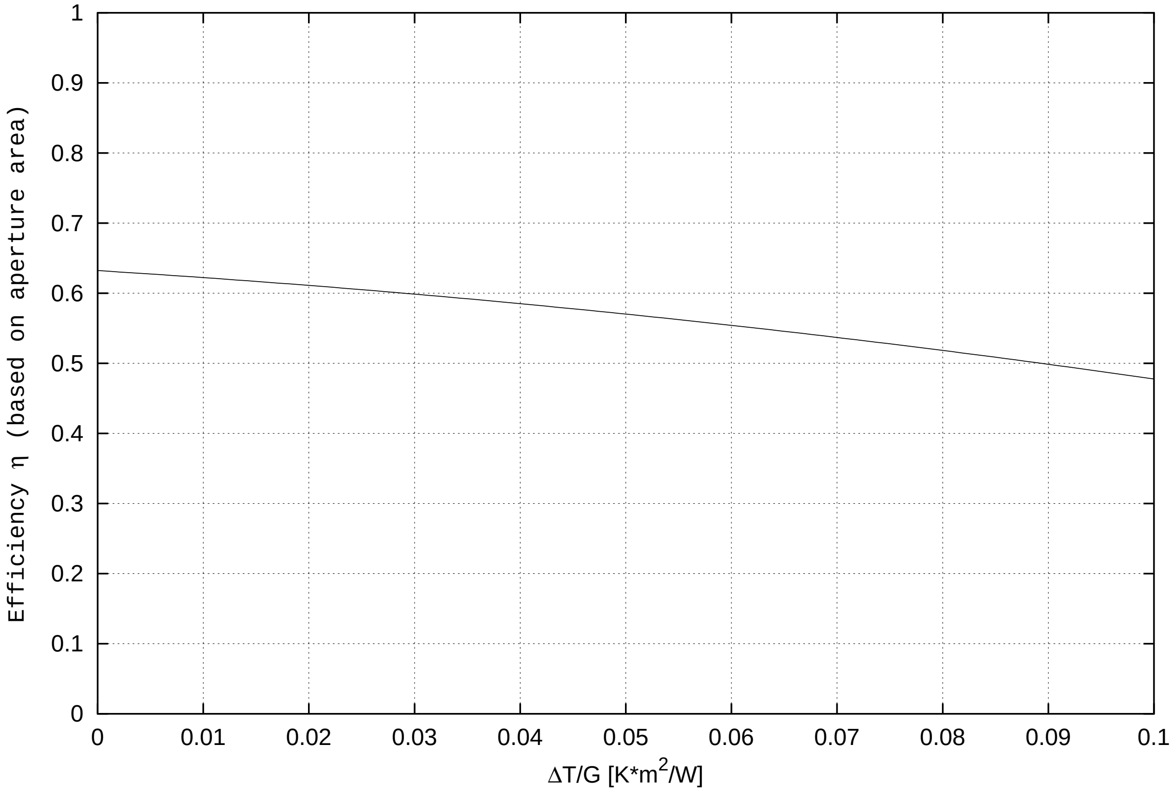

Figure 3: Efficiency curve scaled to 800 W/m² based on aperture area 2.202 m²

based on aperture area:	based on absorber area:
$\eta_{0.05a}$ = 0.570	$\eta_{0.05A}$ = 0.532

$\eta_{0.05}$ is the efficiency of the collector for the follwing conditons (for example):
an irradiation of 800 W/m², 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

The Incidence Angle Modifier IAM (transversal to the pipes) was measured for the angles:

$IAM_{\theta=0°}$ = 1 (per definition)
$IAM_{\theta=20°}$ = 1.019
$IAM_{\theta=40°}$ = 0.985
$IAM_{\theta=60°}$ = 1.061

The Incidence Angle Modifier IAM (longitudinal to the pipes) was measured for the angle:

$IAM_{\theta=50°}$ = 0.957

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} = 0.936 W/m^{2}K and a_{2a} = 0.0076 W/m^{2}K^2 were used.

G [W/m²]	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]	$(t_m - t_a)/G$ [Km²/W]	η_a [-]
0°										
990	0.11	155.1	19.16	26.82	7.66	22.99	22.76	0.23	0.0002	0.634
984	0.11	155.1	19.18	26.79	7.61	22.98	23.23	-0.25	-0.0003	0.632
979	0.11	155.2	19.21	26.77	7.56	22.99	23.45	-0.46	-0.0005	0.632
979	0.11	155.2	19.24	26.76	7.52	23.00	24.10	-1.10	-0.0011	0.628
20°	transv.									
970	0.09	159.5	20.09	27.48	7.39	23.78	20.37	3.42	0.0035	0.641
970	0.09	159.5	20.09	27.48	7.40	23.79	20.85	2.94	0.0030	0.641
970	0.09	159.5	20.10	27.48	7.38	23.79	20.99	2.80	0.0029	0.641
972	0.08	159.5	20.11	27.49	7.38	23.80	21.52	2.28	0.0023	0.639
40°	transv.									
759	0.11	159.4	20.12	25.73	5.61	22.93	22.07	0.86	0.0011	0.622
755	0.11	159.4	20.14	25.71	5.57	22.93	22.46	0.47	0.0006	0.620
753	0.11	159.4	20.15	25.70	5.55	22.93	22.49	0.43	0.0006	0.621
748	0.11	159.4	20.16	25.70	5.54	22.93	23.14	-0.21	-0.0003	0.622
60°	transv.									
345	0.15	158.9	19.19	21.99	2.81	20.59	23.29	-2.70	-0.0078	0.674
327	0.15	158.8	19.18	21.88	2.70	20.53	23.23	-2.70	-0.0083	0.685
458	0.17	153.5	14.12	17.80	3.68	15.96	16.26	-0.31	-0.0007	0.650
446	0.19	153.4	14.16	17.86	3.70	16.01	16.74	-0.73	-0.0016	0.671
50°	long.									
655	0.15	157.0	14.21	18.94	4.73	16.57	17.01	-0.43	-0.0007	0.600
536	0.13	158.7	19.24	23.16	3.92	21.20	23.36	-2.16	-0.0040	0.612
516	0.12	158.8	19.25	23.02	3.77	21.13	23.55	-2.42	-0.0047	0.612
509	0.12	158.7	19.27	22.96	3.69	21.11	23.82	-2.71	-0.0053	0.602

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 475 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. 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.

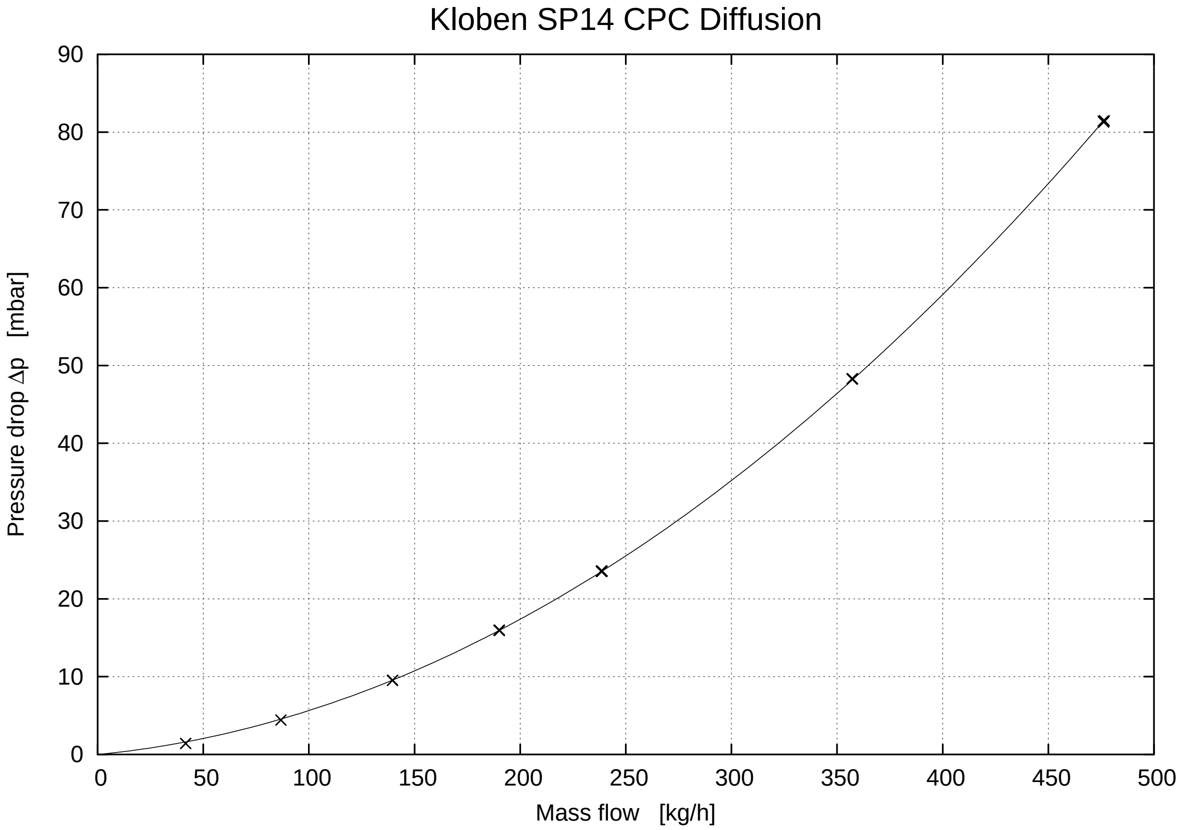

Figure 4: Measured pressure drop of the collector Kloben SP14 CPC Diffusion

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

$$\Delta p = 0.0259 * x + 0.000305 * x^2$$

Example values from fitted curve:

Mass flow [kg/h]	Pressure drop Δp [mbar]
0	0.0
50	2.1
100	5.6
150	10.7
200	17.4
250	25.5
300	35.2
350	46.4
400	59.1
450	73.4
500	89.2

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:

87.8 kJ/K

The effective thermal capacity based on the aperture area 2.202 m^2 is:

39.9 kJ/K m^2

9 Summary statement

The measurements were carried out in September 2003.

No problems or distinctive observations occured during the measurements.

Test report: KTB Nr. 2003-28

Freiburg, 6th October 2003
Fraunhofer-Institute for Solar Energy Systems ISE

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