

1 Summary

1.1 Preliminary remark to the efficiency measurement

The tests on SPA-58-1800-18-C have been passed according to EN 12975-1,2:2006. This report is also valid for the collectors SPA-58/1800-20-C, SPA-58/1800-24-C and SPA-58/1800-30-C. The constructive layout of this collectors is identically to the test collector. Only the number of tubes vary. As the collector is constructed without a reflector or another defined reflecting backside, the efficiency measurements were performed by using a tarpaulin with a defined emission coefficient of 83 %. This corresponds to the emission coefficients of common roof tile. All test results were taken from KTB 2006-12 from 15th of August 2006.

This report is a translation to english.

1.2 Boundary conditions for the collector efficiency parameter determination

Test method: outdoor, steady state
 Latitude: 48.0°
 Longitude: 7.8°
 Collector tilt: tracked between 40° and 50°
 Collector azimuth: tracked
 Mean irradiation: 986 W/m²
 Mean wind speed: 3 m/s
 Mean flow rate: 124 kg/h
 Kind of fluid: water
 Period: July 2006

1.3 Collector efficiency parameters determined

The calculated parameters rely on following areas:
 aperture area of 1.706 m²: absorber area of 1.451 m²:
 $\eta_{0a} = 0.573$ $\eta_{0A} = 0.674$
 $a_{1a} = 2.085 \text{ W/m}^2\text{K}$ $a_{1A} = 2.452 \text{ W/m}^2\text{K}$
 $a_{2a} = 0.0083 \text{ W/m}^2\text{K}^2$ $a_{2A} = 0.0098 \text{ W/m}^2\text{K}^2$

Power output per collector unit [W]:

| tm-ta [K] | 400 [W/m ²] | 700 [W/m ²] | 1000 [W/m ²] |
|-----------|-------------------------|-------------------------|--------------------------|
| 10 | 354 | 647 | 941 |
| 30 | 272 | 565 | 858 |
| 50 | 178 | 471 | 764 |

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

| Test method: | | outdoor | | | | | | | | | |
|--------------------|---------------|--------------|------|------|------|------|------|------|------|------|------|
| transversal: | | dynamic | | | | | | | | | |
| longitudinal: | | steady state | | | | | | | | | |
| Latitude: | | 48.0° | | | | | | | | | |
| Longitude: | | 7.8° | | | | | | | | | |
| Collector tilt: | | tracked | | | | | | | | | |
| Collector azimuth: | | tracked | | | | | | | | | |
| IAM at : | | 0° | 10° | 20° | 30° | 40° | 50° | 60° | 70° | 73° | 80° |
| 90° | transversal: | 1.00 | 1.00 | 1.02 | 1.10 | 1.22 | 1.37 | 1.42 | 1.27 | 1.42 | 0.93 |
| 0.05 | longitudinal: | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.96 | 0.91 | 0.79 | 0.94 | 0.53 |
| 0.00 | | | | | | | | | | | |

Table 1: Measured (bold) and calculated IAM data for SPA-58-1800-18-C

1.5 Effective thermal capacity of the collector

Effective thermal capacity: 25.90 kJ/K

The effective thermal capacity per square meter is: 15.18 kJ/K m²

1.6 Tests on efficiency

| Test | Date | Result |
|---------------------------------------|------------|--------|
| Date of delivery: | 04.05.2006 | |
| Determination of collector parameters | July 2006 | passed |
| Determination of IAM | July 2006 | passed |
| Effective thermal capacity calculated | performed | |

1.7 Summary statement

No problems or distinctive observations occurred during the measurements.

2 Test Center

Test Center for Thermal Solar Systems of Fraunhofer ISE

Heidenhofstrae 2, D-79110 Freiburg

Tel.: +49-761-4588-5354 or -5141; Fax.: +49-761-4588-9354

E-mail: arim.schaefer@ise.fraunhofer.de; rommel@ise.fraunhofer.de

Internet: <http://www.kollektortest.de>

3 Orderer, Expeller, Manufacturer

Orderer Sunpower Solar Water Heater Co., Ltd

69 South Airport Road Luoxi Town Changzhou

Tel: 0086 519 508 3 201

Fax: 0086 519 508 3 220

Expeller and Manufacturer: see orderer

4 Description of the Collector

4.1 Collector

| | |
|-----------------------------------|--|
| Type: | (MS) = Manufacturer Specification vacuum tube collector with heat |
| pipe conception | |
| Brand name: | SPA-58-1800-18-C |
| Serial no.: | 1-180-18-0001 |
| Year of production: | 2006 |
| Number of test collectors: | 1 |
| Collector reference no.: | 2 KT 54 002 052006 |
| Total area: | 2.100 m * 1.487 m = 3.123 m ² (total dimensions without fittings) |
| Aperture area: | 1.706 m ² (projected area of the inner diameter of the cover tube) |
| Absorber area: | 1.451 m ² (MS) (projected area of outer diameter of absorber tubes) |
| Material of the cover tube: | Borosilcat glas (MS) |
| Transmission of the cover tube: | n/a (MS) |
| Outer diameter of the cover tube: | 58 mm (MS) |
| Thickness of the cover tube: | 1.5 mm (MS) |
| Outer diameter of the inner tube: | 47 mm (MS) |
| Thickness of the inner tube: | 1.5 mm (MS) |
| Length of the tubes: | 1775 mm (MS) |
| Distance from tube to tube: | 80 mm (MS) |
| Number of tubes: | 18 (MS) |
| Weight empty: | 58 kg (MS) |
| Volume of the fluid: | 1.1 l (MS) |
| Heat transfer fluid: | antifreeze persistent to high temperatures (MS) |

4.2 Absorber

| | |
|-------------------------------------|---------------------------|
| Material of the absorber: | n/a (MS) |
| Kind/Brand of selective coating: | sputtered (MS) |
| Absorptivity coefficient α : | 93% (MS) |
| Emissivity coefficient ϵ : | > 6.5 % (MS) |
| Material of the absorber pipes: | copper (MS) |
| Layout of the absorber pipes: | parallel, heat pipes (MS) |
| Number of absorber pipes: | 18 (MS) |
| Outer diameter: | 8 mm (MS) |
| Inner diameter: | 6.8 mm (MS) |
| Distance between the pipes: | 80 mm (MS) |
| Material of the header pipe: | copper (MS) |
| Outer diameter of the header pipe: | 22 mm (MS) |
| Inner diameter of the header pipe: | 1 mm (MS) |
| Material of the contact sheets: | aluminium (MS) |

| | |
|---|-----------------------------|
| Thickness of the contact sheets: | 0.2 mm (MS) |
| 4.3 Insulation and Casing | |
| Collector dimensions | |
| Height, width, depth: | 2.100 m; 1.487 m; 1.560 m |
| Medium between the inner and outer tubes of the vacuum flask: | $= < 3 * 10^{-2}$ Pa (MS) |
| Material of the casing: | high-grade steel (MS) |
| Sealing material: | silicon (MS) |
| 4.4 Limitations | |
| Maximum pressure: | 800 kPa (MS) |
| Operating pressure: | 6 bar (MS) |
| Maximum service temperature: | 125°C |
| Maximum stagnation temperature: | 250°C |
| Flow range recommendation: | 1.1 l/m ² h (MS) |
| 4.5 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: | yes (MS) |

4.6 Picture and cut drawing of the collector



Figure 1: Picture of the collector SPA-58-1800-18-C mounted on the test facility of Fraunhofer ISE

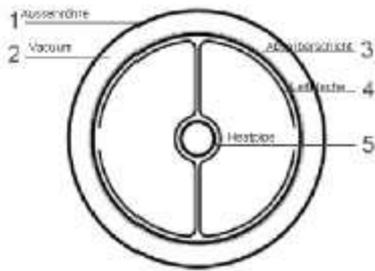


Figure 2: Cut drawing of the vacuum tube KTB Nr.

5 Collector efficiency parameters

5.1 Test method

Outdoor, steady state according to EN 12975-2:2006

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:

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

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

The coefficients η_0 , a_{1a} and 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} 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 Instantaneous efficiency parameters 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 : 986 W/m²
 Mean wind speed: 3 m/s
 Mean flow rate: 124 kg/h
 Kind of fluid: water

Results:

The calculated parameters rely on following areas:
 aperture area absorber area
 (1.706 m²): (1.451 m²):

aperture area
 (1.706 m²):

$$\eta_{0a} = 0.573$$

$$a_{1a} = 2.085 \text{ W/m}^2\text{K}$$

$$a_{2a} = 0.0083 \text{ W/m}^2\text{K}^2$$

absorber area
 (1.451 m²):

$$\eta_{0A} = 0.674$$

$$a_{1A} = 2.452 \text{ W/m}^2\text{K}$$

$$a_{2A} = 0.0098 \text{ W/m}^2\text{K}^2$$

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 ($\eta_{0a} = 0.573 \pm 0.02$). Based on our experience with the test facilities the uncertainty is much smaller and in a range of $\pm 1\%$ -point. The standard deviation of the heat loss parameters resulting from the regression fit curve through the measurements points is:

$$a_{1a} = 2.085 \pm 0.087 \text{ and}$$

$$a_{2a} = 0.0083 \pm 0.0012 .$$

a_{1a} absorber area - projected area of absorber tube,
 a_{2a} aperture area - projected area of inner diameter of cover tube

5.4 Power output per collector unit

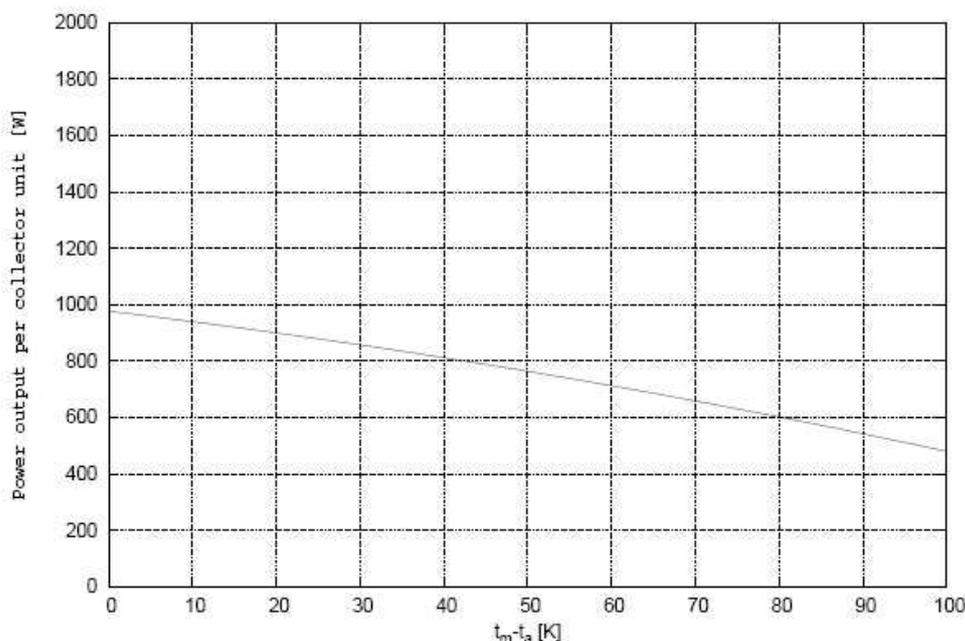


Figure 3: Power output per collector unit based on an irradiance of 1000 W/m²

Figure 3: Power output per collector unit based on an irradiance of 1000 W/m²

Power output per collector unit [W]:

| $t_m - t_a$ [K] | 400 [W/m ²] | 700 [W/m ²] | 1000 [W/m ²] |
|-----------------|-------------------------|-------------------------|--------------------------|
| 10 | 354 | 647 | 941 |
| 30 | 272 | 565 | 858 |
| 50 | 178 | 471 | 764 |

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

6 Incidence angle modifier IAM

The Incidence angle modifier IAM is a correction factor representing how the angle of radiation affects the performance of a collector. The IAM is described by a longitudinal and a transversal component.

IAM longitudinal:

The tilt angle of the collector in combination with the zenith angle of the sun results in the incident angle theta ($=\Theta$) in longitudinal direction.

IAM transversal:

The orientation angle of the collector in combination with the azimuth angle of the sun results in the incident angle theta ($=\Theta$) in transversal direction. 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 (transversal at the present collector means transversal to the ligament of the cover). 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
 transversal: dynamic
 longitudinal: steady state
 Latitude: 48.0°
 Longitude: 7.8°
 Collector tilt: tracked
 Collector azimuth: tracked

| | | | | | | | | | | | |
|---------------|------|------|------|------|------|------|------|------|------|------|------|
| IAM at : | 0° | 10° | 20° | 30° | 40° | 50° | 60° | 70° | 73° | 80° | 90° |
| transversal: | 1.00 | 1.00 | 1.02 | 1.10 | 1.22 | 1.37 | 1.42 | 1.27 | 1.42 | 0.93 | 0.05 |
| longitudinal: | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.96 | 0.91 | 0.79 | 0.94 | 0.53 | 0.00 |

Table 2: Measured (bold) and calculated IAM data for SPA-58-1800-18-C

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

$$K_{\theta} = 1 - \left[\tan \frac{\theta}{2} \right]^{\frac{1}{r}}$$

7 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: 25.90 kJ/K

The effective thermal capacity per square meter is: 15.18 kJ/K m²

8 Final inspection

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

| 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/ delamination/ wrapping/ 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

9 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

10 Summary statement

The measurements were carried out in July 2006.

No problems or distinctive observations occurred during the measurements.

11 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. 2006-12-a-en-k
 Freiburg, 17th August 2006
 Fraunhofer-Institute for Solar Energy Systems ISE



Dipl.-Phys. M. Rommel



Dipl.-Ing. (FH) A. Schäfer

Head of the Test Center for
Thermal Solar Systems

Responsible for testing