Fraunhofer Institut
Solare Energiesysteme

Test Report: KTB Nr. 2007-07-av-en

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

for:
LAM Import & Export Wärmetechnik , Germany

Brand name:
TZ 58/1800 series

Responsible for testing:
Dipl.-Ing. (FH) K. Kramer

Date:
3rd March 2009

Address:
Fraunhofer-Institute for Solar Energy Systems ISE
Heidenhofstraße 2, D-79110 Freiburg
Tel.: +49-761-4588-5354
Fax.: +49-761-4588-9000
E-mail: pzts@ise.fraunhofer.de
Internet: www.kollektortest.de

Accredited according to DIN EN ISO/IEC 17025:2005

Deutscher Akkreditierungs Rat DAR

DIN CERTCO Anerkanntes Prüflaboratorium

Registration No.:
DAP-PL-3926.00

Contents

Fraunhofer Institut Solare Energiesysteme

1 Summary

1.1 Preliminary remark

The tests have been performed according to EN 12975-1,2:2006. Main purpose for testing has been, to fulfill all requirements of the SolarKeymark Scheme rules (version 8.0, January 2003).
All requirements have been met.

The present report is valid for the TZ 58/1800 series including the collectors TZ58/1800-10R, TZ58/1800-12R, TZ58/1800-14R, TZ58/1800-15R, TZ58/1800-16R, TZ58/1800-18R, TZ58/1800-20R, TZ58/1800-24R, TZ58/1800-25R, TZ58/1800-28R and TZ 58/1800 30R of the company LAM Import & Export Wärmetechnik . The tests were performed at the largest and at the smallest collector of this series.

1.2 Collector efficiency parameters determined

Results:
The calculated parameters are based on following areas of the collector TZ 58/1800 10R . These parameters are valid for the complete series.

aperture area of 0.936 m^2:	absorber area of 0.808 m^2:
η_{0a} = 0.734	η_{0A} = 0.850
a_{1a} = 1.529 W/m^{2}K	a_{1A} = 1.771 W/m^{2}K
a_{2a} = 0.0166 W/m^{2}K^2	a_{2A} = 0.0192 W/m^{2}K^2

1.3 Incidence angle modifier - IAM

θ:	0°	10°	20°	30°	40°	50°	53°	60°	70°	80°	90°
$K_{\theta T}$:	**1.00**	1.00	**1.03**	1.11	**1.25**	1.37	1.40	**1.36**	1.11	0.70	0.05
$K_{\theta L}$:	**1.00**	1.00	1.00	0.99	0.96	**0.92**	0.88	0.84	0.69	0.44	0.00

Table 1: Measured **(bold)** and calculated IAM data for TZ 58/1800 10R

1.4 Effective thermal capacity of the collector

Effective thermal capacity (TZ 58/1800 10R):

14.6 kJ/K

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

15.6 kJ/K m^2

1.5 Schedule of tests and callculations

Test	Date	Result
Date of delivery:	October 26th 2006	
1st internal pressure	November 9th 2006	passed
High temperature resistance	March 3rd 2006	passed
Exposure	October 26th 2006 - 14th March 2007	passed
1st external thermal shock	November 15th 2006	passed
2nd external thermal shock	March 8th 2006	passed
1st internal thermal shock	November 7th 2006	passed
2nd internal thermal shock	February 15th 2007	passed
Rain penetration	November 15th 2006	passed
Freeze resistance		not relevant
Mechanical load		passed
Stagnation temperature		200.3 °C
Final inspection		passed
Determination of collector parameters	13th March 2006 - 15th March 2006	passed
Determination of IAM		passed
Effective thermal capacity		performed

1.6 Summary statement

No problems or distinctive observations occured during the measurements.

2 Test Center

Test Center for Thermal Solar Systems of Fraunhofer ISE
Heidenhofstraße 2, D-79110 Freiburg
Tel.: +49-761-4588-5139 or -5354
Fax.: +49-761-4588-9000
E-mail: pzts@ise.fraunhofer.de
Internet: http://www.kollektortest.de

3 Orderer, Expeller, Manufacturer

Expeller:	LAM Import & Export Wärmetechnik Mr. To Ha Lam Bahnhofstr. 15 31303 Burgdorf Germany
Manufacturer:	Jiangsu sunrain solar energy co. ltd Ning hai industrial Zone 222 243 Lianyungang Tel: +86-518-850 5188 9 Fax: +86-518-850 5180 8 E-mail: certification@sunrain.com
Orderer:	Jiangsu sunrain solar energy co. ltd

4 Overview of series TZ 58/1800 series collectors

According to the SolarKeymark Scheme rules (version 8.0, January 2003) there is an agreement concerning collectors, wich differ only in size, so called series or families. 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	number of tubes	length of tubes
TZ 58/1800 10R	yes	10	1.800 m (MS)
TZ58/1800- 12R	no	12 (MS)	1.800 m (MS)
TZ58/1800- 14R	no	14 (MS)	1.800 m (MS)
TZ58/1800- 15R	no	15 (MS)	1.800 m (MS)
TZ58/1800- 18R	no	18 (MS)	1.800 m (MS)
TZ58/1800- 20R	no	20 (MS)	1.800 m (MS)
TZ58/1800- 24R	no	24 (MS)	1.800 m (MS)
TZ58/1800- 25R	no	25 (MS)	1.800 m (MS)
TZ58/1800- 28R	no	28 (MS)	1.800 m (MS)
TZ 58/1800 30R	yes	30	1.800 m (MS)

4.1 Specific data of the largest collector of the series (TZ 58/1800 30R)

Brand name:	TZ 58/1800 30R
Serial no.:	
Year of production:	2006
Number of test collectors:	1
Collector reference no. (ISE):	2 KT 57 001 102006 (function tests)
Total area:	2.025 m * 2.420 m = 4.901 m^2
Collector depth:	0.189 m
Aperture area:	1.710 m x 0.0544 m x 30 tubes = 2.791 m^2
Absorber area:	1.710 m x 0.0470 m x 30 tubes = 2.411 m^2
Weight empty:	106 kg
Volume of the fluid:	2,3 l (MS)

4.2 Specific data of the smallest collector of the series (TZ 58/1800 10R)

Brand name:	TZ 58/1800 10R
Serial no.:	
Year of production:	2006
Number of test collectors:	1
Collector reference no.(ISE):	2 KT 57 003 102006
Total area:	2.008 m * 0.854 m = 1.715 m^2
Collector depth:	0.189 m
Aperture area:	1.720 m x 0.0544 m x 10 tubes = 0.936 m^2
Absorber area:	1.720 m x 0.0470 m x 10 tubes = 0.808 m^2
Weight empty:	39.6 kg
Volume of the fluid:	0,7 l (MS)

4.3 Specification of the tubes

(MS) = Manufacturer Specification

Type:	vacuum tube collector heat pipe, dry conection without mirror
Material of the cover tube:	borosilicate glass (MS)
Transmission of the cover tube:	$\geq$ 91 % (MS)
Outer diameter of the cover tube:	0.058 m (MS)
Thickness of the cover tube:	0.0018 m (MS)
Outer diameter of the inner tube	0.047 m (MS)
Thickness of the inner tube:	0.0016 m (MS)
Distance from tube to tube:	0.078 m (MS)

4.4 Absorber

Material of the absorber:	Cu/Al/SS/N_2 on borosilicate glass (MS)
Kind/Brand of selective coating:	ALN/SS-ALN/Cu (MS)
Absorptivity coefficient α:	$\geq$ 94 % (MS)
Emissivity coefficient ε:	$\leq$ 7 % (MS)
Material of the absorber pipes:	copper (MS)
Layout of the absorber pipes:	heat pipe, dry conection (MS)
Outer diameter:	0.008 m (MS)
Inner diameter:	0.0068 m (MS)
Material of the header pipe:	copper (MS)
Outer diameter of the header pipe:	0.038 m (MS)
Inner diameter of the header pipe:	0.034 m (MS)
Material of the contact sheets:	aluminium (MS)
Thickness of the contact sheets:	0.0002 m (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:	0.040 m (MS)
Material:	polyurethane, mineral wool (MS)
Material of the casing:	aluminium (MS)
Sealing material:	silicon rubber (MS)

4.6 Limitations

Maximum fluid pressure:	1000 kPa (MS)
Operating fluid pressure:	600 kPa (MS)
Maximum service temperature:	95 °C (MS)
Maximum stagnation temperature:	200.3 °C
Maximum wind load:	not spezified
Recommended tilt angle:	15 °- 75 °(MS)
Flow range recommendation:	50 -150 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:	yes (MS)
Free mounting:	no (MS)
Fassade:	yes (MS)

4.8 Picture and cut drawing of the collector

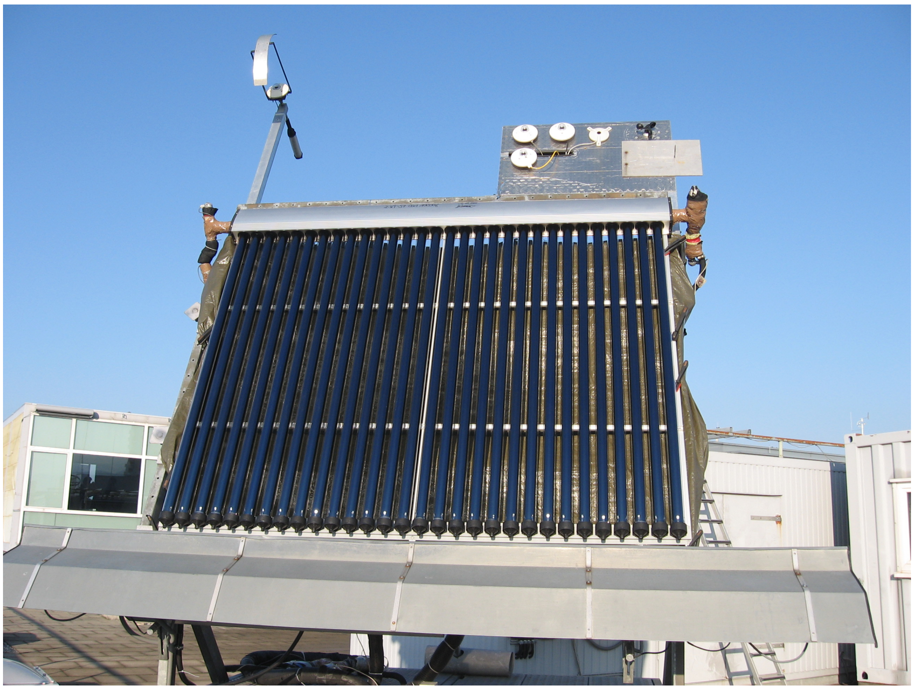

Figure 1: Picture of the collector TZ 58/1800 30R mounted on the test facility of Fraunhofer ISE

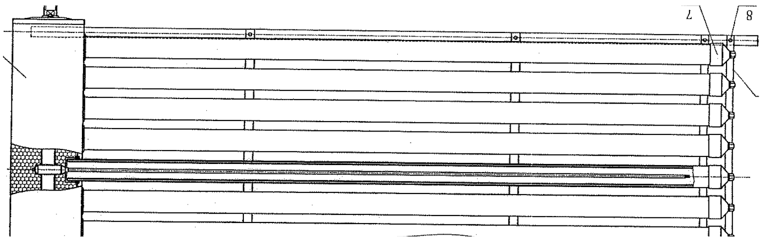

Figure 2: Cut drawing of the collector TZ 58/1800 10R

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:

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

(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 (°C)
t_e = collector outlet temperture (°C)
t_a = ambient temperature (°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:

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

5.3 Efficiency parameters

Boundary conditions:

As the collector is constructed without a reflector or another defined reflecting backside, the effincy messurements were performed by using a tarpaulin with a defined absorption coefficient of 83 %. This corresponds to typical absorption coefficients of common rooftile.

Test method:	outdoor, steady state
Latitude:	48.0°
Longitude:	7.8°
Collector tilt:	tracked between 35°and 55°
Collector azimuth:	tracked
Mean irradiation :	936 W/m^2
Mean wind speed:	3 m/s
Mean flow rate:	66 kg/h
Kind of fluid:	water
date of the Measurement	February 2007

Results:
The calculated parameters are based on following areas of the collector TZ 58/1800 10R . These values are also valid for the complete series.[1]:

aperture area of 0.936 m^2:	absorber area of 0.808 m^2:
η_{0a} = 0.734	η_{0A} = 0.850
a_{1a} = 1.529 W/m^{2}K	a_{1A} = 1.771 W/m^{2}K
a_{2a} = 0.0166 W/m^{2}K^2	a_{2A} = 0.0192 W/m^{2}K^2

The determination of the standard deviation was performed according to ENV 13025:1999 (GUM). Based on this calculation method the standard uncer- tainty of measured efficiency values results to 0.02. This uncertainty is an ex- panded measurement uncertainty. It is calculated using the standard uncertainty of 0.01 multiplied with the expansion factor of k=2. This results in a confidence range of about 95%. (EAL-G23, 08/96 Rev01)

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

[1] absorber area - projected area of absorber tube,
aperture area - projected area of inner diameter of cover tube

5.4 Power output per collector unit

The power output per collector unit will be documented for the largest collector of the series TZ 58/1800 30R with the highest output per collector unit and for the smallest collector of the series TZ 58/1800 10R with the lowest output per collector unit.

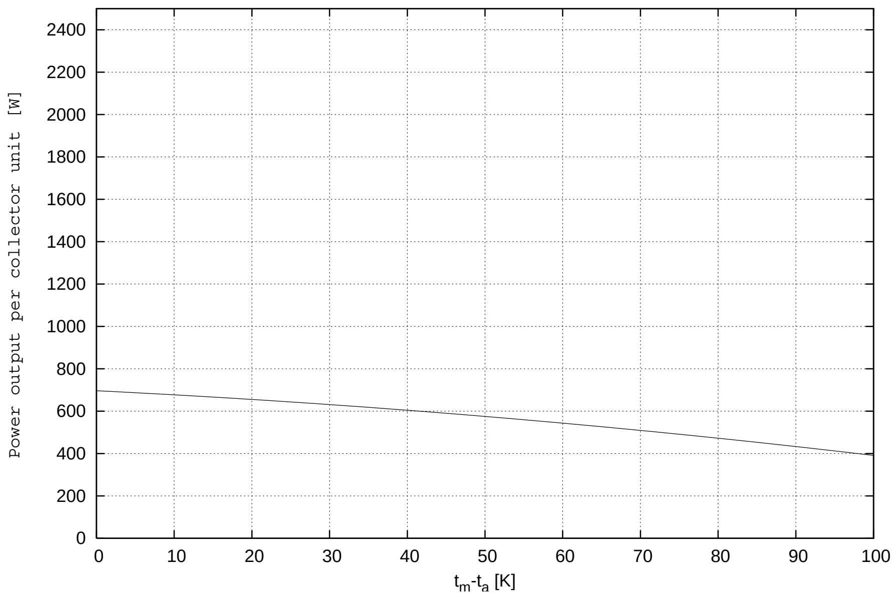

Figure 3: Power output for collector TZ 58/1800 10R based on 1000 W/m^2

Power output per collector unit [W] for collector TZ 58/1800 10R (aperture area of 0.936 m^2):

$t_m - t_a$ [K]	400 [W/m^2]	700 [W/m^2]	1000 [W/m^2]
10	259	465	671
30	218	424	630
50	164	371	577

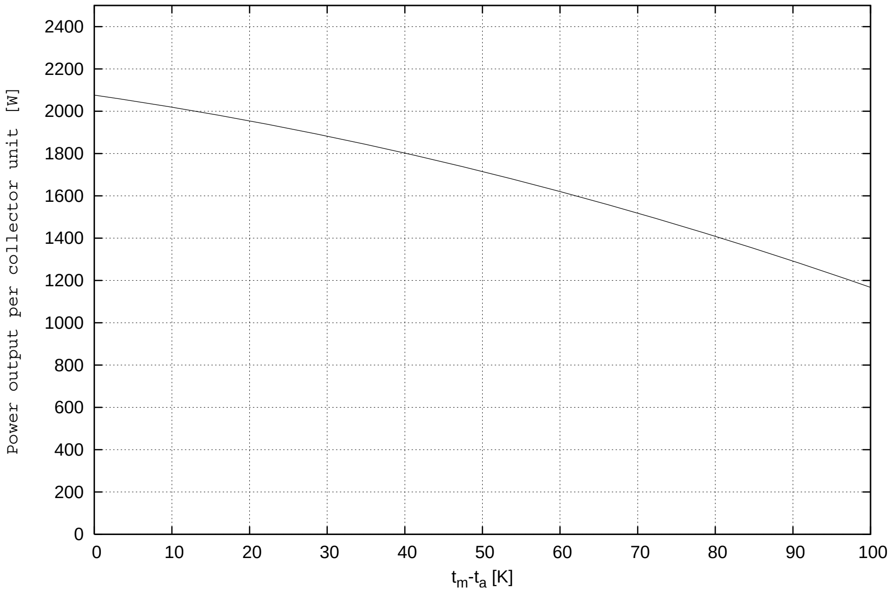

Figure 4: Power output for collector TZ 58/1800 30R based on 1000 W/m^2

Power output per collector unit [W] for collector TZ 58/1800 30R (aperture area of 2.791 m^2):

$t_m - t_a$ [K]	400 [W/m^2]	700 [W/m^2]	1000 [W/m^2]
10	772	1387	2001
30	650	1264	1879
50	490	1105	1719

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 TZ 58/1800 10R , (values see table)
A_a	= Aperture area of a different collector of the series
$A_{a,ref}$	= Aperture area of collector TZ 58/1800 10R = 0.936 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 vacuum tube collectors and collectors with CPC reflectors), it is necessary to meassure 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 meassured incidence angle modifiers $K_{\theta L}$ and $K_{\theta T}$ of two orthogonal planes (equation 2).

$$K_\theta = K_{\theta L} x K_{\theta T} \tag{2}$$

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

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

θ:	0°	10°	20°	30°	40°	50°	53°	60°	70°	80°	90°
$K_{\theta T}$:	**1.00**	1.00	**1.03**	1.11	**1.25**	1.37	1.40	**1.36**	1.11	0.70	0.05
$K_{\theta L}$:	**1.00**	1.00	1.00	0.99	0.96	**0.92**	0.88	0.84	0.69	0.44	0.00

Table 2: Measured **(bold)** and calculated IAM data for TZ 58/1800 10R

The angles for the transversal IAM in table 2 were calculated according to Ambrosetti [1] (equation 3).

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

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

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 12975-2:2006. For the heat transfer fluid a mixture 2/1 of water/propylenglycol at a temperature of 50°C has been chosen.

Effective thermal capacity (TZ 58/1800 10R):

14.6 kJ/K

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

15.6 kJ/K m^2

8 Internal pressure test

Maximum pressure:	1000 kPa (MS)
Test temperature:	12.3 °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.

9 High temperature resistance test

Method:	Indoor testing
Collector tilt angle:	45°
Average irradiance during test:	1011 W/m^2
Average surrounding air temperature:	25.3 °C
Average surrounding air speed:	< 0.5 m/s
Average absorber temperature:	197,5 °C
Duration of test:	1 h

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

10 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/m^{2}d was 41 . 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 41.7 h.

The evaluation of the exposure test is described in the chapter 17 "Final inspection".

11 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:	850 W/m^2	860 W/m^2
Average surrounding air temperature:	17.8 °C	12.6°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:	16.6 °C	16.0 °C
Duration of water spray:	15 min	15 min
Absorber temperature immediately prior to water spray:	162.0 °C	159.1°C

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

12 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:	884 W/m^2	957 W/m^2
Average surrounding air temperature:	9.8 °C	10.4 °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:	16.6 °C	16.4 °C
Duration of heat transfer fluid flow:	5 min	5 min
Absorber temperature immediately prior to heat transfer fluid flow:	160.0 °C	180.2 °C

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

13 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.

14 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.

15 Mechanical load test

15.1 Positive pressure test of the collector cover

This test was not performed by means of implementing pressure. The collector was visualy observed and the structur was checked from a technical point of view.

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

This test was not performed by means of implementing pressure. The collector was visualy observed and the structur was checked from a technical point of view.

15.3 Negative pressure test of mountings

The mechanical load test is not reasonable for this collector because of the vacuum tube type without reflector.

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/m^2 and an ambient temperatur of 30 °C. The calculation is as follows:

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

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

Irradiance	Surrounding air temperature	Absorber temperature
[W/m^2]	[°C]	[°C]
1008	13.1	182.8
994	13.5	181.7
967	13.8	179.2
948	13.8	174.7
988	12.4	183.3

The resulting stagnation temperature is:

200.3 °C

17 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

18 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
  (not for mounting integrated in tilted roof or fassade mounting, no pressure lost)
- List of used materials

19 Summary statement

The measurements were carried out from
October 2006 until February 2007 .

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. 2007-07-av-en

Freiburg, 3rd March 2009
Fraunhofer-Institute for Solar Energy Systems ISE

Dipl.-Phys. M. Rommel Head of the Test Center for Thermal Solar Systems	Dipl.-Ing. (FH) K. Kramer Responsible for testing and report

A Drawing of absorber layout

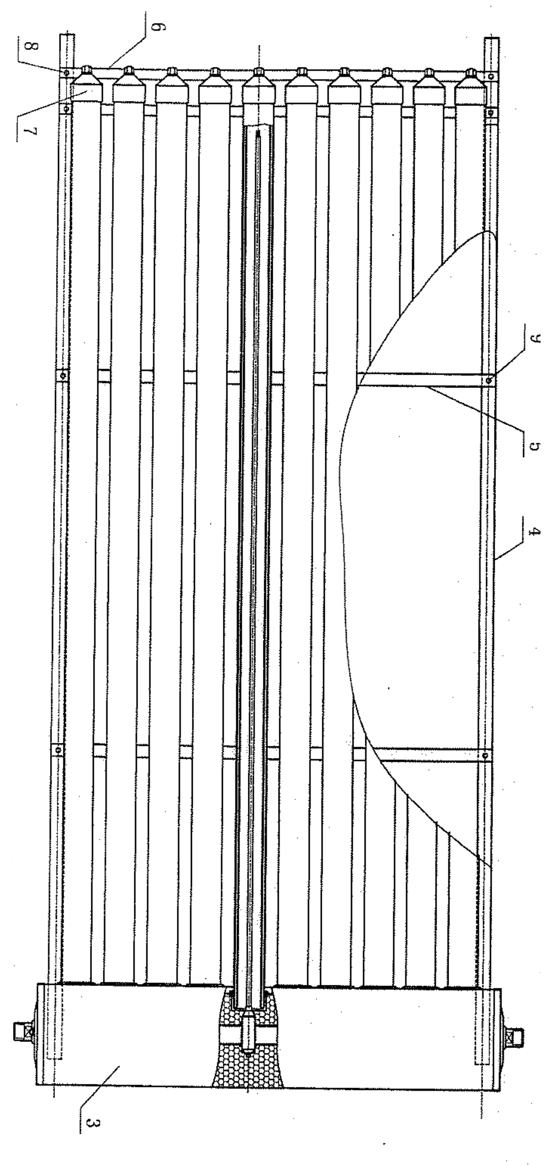

Figure 5: Drawing of absorber layout TZ 58/1800 10R

B Efficiency curve

B.1 Efficiency curve with measurement points based on aperture area 0.936 m^2

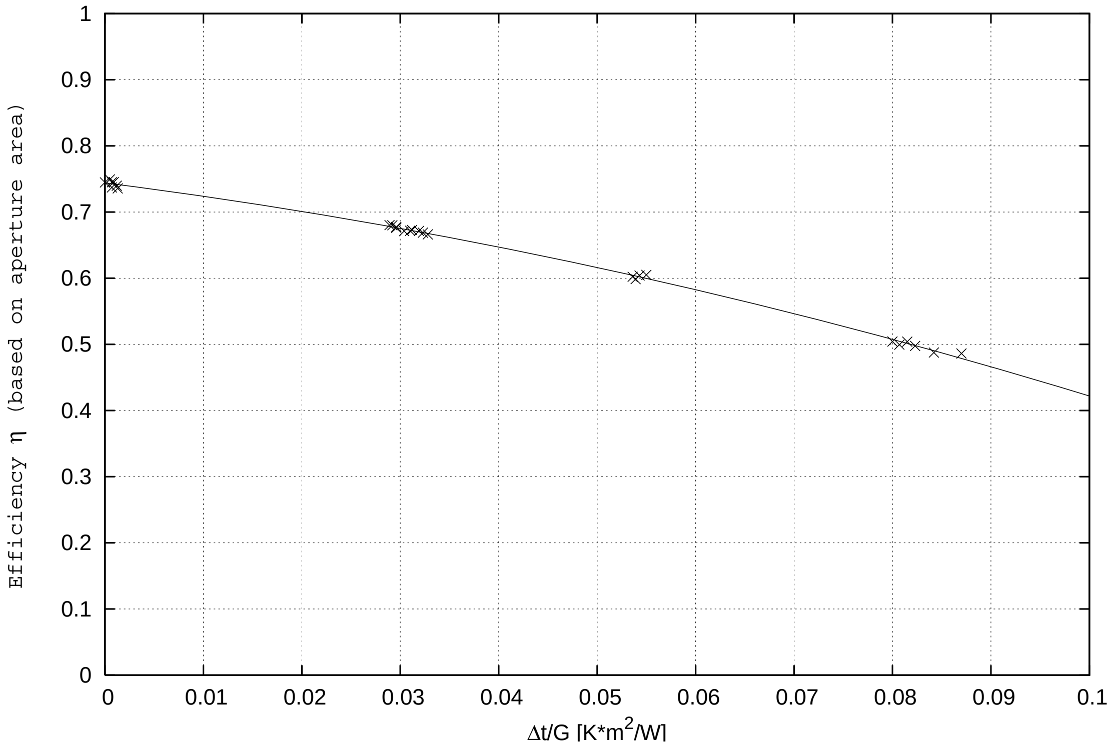

Figure 6: Efficiency curve with measurement points based on aperture area 0.936 m^2

Results:

The calculated parameters are based on following areas:

aperture area of 0.936 m^2:	absorber area of 0.808 m^2:
η_{0a} = 0.734	η_{0A} = 0.850
a_{1a} = 1.529 W/m^2K	a_{1A} = 1.771 W/m^2K
a_{2a} = 0.0166 W/m^2K^2	a_{2A} = 0.0192 W/m^2K^2

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

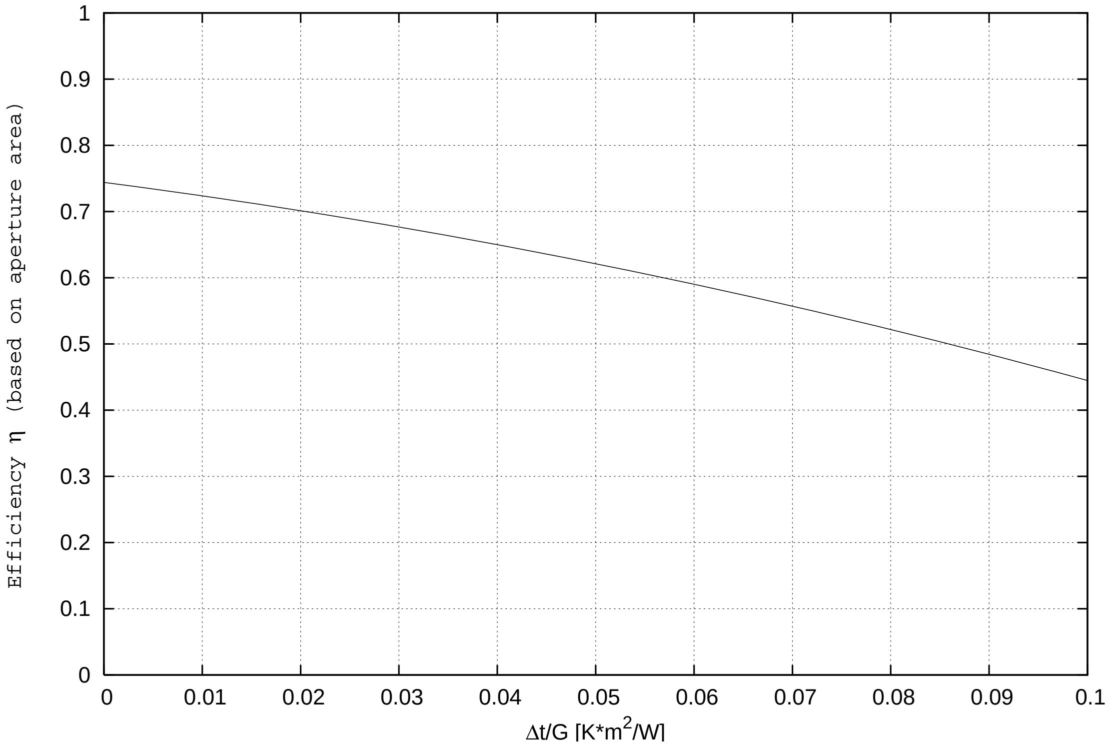

Figure 7: Efficiency curve scaled to 800 W/m^2 based on aperture area 0.936 m^2

The calculated parameters are based on following areas:

aperture area:	absorber area:
$\eta_{0.05a}$ = 0.624	$\eta_{0.05A}$ = 0.723

$\eta_{0.05}$ 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.

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 [-]
980	0.14	67.7	6.79	15.38	8.60	11.08	9.88	1.21	0.0012	0.740
992	0.13	67.7	6.81	15.46	8.65	11.14	9.88	1.26	0.0013	0.736
969	0.11	67.7	6.84	15.39	8.55	11.12	11.14	-0.02	-0.0000	0.745
937	0.09	67.8	7.78	16.05	8.27	11.91	11.05	0.86	0.0009	0.745
944	0.08	67.8	7.82	16.06	8.24	11.94	11.27	0.67	0.0007	0.737
852	0.17	60.8	6.76	15.14	8.38	10.95	10.39	0.56	0.0007	0.745
843	0.16	60.9	6.78	15.11	8.33	10.95	10.50	0.44	0.0005	0.749
892	0.12	66.1	33.03	40.28	7.25	36.66	7.43	29.23	0.0328	0.666
898	0.12	66.0	33.08	40.42	7.34	36.75	7.75	29.00	0.0323	0.669
905	0.12	66.1	33.10	40.52	7.42	36.81	7.97	28.84	0.0319	0.671
909	0.12	66.0	33.13	40.61	7.48	36.87	8.46	28.41	0.0312	0.673
916	0.12	65.8	33.15	40.69	7.54	36.92	8.56	28.36	0.0310	0.672
923	0.12	65.8	33.18	40.77	7.59	36.97	8.96	28.01	0.0304	0.671
921	0.12	65.9	33.26	40.87	7.61	37.07	9.85	27.21	0.0296	0.676
921	0.12	65.8	33.31	40.96	7.64	37.14	9.89	27.25	0.0296	0.678
919	0.12	65.9	33.36	41.00	7.64	37.18	10.33	26.85	0.0292	0.680
922	0.13	65.9	33.38	41.06	7.67	37.22	10.59	26.63	0.0289	0.680
967	0.09	66.6	60.04	67.08	7.04	63.56	11.76	51.80	0.0536	0.602
960	0.09	66.2	60.06	67.04	6.99	63.55	11.79	51.76	0.0539	0.599
944	0.09	66.3	60.04	66.97	6.93	63.50	11.58	51.92	0.0550	0.605
914	0.10	67.3	60.10	66.71	6.61	63.40	13.83	49.57	0.0543	0.604
931	0.10	65.7	85.10	90.63	5.53	87.87	6.87	80.99	0.0870	0.486
957	0.09	65.7	85.21	90.90	5.69	88.05	7.48	80.57	0.0842	0.488
980	0.08	65.6	85.47	91.43	5.97	88.45	7.81	80.64	0.0823	0.498
985	0.08	65.4	85.50	91.59	6.09	88.54	8.33	80.21	0.0815	0.504
987	0.08	64.9	85.57	91.66	6.09	88.61	8.92	79.69	0.0807	0.499
991	0.08	65.2	85.50	91.65	6.15	88.58	9.31	79.27	0.0800	0.504

Table 3: 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 °C
t_a:	surrounding air temperature
rain:	daily rain [mm]

Date	H [MJ/m^2]	*valid period* [h]	t_a [°C]	*rain* [mm]
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
20061114	2.1	0.0	12.9	0
20061115	17.8	0.0	14.1	0
20061116	16.1	0.2	13.2	1
20061117	1.8	0.0	13.8	0
20061118	16.1	0.4	12.1	0
20061119	3.1	0.0	9.6	10
20061120	13.3	0.2	7.7	3
20061121	2.5	0.0	10.1	11
20061122	7.9	0.0	5.8	0
20061123	2.8	0.0	12.3	1
20061124	6.8	0.1	14.1	0
20061125	4.8	0.0	14.4	0
20061126	7.0	0.0	11.9	0
20061127	7.2	0.0	11.0	0
20061128	14.4	0.0	8.4	3
20061129	1.2	0.0	8.9	4
20061130	1.3	0.0	6.9	0

Continuation, see next page:

Date	*H* [MJ/m^2]	*valid period* [h]	t_a [°C]	*rain* [mm]
20061201	14.8	0.0	7.0	0
20061202	9.0	0.1	7.8	0
20061203	8.2	0.0	13.7	0
20061204	3.5	0.0	11.6	4
20061205	4.1	0.1	15.3	12
20061206	0.9	0.0	9.9	4
20061207	11.5	0.1	8.6	1
20061208	1.3	0.0	9.2	20
20061209	1.3	0.0	6.2	6
20061210	7.3	0.0	4.9	0
20061211	1.7	0.0	4.4	3
20061212	1.5	0.0	7.2	0
20061213	15.4	0.0	6.2	0
20061214	14.9	0.0	3.9	0
20061215	16.1	0.0	5.5	0
20061216	6.2	0.0	10.4	0
20061217	1.8	0.0	5.8	4
20061218	9.2	0.0	2.3	not spezified
20061219	13.9	0.0	3.1	not spezified
20061220	15.5	0.0	2.1	not spezified
20061221	15.7	0.0	2.0	not spezified
20061222	14.4	0.0	2.0	not spezified
20061223	0.9	0.0	-1.3	not spezified
20061224	1.0	0.0	0.1	not spezified
20061225	0.6	0.0	-0.9	not spezified
20061226	1.1	0.0	-0.9	not spezified
20061227	9.4	0.0	-1.7	not spezified
20061228	11.0	0.0	-1.5	not spezified
20061229	12.3	0.0	1.4	not spezified
20061230	5.0	0.0	5.8	not spezified
20061231	9.3	0.0	12.0	not spezified
20070101	1.6	0.0	10.9	not spezified
20070102	2.0	0.0	4.7	not spezified
20070103	3.7	0.0	5.5	not spezified
20070104	1.0	0.0	7.4	not spezified
20070105	1.1	0.0	7.5	not spezified
20070106	1.7	0.0	10.1	not spezified
20070107	2.5	0.0	9.8	not spezified
20070108	1.0	0.0	10.8	not spezified
20070109	1.5	0.0	12.6	not spezified
20070110	13.4	0.0	13.5	not spezified

Continuation, see next page:

Date	H [MJ/m^2]	*valid period* [h]	t_a [°C]	*rain* [mm]
20070111	5.6	0.0	10.3	not spezified
20070112	4.1	0.0	9.3	not spezified
20070113	17.0	0.1	10.7	not spezified
20070114	4.3	0.1	9.1	not spezified
20070115	2.4	0.0	2.2	not spezified
20070116	3.0	0.0	6.2	not spezified
20070117	1.8	0.0	11.0	not spezified
20070118	0.3	0.0	13.1	not spezified
20070119	1.5	0.0	12.8	not spezified
20070120	7.6	0.2	12.7	not spezified
20070121	9.6	0.1	8.9	not spezified
20070122	2.1	0.0	4.6	not spezified
20070123	0.8	0.0	0.4	not spezified
20070124	1.7	0.0	-4.4	not spezified
20070125	3.6	0.0	-5.3	not spezified
20070126	19.2	0.0	-4.1	not spezified
20070127	2.0	0.0	-0.6	not spezified
20070128	16.5	0.0	2.9	not spezified
20070129	2.1	0.0	4.3	not spezified
20070130	18.1	0.0	3.5	not spezified
20070131	3.0	0.0	2.0	not spezified
20070201	4.0	0.0	3.6	0
20070202	18.0	0.0	4.7	0
20070203	19.5	0.0	6.3	0
20070204	21.0	0.7	5.0	1
20070205	6.5	0.0	5.9	5
20070206	0.8	0.0	3.6	1
20070207	1.6	0.0	5.0	4
20070208	2.5	0.0	7.5	6
20070209	18.9	1.7	8.0	3
20070210	2.3	0.0	7.7	3
20070211	5.0	0.7	8.8	3
20070212	1.6	0.0	9.3	5
20070213	2.9	0.0	7.2	0
20070214	1.5	0.0	5.5	12
20070215	16.5	1.6	8.3	0
20070216	20.6	1.7	5.3	0
20070217	11.2	0.0	4.9	0

Continuation, see next page:

Date	*H* [MJ/m^2]	*valid period* [h]	t_a [°C]	*rain* [mm]
20070218	19.4	1.6	6.4	0
20070219	14.9	0.0	5.5	0
20070220	13.0	0.0	3.1	0
20070221	21.1	2.6	7.3	0
20070222	18.6	0.4	11.2	0
20070223	16.3	1.1	11.7	6
20070224	4.0	0.0	10.7	5
20070225	4.2	0.0	8.9	3
20070226	3.1	0.0	6.9	5
20070227	7.1	0.0	6.7	2
20070228	6.6	0.2	10.9	2
20070301	1.9	0.0	9.4	0
20070302	11.3	0.1	8.1	0
20070303	12.7	1.7	12.0	0
20070304	23.7	4.0	11.2	0
20070305	9.1	0.1	10.3	0
20070306	9.8	0.4	9.5	0
20070307	8.9	0.5	10.3	0
20070308	20.8	3.5	8.4	0
20070309	14.8	0.8	7.6	0
20070310	22.2	1.1	6.7	0
20070311	25.7	2.6	7.4	0
20070312	25.5	3.6	8.6	0
20070313	23.6	3.0	10.1	0
20070314	21.3	2.3	9.5	0