Institut für Solarenergieforschung GmbH
Hameln / Emmerthal

Test Centre for Solar Thermal
Components and Systems

Am Ohrberg 1 · 31860 Emmerthal · Germany

Report of Performance Test according to EN 12975-2 for a Glazed Solar Collector

Test Centre

Address	Institut für Solarenergieforschung GmbH, Hameln/Emmerthal Am Ohrberg 1 31860 Emmerthal, Germany
Contact person	Dipl.-Ing. C. Lampe Tel.: +49 (0)5151/ 999-522 Fax: -500 E-Mail: Pruefstelle@isfh.de

Deutscher Akkreditierungs Rat
DAP-PL-3662.00

Test Basis

Test according to	EN 12975-2:2006 Section 6

Test Report

Number	106-06/D
Date	02.11.2006
Number of pages	20

Customer

Address	Thermomax Ltd. Balloo Crescent Bangor, BT 19 7UP United Kingdom
Contact person	Herr Carsten Onneken Tel.: +44 2891 270-411, Fax: -572

Test Collector

Type	DF 100 20
Manufacturer	Thermomax Ltd.
Serial- or Prototype	Serial type
Year of production	2006
Serial number	MB 08626

Contents

Test Centre for Solar Thermal Components and Systems

1. Summary

Company:	**Thermomax Ltd.** Balloo Crescent Bangor, BT 19 7UP, United Kingdom	Report no.: Report date:	106-06/D 02.11.2006
Type:	**DF 100 20**	Serial no.: Year of production:	MB 08626 2006

The following results were obtained from a test of the thermal performance of a solar collector according to **EN 12975-2:2006**. They apply to the collector described more precisely in the test report no. 106-06/D and to the tests and procedures described herein.

Description of the collector

Type	evacuated tubular collector	Aperture area	2.153 m²
Length/Width/Height	1996 / 1418 / 97 mm	Absorber area	2.004 m²
Max. operation pressure	8 bar	Gross area	2.830 m²
Weight, empty	54.8 kg	Recommended flow rate	60..150 kg/m²h
Heat transfer fluid	polypropylene	Thickness of absorber sheet	0.12 mm
		number of tubes	20

Test results

Coefficients of efficiency
(determined in the sun simulator SUSI I)

$$\eta = \eta_0 - a_1 \cdot (t_m - t_a)/G - a_2 \cdot (t_m - t_a)^2/G$$

Based on:	aperture area	absorber area
η_0 =	0.773	0.830
a_1 =	1.43 W/m²K	1.53 W/m²K
a_2 =	0.0059 W/m²K²	0.0063 W/m²K²

Incident angle modifier
(determined outdoor)

proj. angle of incidence θ	0°	10°	20°	30°	40°	50°	60°
$K_{\theta b,trans}(\theta_{trans})$	1.00	1.00	1.02	1.04	1.05	0.99	0.85
$K_{\theta b,long}(\theta_{long})$	1.00	1.00	0.99	0.98	0.96	0.92	0.86

$K_{\theta d}$ = 0.88

Power output per collector unit

$T_m - T_a$	Irradiance 400 W/m²	700 W/m²	1000 W/m²
10 K	634	1133	1632
30 K	562	1062	1561
50 K	481	980	1479

Peak power per collector unit		**1664 W_{peak}**	at G = 1000 W/m² and $t_m - t_a$ = 0 K
Pressure drop (water, 20 °C)	Δp =	1.6 mbar	at $\dot{m}$ = 70.8 kg/h
	Δp =	6.9 mbar	at $\dot{m}$ = 209.9 kg/h
Thermal capacity (calculated)	c =	9.3 kJ/(m²K)	C = 20.1 kJ/K
Stagnation temperature	t_{stg} =	286 °C	at G_S = 1000 W/m² and t_{as} = 30 °C

Emmerthal, 02.11.2006 pp

Dipl.-Ing. C. Lampe, deputy head of Test Centre-EN

2. Description of the Collector

2.1. Collector

Manufacturer	Thermomax Ltd. Balloo Crescent; Bangor, BT 19 7UP;United Kingdom
Type	DF 100 20
Construction	evacuated tubular collector, Serial type
Year of production	2006
Serial number	MB 08626
Weight, empty, without glazing	28.3 kg (according to manufacturer)
Weight, empty, with glazing	54.8 kg (weighed at ISFH)

2.2. Evacuated Tubes

Number of tubes	20
Dimensions	65 mm / 1.5 mm (outer diameter/ thickness)
Material	borosilicate glass, clear
Aperture area	20 x 1736.5 mm x 62 mm = 2.153 m²

2.3. Absorber

Absorber material	copper sheet, thickness 0.12 mm (according to manufacturer)
Material of fluid tubes	copper
Connection between absorber and tubes	inductive welding
Hydraulic construction	parallel
Absorber layer	selective (TiNOX, type TiNOX)
Absorber dimensions	20 x 1698.5 mm x 59 mm = 2.004 m² (according to manufacturer)

2.4. Heat Transfer Fluid

Specifications	polypropylene
Alternative acceptable heat transfer fluids	no details
Fluid content	3.8 l (weighed at ISFH)

2.5. Casing

Dimensions (L / W / H)	1996 / 1418 / 97 mm
Material of frame	aluminium profiles

2.6. Insulation in the Distributor Casing

Insulation construction	machine-cut foamed plastic
Insulation material	foamed melamine resin

2.7. Reference Areas

Absorber area	2.004 m²
Aperture area	2.153 m²
Gross area	2.830 m²

2.8. Collector Mounting

Collector tilt angle	0°..90°
On sloped roof	yes
Integrated into sloped roof	no
On flat roof	yes
On flat roof with stand	yes
Facade	yes

3. Validity

1. This test report is valid for the collector DF 100 20 (description see section 2) with the serial number MB 08626.
2. According to the customers specifications the collector type DF 100 20 is distributed with the selective absorber layer type TiNOX (TiNOX) and type Sunselect (Alanod-Sunselect). In an agreement of the Erfahrungsaustauschkreis „Thermische Solaranlagen und deren Bauteile“(EK-TSuB) which consists of represantatives from all German-speaking test centres acknowledged by DIN CERTCO (Certification body of DIN) the test results of this two absorber layers are transverable (confirmed 21.03.2006). Therefore the report no. 106-06/D is also valid for the collector type DF 100 20 with the selective absorber layer type Sunselect (Alanod-Sunselect).

4. Photograph and Sketch of the Collector

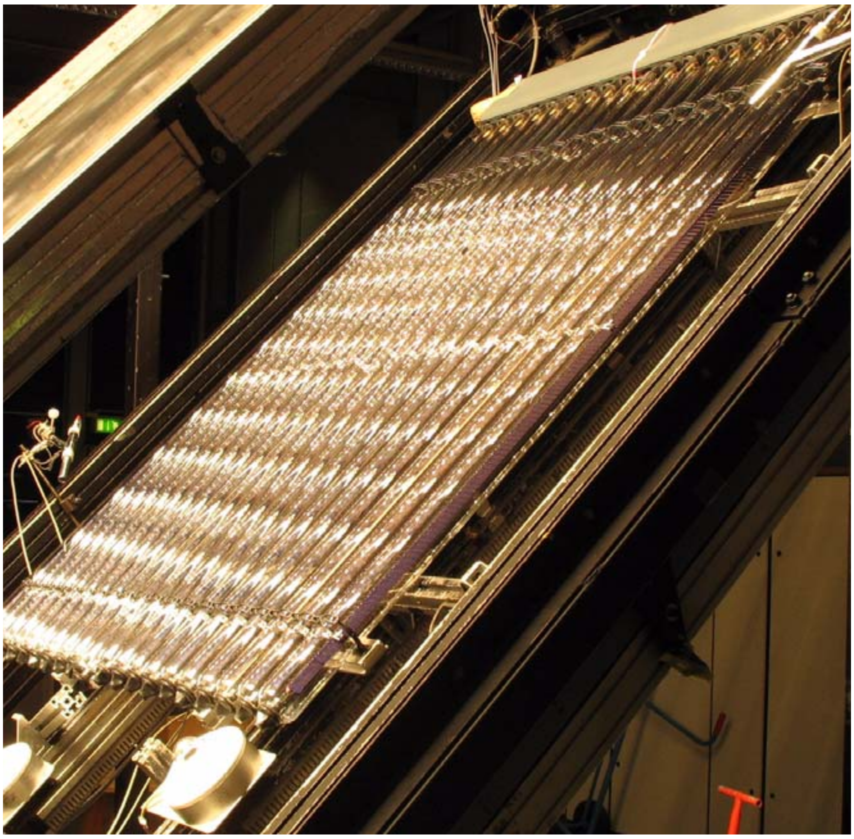


Fig. 4-1: Picture of the collector, mounted in the sun simulator SUSI I

Fig. 4-2: Sketch of the collector

5. Sampling

Date of sampling:	29.03.2006
Place of sampling:	Store of the company Thermomax Ltd.; Bangor, BT 19 7UP; United Kingdom
Inspector:	Daniel Eggert (employee of the Test Centre)
Description of sampling: The collector casing with the serial number MB 08626 and the evacuated tubes with the serial number C063LT00026, C063LT00025, C063LT00024 and C063LT00023 were chosen out of more than 6 identically products. The products were marked in the store and delivered to the test centre. The customer has proved with his quality management that the chosen products accord with the serial production.	

6. Documents; Collector Identification

Drawings:	The following drawings were presented by the customer * sketch of the collector * Top view * Lateral view
Collector data sheet:	A data sheet with details about the tested collector was presented by the customer.
Labelling of the collector:	The test collector has a durable type label. The label is fixed inside the manifold lid to avoid early destruction. The manifold can be opened without any tool. The stagnation temperature isn´t printed on the label, because the determination will be carried out with this report.
Installer instruction manual:	The following documents were presented by the customer: Installation manual (2006 B4815A) Operatung manual (2006 B4986A)

7. Installation of Sensors

The collector was equipped with temperature sensors (Pt 100, class A), as described in the following. Care was taken that the sensors do not influence the results of the following tests. The temperatures measured are given in table A-2 in the appendix.

Name of the sensor	Position
t_{sm}	Absorber temperature sensor, at 2/3 of the height of the absorber tube, inside the 10th fluid tube (installed only during the exposure to irradiation)
t_{glas}	Glass temperature sensor, at 2/3 of the height of the glass tube (10th tube from the left side)
t_{back}	Backside temperature sensor (exactly beneath glass temperature sensor)

8. Exposure to Irradiation

The empty collector was exposed to irradiation before the performance test.

Tab. 8-1: Test conditions during the exposure

Date: 05.04.2006
Test facility: SUSI I (indoor test with sun simulator)
Inspector: Gerd Schiewe (employee of the Test Centre)

	Conditions stipulated in EN 12975-2	Test conditions
Collector tilt angle	-	45 °
Solar irradiance	> 700 W/m²	895 W/m²
Ambient temperature, mean value	-	30.1 °C
Duration of exposure	> 5 h	5 h

Result:

The collector showed no changes during and after the exposure test.

9. Determination of the Stagnation Temperature

During the exposure to irradiation (see section 8), the stagnation temperature of the collector was determined.

9.1. Mathematical Procedure[a]

$$t_{stg} = a \cdot G_s^{\frac{1}{1.3}} + t_{as} \qquad \text{eqn. (9.1)}$$

t_{stg} = stagnation temperature under standard conditions in °C
G_s = standard global irradiance
t_{as} = standard ambient temperature

$$a = \frac{(t_{sm} - t_{am})}{G_m^{1/1.3}} \qquad \text{eqn. (9.2)}$$

t_{sm} = measured absorber temperature in °C
t_{am} = measured ambient temperature in °C
G_m = measured global irradiance (in the collector plane) in W/m²

9.2. Test Conditions and Results

Date: 05.04.2006
Test facility: SUSI I (indoor test with sun simulator)
Inspector: Gerd Schiewe (employee of the Test Centre)
Collector tilt angle: 45°

	Test conditions	Standard conditions according to ISO 9806-2	
		Class A (temperate), corresponding to conditions stipulated in EN 12975-2	Class B (sunny)
Global irradiance	895 W/m²	1000 W/m²	1100 W/m²
Surrounding air speed	< 1 m/s	< 1 m/s	< 1 m/s
Ambient temperature	30.1 °C	30 °C	40 °C
Measured absorber temperature (t_{sm})	264.9 °C		
Calculated stagnation temperature (t_{stg})		**286 °C**	315 °C

a. For the calculation of the stagnation temperature under standard conditions, the eqns. (9.1) and (9.2) are used, as this method has a lower uncertainty than the procedure described in EN 12975-2.

10. Instantaneous Collector Efficiency

10.1. Test Procedure

Thermal performance testing under steady state conditions by using a solar irradiance simulator (see EN 12975-2, section 6.1.5).

10.2. Indications for the Sun Simulator

The sun simulator in use adheres to the requirements given in EN 12975-2, section 6.1.5.2. To evaluate the quality of indoor measurement, the value of convperformanceersion factor η_0 measured by using the sun simulator was compared to that from outdoor measurement (determined simultaneously to the incidence angle modifier, see section 11). As a result, the conversion factor was marginally adjusted. The conversion factor η_0 given in this report corresponds to a value that would be measured outdoor at a ratio of diffuse to global radiation of $G_d/G = 0.15$.

10.3. Mathematical Description

$$\eta = \eta_0 - a_1 \cdot \frac{t_m - t_a}{G} - a_2 \cdot \frac{(t_m - t_a)^2}{G} \qquad \text{eqn. (10.1)}$$

η	= efficiency
η_0	= efficiency for $t_m - t_a = 0$ (conversion factor)
a_1	= heat loss coefficient, independent of temperature, in W/m²K
a_2	= heat loss coefficient, depending on temperature, in W/m²K²
G	= global irradiance in W/m²
t_m	= mean fluid temperature in the collector in °C, $t_m := (t_{in} + t_e)/2$
t_{in}	= collector inlet temperature in °C
t_e	= collector outlet temperature in °C
t_a	= ambient temperature in °C
T_m^*	= reduced temperature difference, in m²K/W

10.4. Test Conditions and Results

The test conditions are shown in table 10-1. All measured data are given in table A-1 and table A-2 in the appendix.

Tab. 10-1: Test conditions of the efficiency measurements in the sun simulator

Date: 06.04.2006 and 07.04.2006 Test facility: SUSI I (indoor test with sun simulator) Inspector: Gerd Schiewe (employee of the Test Centre) Lamps used: halogen lamps, Philips type 13117 Heat transfer fluid: water		
	Conditions stipulated in EN 12975-2	Test conditions
Collector tilt angle	40...50°	45°
Mean global irradiance	> 700 W/m²	872 W/m²
Mean thermal irradiance[1)]	≤ 498 W/m²	443 W/m²
Mean ambient temperature	-	26.0 °C
Mean air speed over the collector	3 m/s ± 1 m/s	3.3 m/s
Mass flow rate of the heat transfer fluid	0.02 kg/(m²s) or according to manufacturer	150 kg/h

1) For protection against long wave radiation there is an air cooled channel, made of two acrylic glass panes, between the lamps and the collector. The thermal irradiance is determined from a measurement of the surface temperature of the lower acrylic glass pane.

Tab. 10-2: Coefficients of the efficiency curve, related to different areas

Related to area:	η_0	a_1	a_2
Aperture area (2.153 m²)	**0.773**	**1.43 W/m²K**	**0.0059 W/m²K²**
Absorber area (2.004 m²)	0.830	1.53 W/m²K	0.0063 W/m²K²
Gross area (2.830 m²)	0.588	1.08 W/m²K	0.0045 W/m²K²

Note:

If the parameters are given in the documents of the collector, the area to which they are related must be mentioned.

The power curve per collector unit for G = 1000 W/m² is given on page 19.

11. Incident Angle Modifier of the Collector

11.1. Test Procedure

The collector is mounted on the outdoor test facility (Tracker), facing south in a fixed position. The variation of the incident angle is achieved by the sun's path over the collector. The vacuum tube collector on hand shows a biaxial incident angle dependence. So, after determination of the transversal incident angle modifier the collector is turned by 90°, and the longitudinal incident angle modifier is determined in a second measurement. The incident angle modifiers for direct radiation and for diffuse radiation are determined separately.

11.2. Mathematical Description

$$K_{\theta b}(\theta) = \frac{F'(\tau\alpha)_{en}(\theta)}{F'(\tau\alpha)_{en}} \qquad \text{eqn. (11.1)}$$

$K_{\theta b}(\theta)$ = incident angle modifier for beam radiation as a function of the incident angle θ

$F'(\tau\alpha)_{en}$ = conversion factor for pure beam radiation at normal incidence

$F'(\tau\alpha)_{en}(\theta)$ = conversion factor for pure beam radiation as a function of the incident angle θ

The incident angle modifier for beam radiation must be split into a transversal and a longitudinal component:

$$K_{\theta b}(\theta) = K_{\theta b,\,trans}(\theta_{trans}) \cdot K_{\theta b,\,long}(\theta_{long}) \qquad \text{eqn. (11.2)}$$

θ_{trans} = transversal incident angle

θ_{long} = longitudinal incident angle

11.3. Test Conditions and Results

Tab. 11-1: Test conditions during the measurement of the incident angle modifier

Date: 03.05.2006 to 05.05.2006 Test facility: Testdach Inspector: Florian Kohlenberg (Mitarbeiter des Prüfzentrums) Heat transfer fluid: water		
	Conditions stipulated in EN 12975-2	Test conditions
Collector tilt angle	40...50°	38°[1)]
Collector azimuth angle	-	0° (south)
Mass flow rate $\dot{m}$	0.02 kg/(m²s) or according to manufacturer	150 kg/h
Latitude	-	52.1° N
Longitude	-	9.4° E
Local time (MEZ) at solar noon	-	12:19

1) This tilt angle was selected in order to achieve the best approximation of normal irradiance. The tilt angle is only insignificantly below the smallest demanded value. The influence of the tilt angle on the collector performance is assessed to be minimal in this range of angles.

Tab. 11-2: Incident angle modifier

θ_{trans} or θ_{long}	0°	10°	20°	30°	40°	50°	60°
$K_{\theta b,\,trans}(\theta_{trans})$	1.00	1.00	1.02	1.04	1.05	0.99	0.85
$K_{\theta b,\,long}(\theta_{long})$	1.00	1.00	0.99	0.98	0.96	0.92	0.86
$K_{\theta d}$	0.88						

Nomenclature

- θ_{trans} = transversal incident angle
- θ_{long} = longitudinal incident angle
- $K_{\theta b}(\theta)$ = incident angle modifier for beam radiation as a function of the incident angle θ
- $K_{\theta d}$ = incident angle modifier for diffuse radiation

12. Thermal Capacity of the Collector

The thermal capacity of the collector is calculated according to EN 12975-2, as the sum of the capacities of its constituent elements, taking into account weighting factors. These weighting factors evaluate that some elements are only partially involved in the thermal inertia of the collector.

$$C = \sum p_i \cdot m_i \cdot c_i \qquad \text{eqn. (12.1)}$$

C = effective thermal capacity of the collector in kJ/K

p_i = weighting factor of the component (according to tabular 6 in EN 12975-2:2001, chapter 6.1.6.2)

m_i = Mass of the component in kg

c_i = specific thermal capacity of the component kJ/(kgK)

12.1. Result

Date: 20.07.2006
Inspector: Wolfgang Wetzel

	calculated according to EN 12975-2
effective thermal capacity	20.1 kJ/K
specific thermal capacity related to the aperture area	9.3 kJ/(m²K)

13. Pressure Drop across the Collector

13.1. Test Procedure

The pressure drop is measured at different mass flow rates according to EN 12975-2, chapter 6.1.8.

13.2. Test Conditions and Results

Tab. 13-1: Results of the pressure drop measurements

Date:	11.05.2006				
Test facility:	Δp-test facility with U-tube differential pressure gauge				
Inspector:	Gerd Schiewe (employee of the Test Centre)				
Heat transfer Fluid:	water				
Fluid temperature:	20 ± 2°C				
Mass flow rate in kg/h	30.1	70.8	129.9	209.9	301.3
Pressure drop in mbar	0.5	1.6	3.5	6.9	12.0

Compared to the measurement using water, the pressure drop will be markedly higher when using a water-glycol mixture as heat transfer fluid, because its viscosity is much higher.

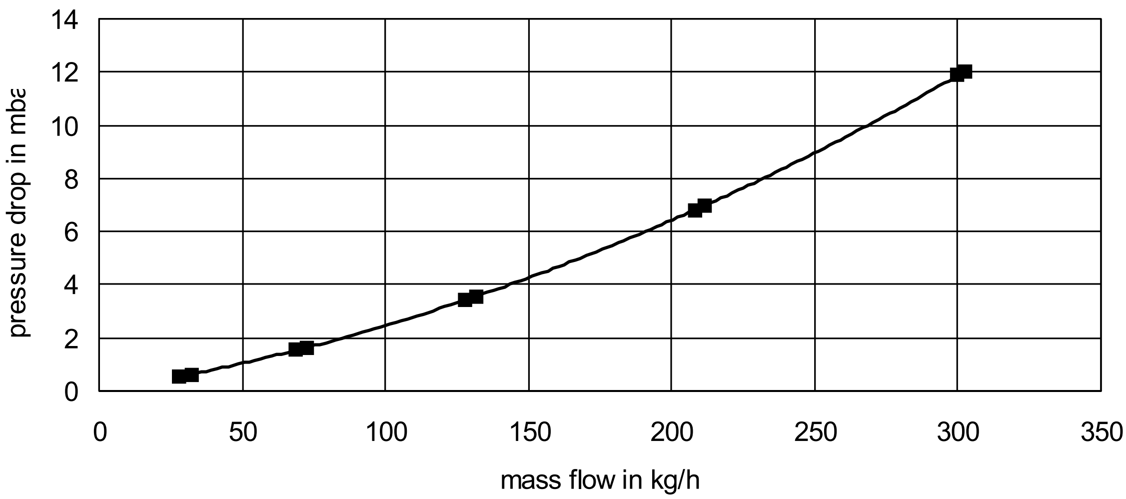


Fig. 13-1: Measured pressure drop of the collector (heat transfer fluid: water)

14. Observations; Status of the Collector

Status of the collector after

- delivery: faultless
- exposure to irradiation: no change
- performance test: no change
- end of tests: no change

There were no extraordinary incidents during the tests.

No sharp edges, loose fixing elements or other characteristics representing a possible endangering were observed.

15. Stipulations from the Test Centre

1. This test report is valid for the collector DF 100 20 (description see section 2) with the serial number MB 08626.
2. Prior to passing on to others or reproducing parts of this test report, permission must be obtained. Passing on the single pages 3, 19 and 20 or the coherent pages 1 to 16 or the complete test report is generally approved.

Test Centre for Solar Thermal

Components and Systems

pp

Dipl.-Ing. C. Lampe

deputy head of Test Centre-EN

CLa/02.11.2006
blg10606_engl.fm

Table A-1: Measured and Calculated Data from the Efficiency Tests, Related to the Aperture Area

No.	**G**	$\dot{m}$	t_{in}	t_e	$t_e - t_{in}$	t_m	t_a	$t_m - t_a$	T^*_m	η_a
-	**W/m²**	**kg/h**	**°C**	**°C**	**K**	**°C**	**°C**	**K**	**Km²/W**	**-**
1	874.5	149.6	21.6	30.0	8.4	25.8	25.8	0.0	0.0000	0.774
2	874.6	149.5	21.6	30.0	8.4	25.8	25.9	0.0	0.0000	0.773
3	875.2	150.3	40.5	48.5	8.0	44.5	26.0	18.5	0.0211	0.741
4	874.1	150.1	40.5	48.5	8.0	44.5	26.0	18.5	0.0212	0.741
5	873.6	149.5	60.3	67.9	7.6	64.1	26.1	38.0	0.0435	0.701
6	875.1	149.5	60.3	67.9	7.6	64.1	25.9	38.2	0.0437	0.701
7	873.9	150.0	80.2	87.3	7.1	83.7	26.1	57.6	0.0660	0.657
8	873.5	150.1	80.3	87.3	7.0	83.8	26.0	57.8	0.0662	0.656
9	872.9	150.7	80.3	87.3	7.0	83.8	26.4	57.4	0.0658	0.657
10	873.1	150.7	80.3	87.3	7.0	83.8	26.3	57.5	0.0658	0.658
11	874.0	149.4	60.4	68.0	7.6	64.2	26.3	37.9	0.0434	0.700
12	875.0	149.4	60.3	67.9	7.6	64.1	26.3	37.8	0.0432	0.700
13	874.6	149.9	40.5	48.5	8.0	44.5	25.9	18.6	0.0213	0.742
14	875.5	149.9	40.5	48.5	8.0	44.5	26.0	18.6	0.0212	0.742
15	874.0	150.0	21.7	30.0	8.3	25.8	25.8	0.1	0.0001	0.772
16	872.8	150.1	21.7	30.0	8.3	25.8	25.7	0.1	0.0001	0.773

Nomenclature:

G	W/m²	hemispherical (= global) solar irradiance in the collector plane
$\dot{m}$	kg/h	mass flow rate of the heat transfer fluid
t_{in}, t_e	°C	collector inlet temperature and collector outlet (exit) temperature
t_m	°C	mean temperature of heat transfer fluid, t_m: = (t_{in} + t_e)/2
t_a	°C	ambient temperature
T^*_m	(m²K)/W	reduced temperature difference, $T^*_m = (t_m - t_a)/G$
η_a	-	collector thermal efficiency, related to the aperture area

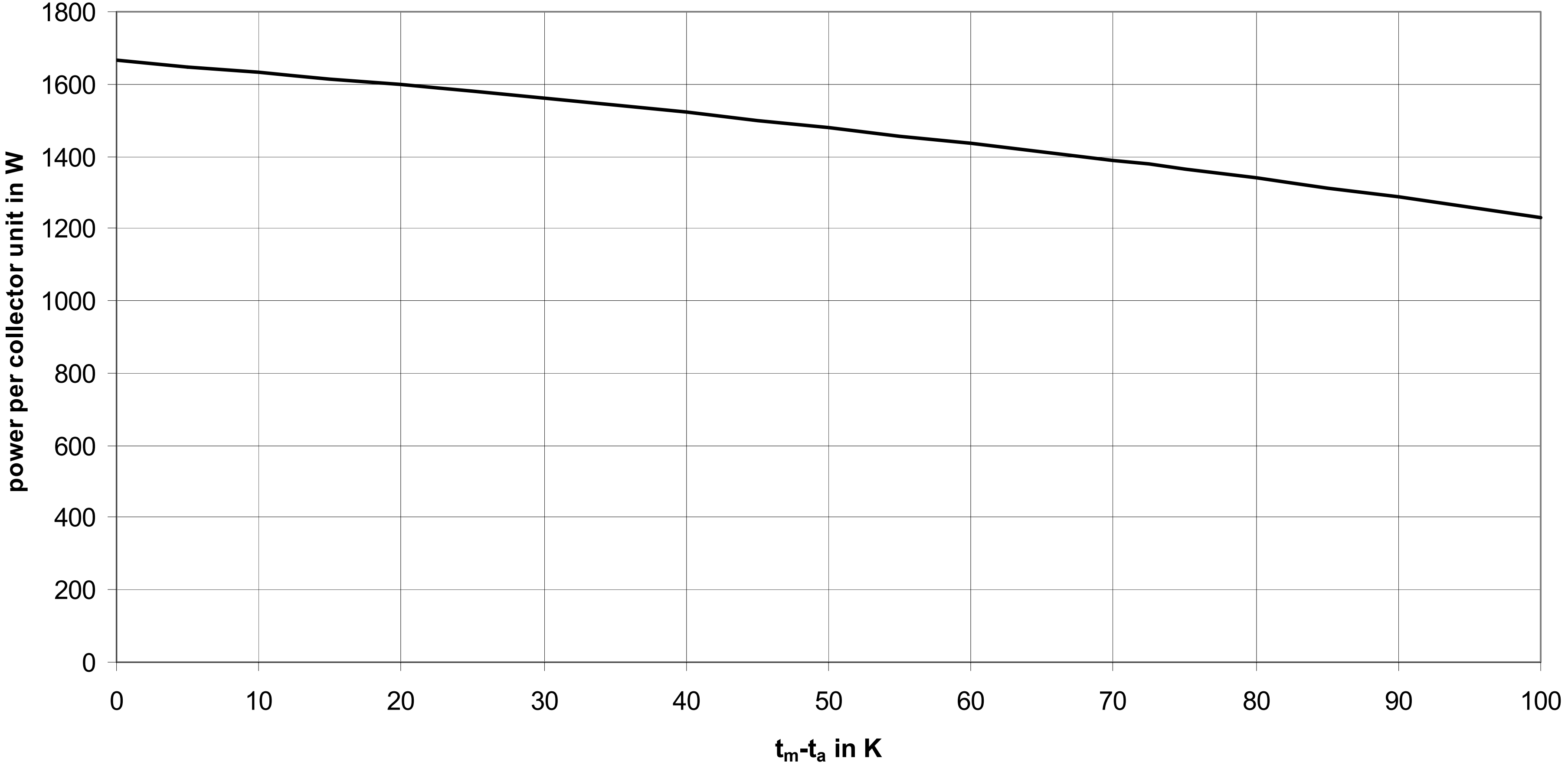
Table A-2: Temperatures at Different Positions of the Collector, Meteorological Quantities

No.	t_{in}	t_e	t_m	t_a	t_s	t_{glas}	t_{back}	u
-	°C	°C	°C	°C	°C	°C	°C	m/s
1	21.6	30.0	25.8	25.8	24.1	27.7	26.2	3.3
2	21.6	30.0	25.8	25.9	24.2	27.7	26.2	3.3
3	40.5	48.5	44.5	26.0	24.3	28.1	26.4	3.3
4	40.5	48.5	44.5	26.0	24.3	28.2	26.5	3.3
5	60.3	67.9	64.1	26.1	24.2	28.6	26.6	3.3
6	60.3	67.9	64.1	25.9	23.9	28.4	26.5	3.3
7	80.2	87.3	83.7	26.1	24.1	29.0	26.7	3.3
8	80.3	87.3	83.8	26.0	23.9	28.9	26.6	3.3
9	80.3	87.3	83.8	26.4	24.4	29.3	27.0	3.3
10	80.3	87.3	83.8	26.3	24.3	29.1	26.9	3.3
11	60.4	68.0	64.2	26.3	24.8	28.7	26.6	3.3
12	60.3	67.9	64.1	26.3	24.9	28.7	26.7	3.3
13	40.5	48.5	44.5	25.9	24.1	28.0	26.2	3.3
14	40.5	48.5	44.5	26.0	24.2	28.0	26.2	3.3
15	21.7	30.0	25.8	25.8	24.0	27.7	26.0	3.3
16	21.7	30.0	25.8	25.7	23.8	27.6	26.0	3.3

Nomenclature:

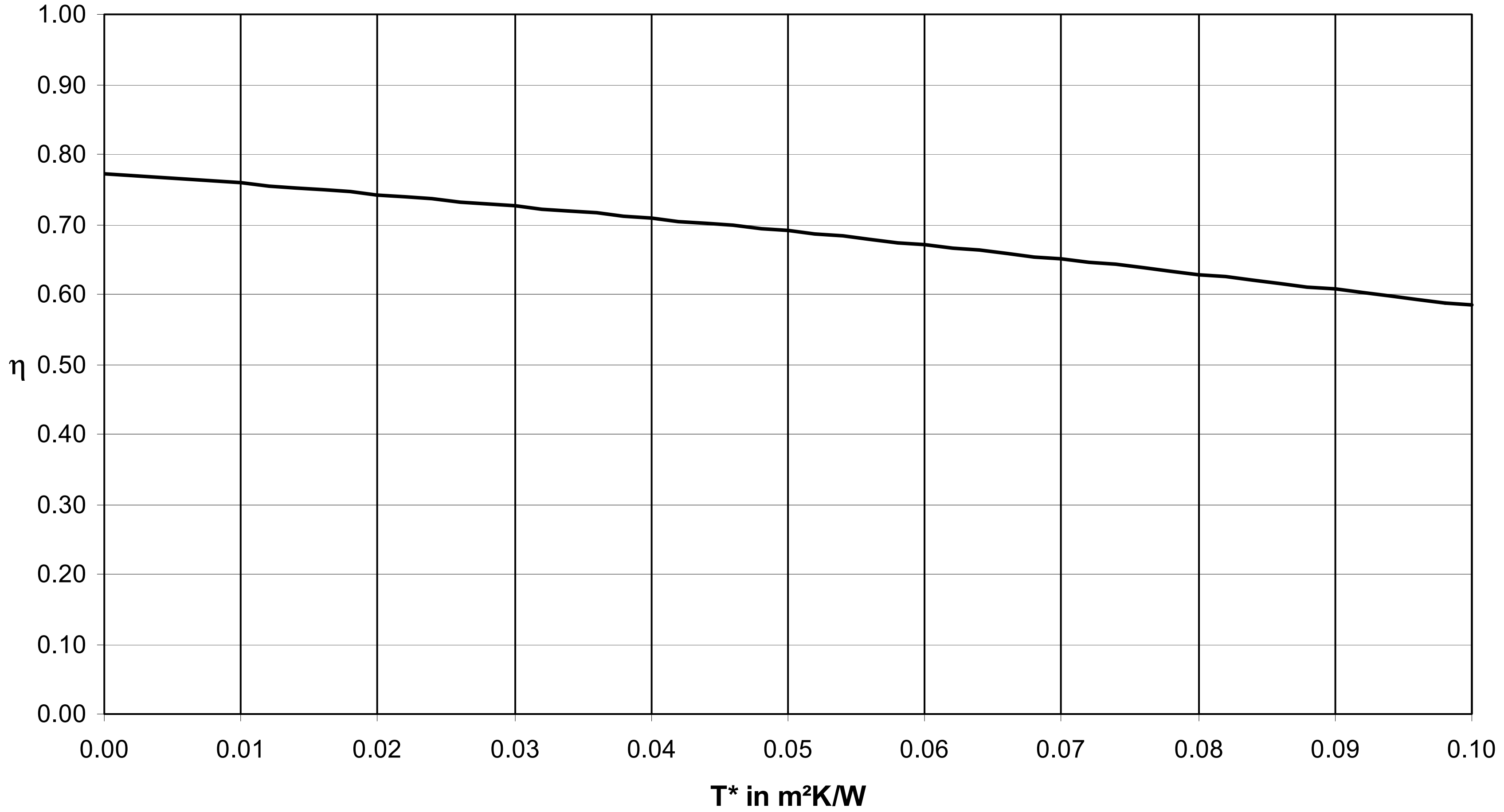
t_{in}, t_e	°C	collector inlet temperature and collector outlet (exit) temperature
t_m	°C	mean temperature of heat transfer fluid, t_m: = (t_{in} + t_e)/2
t_a	°C	ambient temperature
t_s	°C	sky temperature
t_{glas}	°C	temperature of the transparent cover
t_{back}	°C	temperature of the backside of the collector
u	m/s	surrounding air speed

Power Curve for G = 1000 W/m², Related to Collector Unit



Company:	Thermomax Ltd.	Solar collector test	Report date: 02.11.2006
Collector type:	DF 100 20	according to EN 12975-2	Report no.: 106-06/D
Serial No.:	MB 08626		Page 19 of 20
Aperture area:	2.153 m²		

Collector Efficiency Curve for G = 800 W/m², Related to the Aperture Area



Company:	Thermomax Ltd.	Solar collector test according to EN 12975-2	Report date: 02.11.2006
Collector type:	DF 100 20		Report no.: 106-06/D
Serial No.:	MB 08626		Page 20 of 20
Aperture area:	2.153 m²		