

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



Test Centre

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Test Basis

Test according to DIN EN 12975-2:2001 + AC:2002
Section 6

Test Report

Number 32-05/D
Date 28.06.2005
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Number of pages 19

Customer

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Test Collector

Type FLATLINE BE Pro plus
Manufacturer NAU GmbH
Serial- or Prototype Serial type
Year of production 2005
Serial number 370000000 / F

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Test Centre for Solar Thermal
Components and Systems

1. Summary of the Results

Company:	NAU GmbH Naustraße 1 D- 85368 Moosburg- Pfrombach, Germany	Report no.:	32-05/D
		Report date:	28.06.2005
Type:	FLATLINE BE Pro plus	Serial no.:	370000000 / F
		Year of production:	2005

The following results were obtained from a test of the thermal performance of a solar collector according to **DIN EN 12975-2:2001 + AC:2002**. They apply to the collector described more precisely in the test report no. 32-05/D and to the tests and procedures described herein.

Description of the collector

Type	flat plate collector	Aperture area	1.915 m ²
Drawing no.	19202211_ZE_001_01	Absorber area	1.911 m ²
Length/Width/Height	1993 / 1054 / 92 mm	Gross area	2.101 m ²
Max. operation pressure	10 bar	Recommended flow rate	36 kg/m ² h
Weight, empty	34.5 kg	Thickness of absorber sheet	0.2 mm
Heat transfer fluid	Tyfocon L	Tube distance	70 mm

Test results

Coefficients of efficiency

(determined in the sun simulator SUSI I under steady state conditions)

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

Based on: aperture area absorber area

$\eta_0 =$	0.815	0.817
$a_1 =$	3.35 W/m ² K	3.36 W/m ² K
$a_2 =$	0.0133 W/m ² K ²	0.0134 W/m ² K ²

Incident angle modifier

(determined outdoor)

$$K_{\theta b}(\theta) = 1 - b_0 (1/\cos \theta - 1)$$

$K_{\theta}(50^\circ) =$	0.93, for $G_d/G = 0.15$
$b_0 =$	0.144
$K_{\theta d} =$	0.872

Power output per collector unit

$T_m - T_a$	400 W/m ²	Irradiance 700 W/m ²	1000 W/m ²
10 K	558 W	1026 W	1494 W
30 K	409 W	877 W	1345 W
50 K	240 W	708 W	1176 W

Pressure drop (water, 20 °C)

$\Delta p =$	3.9 mbar	at $\dot{m} = 69.3$ kg/h
$\Delta p =$	29.2 mbar	at $\dot{m} = 210.4$ kg/h

Thermal capacity (calculated)

$c =$	4.2 kJ/(m ² K)	$C =$	8.1 kJ/K
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Stagnation temperature

$t_{stg} =$	213 °C	at $G_S = 1000$ W/m ² and $t_{as} = 30$ °C
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Emmerthal, 10.04.2008

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

2. Description of the Collector

2.1. Collector

Manufacturer	NAU GmbH Naustraße 1, D- 85368 Moosburg- Pfrombach, Germany
Type	FLATLINE BE Pro plus
Construction	flat plate collector, Serial type
Year of production	2005
Serial number	370000000 / F
Weight, empty, with glazing	34.5 kg (weighed at ISFH)

2.2. Glazing

Number of glazings	one
Dimensions	1954 mm x 1014 mm x 3.2 mm
Material	safety glass, low iron; manufacturer: Flabeg, type ESG matt/matt
Aperture area	1.933 m x 0.991 m = 1.915 m ²
Solar transmittance	no details

2.3. Absorber

Absorber material	copper plate, thickness 0.2 mm (according to manufacturer)
Material of fluid tubes	copper, $d_i / d_a = 8 / 7.2$ mm
Connection between absorber and tubes	soldering
Hydraulic construction	2 two series-connected groups of 6 parallel tubes, tube distance approx. 70 mm
Absorber layer	selective (TiNOX, type TiNOX)
Solar absorptance	no details
Hemispherical emittance	no details
Absorber dimensions	1.932 x 0.989 m ² = 1.911 m ²

2.4. Heat Transfer Fluid

Specifications	Tyfocor L
Alternative acceptable heat transfer fluids	no details
Fluid content	1.32 l (weighed at ISFH)

2.5. Casing

Dimensions (L / W / H)	1993 / 1054 / 92 mm
Material of frame	aluminium profiles
Material of back plate	aluminium sheet
Sealing material between the frame segments	silicone
Sealing material between the frame and the glazing	EPDM

2.6. Insulation

Insulation construction	plate
Insulation material	mineral wool
Thickness	40 mm

2.7. Reference Areas

Absorber area	1.911 m ² (partially limited by the aperture area)
Aperture area	1.915 m ²
Gross area	2.101 m ²

2.8. Collector Mounting

Collector tilt angle	8°..90°
On sloped roof	yes
Integrated into sloped roof	yes
On flat roof	no
On flat roof with stand	no
Facade	no

2.9. Limitations

Stagnation temperature	221 °C (according to manufacturer; new determination in section 9 of this report)
Maximum pressure	10 bar

3. Validity

1. This test report is valid for the collector FLATLINE BE Pro plus (description see section 2) with the serial number 370000000 / F.

4. Photograph of the Collector

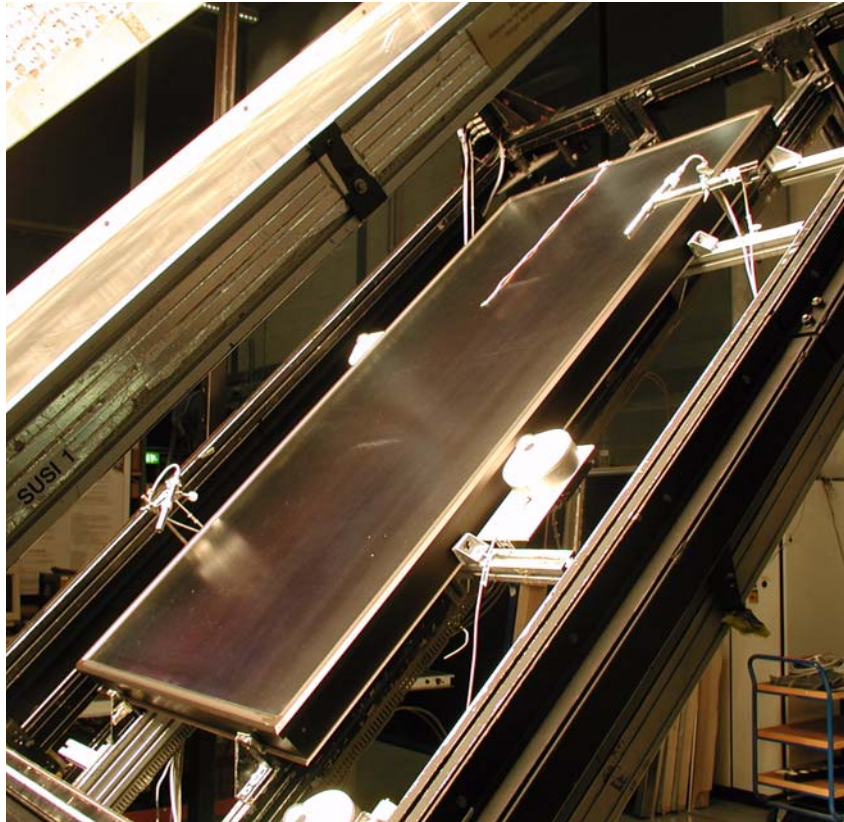


Fig. 4-1: Picture of the collector, mounted in the sun simulator SUSI I

5. Sampling

A sampling was not carried out.

6. Documents; Collector Identification

Drawings: The following drawings were presented by the customer
* 19202211_ZE_001_01

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 visible and durable type label.

Installer instruction manual: The following documents were presented by the customer:
* Installation instruction for mounting (Code: 91941000/0504)

7. Installation of Sensors

The collector was equipped with three temperature sensors (Pt 100, class A), as described in the following. These sensors measure the temperatures of the glass cover, of the collector back and the absorber temperature. Care was taken that the sensors do

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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, between the fourth and the fifth absorber tube from the right (as seen from the front side)
t_{glas}	Glass temperature sensor, at 2/3 of the height of the glass pane
t_{back}	Backside temperature sensor (exactly beneath glass temperature sensor)

8. Exposure to Irradiation

As no qualification tests were carried out on the collector in question, the empty collector was exposed to irradiation before the performance test.

Tab. 8-1: Test conditions during the exposure

Date:	10.06.2005	
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/m ²	890 W/m ²
Ambient temperature, mean value	-	30.8 °C
Duration of exposure	> 5 h	5.1 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

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

t_{stg} = stagnation temperature under standard conditions in °C

G_s = standard global irradiance

t_{as} = standard ambient temperature

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

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:	10.06.2005		
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	891 W/m ²	1000 W/m ²	1100 W/m ²
Surrounding air speed	< 1 m/s	< 1 m/s	< 1 m/s
Ambient temperature	30.9 °C	30 °C	40 °C
Measured absorber temperature (t_{sm})	198.7 °C		
Calculated stagnation temperature (t_{stg})		213 °C	237 °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 conversion 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 values of the indoor measurements were slightly corrected. 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

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

η = efficiency

η_0 = efficiency for $t_m - t_a = 0$ (conversion factor)

a_1 = heat loss coefficient, independent of temperature, in W/m^2K

a_2 = heat loss coefficient, depending on temperature, in W/m^2K^2

G = global irradiance in W/m^2

t_m = mean fluid temperature in the collector in $^{\circ}C$, $t_m = (t_{in} + t_e)/2$

t_{in} = collector inlet temperature in $^{\circ}C$

t_e = collector outlet temperature in $^{\circ}C$

t_a = ambient temperature in $^{\circ}C$

T_m^* = reduced temperature difference, in m^2K/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:	13.06.2005 and 14.06.2005	
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	-	45°
Mean global irradiance	> 700 W/m ²	880 W/m ²
Mean thermal irradiance ¹⁾	≤ 496 W/m ²	436 W/m ²
Mean ambient temperature	-	25.6 °C
Mean air speed over the collector	3 m/s ± 1 m/s	3.4 m/s
Mass flow rate of the heat transfer fluid	0.02 kg/(m ² s) or according to manufacturer	207 kg/h ²)

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.

2) According to the manufacturer, always at least three collectors are installed in a series connection.

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

Related to area:	η_0	a_1	a_2
Aperture area (1.915 m²)	0.815	3.35 W/m²K	0.0133 W/m²K²
Absorber area (1.911 m ² (partially limited by the aperture area))	0.817	3.36 W/m ² K	0.0134 W/m ² K ²
Gross area (2.101 m ²)	0.743	3.06 W/m ² K	0.0122 W/m ² K ²

Note:

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

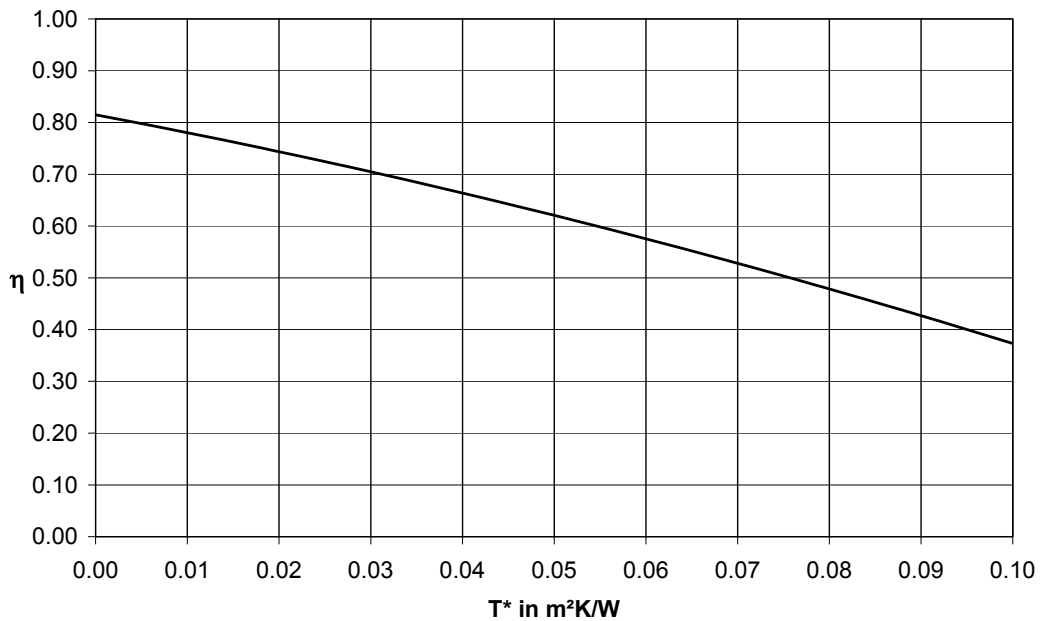


Fig. 10-1: Collector efficiency curve for $G = 800 \text{ W/m}^2$, related to the aperture area

11. Incident Angle Modifier of the Collector

11.1. Test Procedure

The incident angle modifier is measured outdoor under quasi-dynamic test conditions (see chapter 6.3.4.6.4 a) of EN 12975-2). During the measurement the mean fluid temperature of the collector is close to the ambient temperature (low deviations are corrected by the heat loss coefficients given in section 10). The variation of the incident angle is achieved by the sun's path over the collector.

11.2. Mathematical Description

The determination of the incident angle modifier is based on the division of the natural solar irradiance into a diffuse part (G_d) and a direct part (G_b). In accordance with EN 12975-2 (chapter 6.3.4.8.2) the efficiency can be calculated with the following equation (for the sake of simplification, it is assumed that the mean fluid temperature and the ambient temperature are equal).

$$\eta_0 \cdot G = F'(\tau\alpha)_{en} \cdot G \cdot \left(K_{\theta b}(\theta) \cdot \left(1 - \frac{G_d}{G} \right) + K_{\theta d} \cdot \frac{G_d}{G} \right) - \left(c \cdot \frac{dt_m}{dt} \right) \quad \text{eqn. (11.1)}$$

η_0 = efficiency for $t_m - t_a = 0$ (conversion factor)

G = global irradiance in W/m^2

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

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

$K_{\theta d}$ = incident angle modifier for diffuse radiation

G_d = diffuse irradiance in W/m^2

c = effective heat capacity of the collector in J/m^2K

t_m = mean temperature of heat transfer fluid in $^{\circ}C$

$$K_{\theta b}(\theta) = \frac{F'(\tau\alpha)_{en}(\theta)}{F'(\tau\alpha)_{en}} \quad \text{eqn. (11.2)}$$

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

The incident angle modifier for beam radiation ($K_{\theta b}$) as a function of the incident angle is described by the following equation (see chapter 6.3.6 of EN 12975-2)

$$K_{\theta b}(\theta) = 1 - b_0 \cdot \left(\frac{1}{\cos\theta} - 1 \right) \quad \text{eqn. (11.3)}$$

b_0 = coefficient characterizing the incident angle modifier for beam radiation

Effective incident angle modifiers for global radiation can be calculated with the following equation.

$$K_{\theta}(\theta) = \frac{K_{\theta b}(\theta) \cdot 0.85 + K_{\theta d} \cdot 0.15}{0.85 + K_{\theta d} \cdot 0.15} \quad \text{eqn. (11.4)}$$

$K_{\theta}(\theta)$ = incident angle modifier for $G_d/G = 0.15$

$K_{\theta d}$ = incident angle modifier for diffuse radiation

11.3. Test Conditions and Results

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

Date:	19.06.2005 and 20.06.2005	
Test facility:	Test roof I	
Inspector:	Daniel Eggert (employee of the test centre)	
Heat transfer fluid:	water	
	Conditions stipulated in EN 12975-2	Test conditions
Collector tilt angle	-	38°
Collector azimuth angle	-	0° (south)
Mass flow rate \dot{m}	0.02 kg/(m ² s) or according to manufacturer	207 kg/h
Latitude	-	52.1° N
Longitude	-	9.4° E
Local time (MEZ) at solar noon	-	12:25

Tab. 11-2: Coefficients of the incident angle modifier

$K_{\theta}(50^{\circ})$	b_0	$K_{\theta d}$
0.93, for $G_d/G = 0.15$	0.144	0.872

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.

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

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

p_i = weighting factor of the component (according to tabular 6 in DIN EN 12975-2:2001 + AC:2002, 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:	22.06.2005
Inspector:	Carsten Lampe
	calculated according to EN 12975-2:
effective thermal capacity	8.1 kJ/K
specific thermal capacity related to the aperture area	4.2 kJ/(m ² K)

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:	29.06.2005				
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:	$20 \pm 2^\circ\text{C}$				
Mass flow rate in kg/h	30.3	69.3	130.5	210.4	301.1
Pressure drop in mbar	1.1	3.9	11.5	29.2	56.9

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.

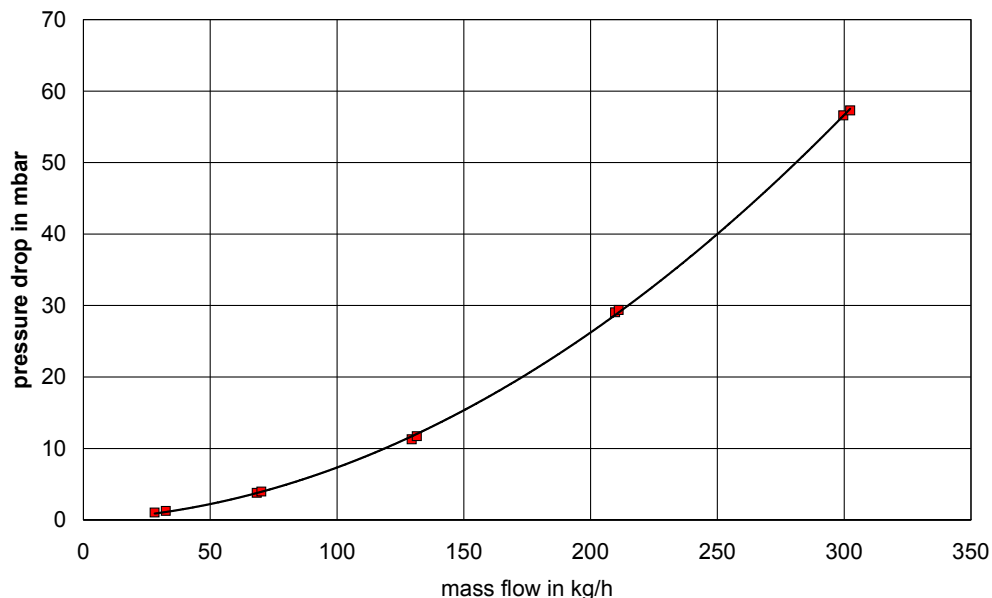


Fig. 13-1: Measured pressure drop of the collector (heat transfer fluid: water)

14. Observations; Status of the Collector

Status of the collector after

- * delivery: faultless
- * exposure to irradiation: no change (no severe problems)
- * performance test: no change (no severe problems)
- * end of tests: no change (no severe problems)

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 FLATLINE BE Pro plus (description see section 2) with the serial number 370000000 / F.
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 or the coherent pages 1 to 16 or the complete test report is generally approved.

Test Centre for Solar Thermal

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Head of Test Centre-EN

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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/m ²	kg/h	°C	°C	K	°C	°C	K	Km ² /W	-
1	880.8	207.2	22.6	28.4	5.7	25.5	25.3	0.2	0.0002	0.814
2	879.8	207.1	22.7	28.4	5.7	25.5	25.5	0.1	0.0001	0.814
3	880.6	207.0	40.5	45.8	5.2	43.2	25.5	17.6	0.0200	0.744
4	879.6	206.5	40.5	45.7	5.2	43.1	25.5	17.7	0.0201	0.742
5	880.7	207.2	60.4	65.0	4.6	62.7	25.6	37.1	0.0422	0.652
6	880.8	207.2	60.4	65.0	4.6	62.7	25.7	37.0	0.0421	0.653
7	878.5	207.4	80.3	84.1	3.8	82.2	26.0	56.3	0.0640	0.552
8	879.1	207.3	80.3	84.2	3.8	82.2	26.0	56.2	0.0640	0.552
9	880.6	207.0	80.4	84.2	3.8	82.3	25.4	56.9	0.0646	0.550
10	880.7	207.0	80.4	84.2	3.8	82.3	25.5	56.8	0.0645	0.550
11	879.9	207.4	60.4	65.0	4.5	62.7	25.4	37.3	0.0424	0.651
12	878.4	207.2	60.4	65.0	4.6	62.7	25.6	37.1	0.0423	0.652
13	878.8	206.5	40.6	45.8	5.2	43.2	25.6	17.6	0.0201	0.744
14	877.8	206.5	40.6	45.8	5.2	43.2	25.5	17.6	0.0201	0.744
15	880.9	207.5	22.7	28.4	5.7	25.6	25.7	-0.1	-0.0001	0.816
16	879.2	207.4	22.7	28.4	5.7	25.6	25.7	-0.1	-0.0001	0.816

Outdoor measurement

1	990.7	207.0	27.5	33.9	6.4	30.7	28.6	2.2	0.0022	0.812
2	1011.7	207.2	24.5	31.1	6.5	27.8	25.7	2.1	0.0021	0.812
3	1009.2	207.1	24.6	31.1	6.5	27.8	26.0	1.8	0.0018	0.814
4	1001.9	207.5	27.5	34.0	6.5	30.8	29.6	1.2	0.0012	0.811

Nomenclature:

G	W/m ²	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	(m ² K)/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}	t_{sm}	u
-	°C	°C	°C	°C	°C	°C	°C	°C	m/s
1	22.6	28.4	25.5	25.3	22.7	35.5	26.8	25.2	3.4
2	22.7	28.4	25.5	25.5	22.7	35.5	26.9	25.3	3.4
3	40.5	45.8	43.2	25.5	22.8	52.2	29.0	25.9	3.4
4	40.5	45.7	43.1	25.5	22.7	52.2	29.0	25.9	3.4
5	60.4	65.0	62.7	25.6	22.9	70.7	31.9	26.6	3.4
6	60.4	65.0	62.7	25.7	23.0	70.7	32.0	26.7	3.4
7	80.3	84.1	82.2	26.0	23.2	89.0	35.6	27.7	3.4
8	80.3	84.2	82.2	26.0	23.3	89.0	35.6	27.7	3.4
9	80.4	84.2	82.3	25.4	22.8	89.1	35.0	27.3	3.4
10	80.4	84.2	82.3	25.5	23.0	89.1	35.0	27.4	3.4
11	60.4	65.0	62.7	25.4	22.8	70.6	31.7	26.4	3.4
12	60.4	65.0	62.7	25.6	23.1	70.6	31.9	26.6	3.4
13	40.6	45.8	43.2	25.6	23.0	52.3	29.1	25.9	3.4
14	40.6	45.8	43.2	25.5	23.0	52.2	29.1	26.0	3.4
15	22.7	28.4	25.6	25.7	23.0	35.6	27.2	25.5	3.4
16	22.7	28.4	25.6	25.7	23.0	35.6	27.2	25.5	3.4

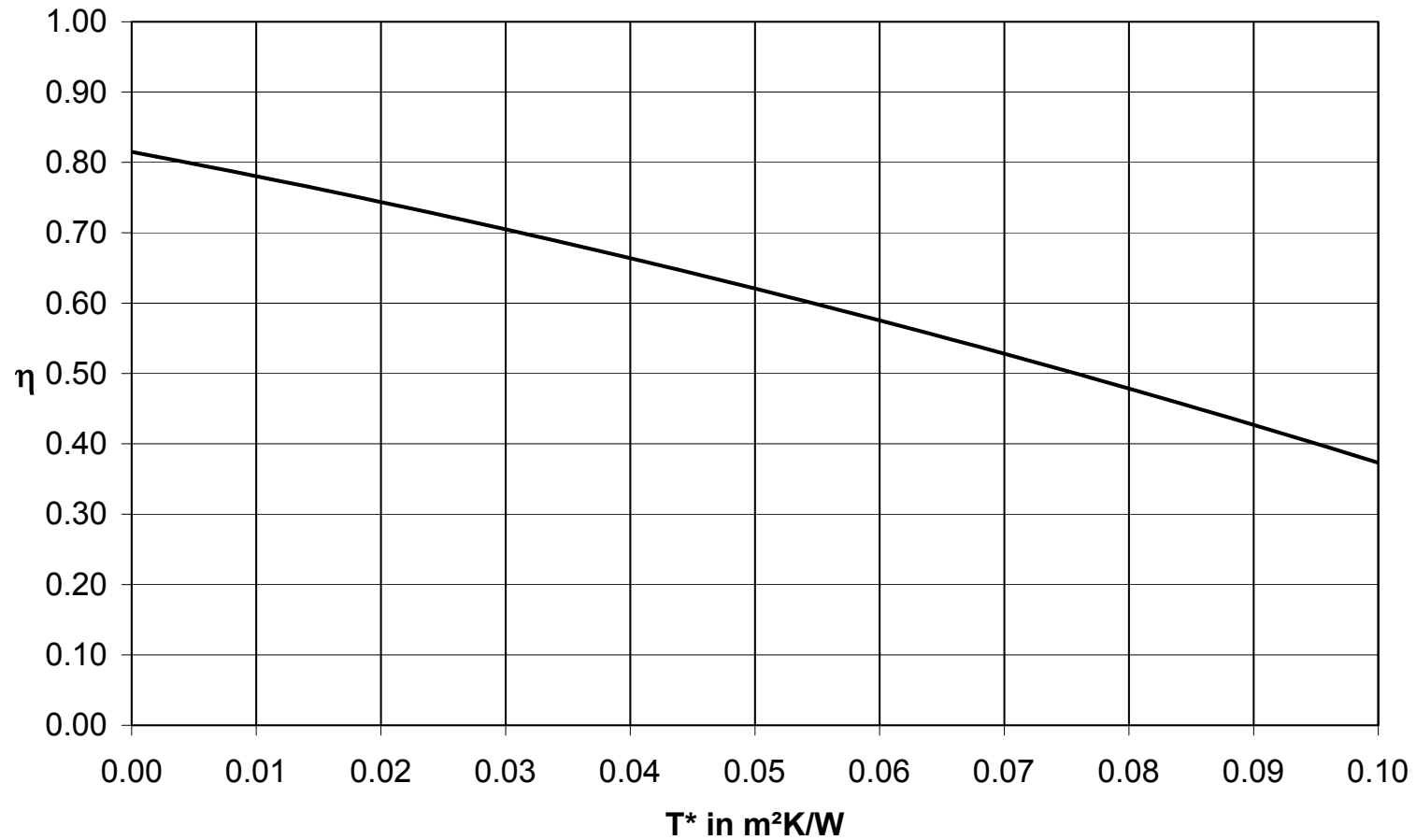
Outdoor measurement

1	27.5	33.9	30.7	28.6					3.0
2	24.5	31.1	27.8	25.7					1.7
3	24.6	31.1	27.8	26.0					1.8
4	27.5	34.0	30.8	29.6					2.9

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
t_{sm}	°C	absorber temperature
u	m/s	surrounding air speed

Collector Efficiency Curve for $G = 800 \text{ W/m}^2$, Related to the Aperture Area



Company: NAU GmbH
Collector type: FLATLINE BE Pro plus
Serial No.: 370000000 / F
Aperture area: 1.915 m^2

Solar collector test
according to DIN EN 12975-2:2001 +
AC:2002



Report date: 28.06.2005
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