Institut für Solarenergieforschung GmbH
Hameln / Emmerthal

Test Centre for Solar Thermal
Components and Systems

Am Ohrberg 1 · 31860 Emmerthal · Germany

Report of Performance Test similar 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. D. Eggert Tel.: +49 (0)5151/ 999-522 Fax: -500 E-Mail: Pruefstelle@isfh.de

Test Basis

Test similar to	EN 12975-2:2006 Section 6

Test Report

Number	97-10/KP
Date	30.04.2010
Number of pages	26

Customer

Address	Solimpeks Konsan Org. San. Hilal Sk. no:20 42300 Karatay / Konya Turkey
Contact person	Mr. Hoek Tel.: +31 0546/575360, Fax: -575316

Test Collector

Type	Volther Hybrid Collector glazed	Volther Hybrid Collector unglazed
Distributor	Solimpeks	Solimpeks
Serial- or Prototype	Prototype	Prototype
Year of production	2006	2006
Serial number	-	-

Contents

1. Summary of the Prototypes Results

Company:	**Solimpeks** Konsan Org. San. Hilal Sk. no:20 42300 Karatay / Konya, Turkey	Report no.: Report date:	97-10/KP 30.04.2010
Type:	**Volther Hybrid Collector glazed,** **Volther Hybrid Collector unglazed**	Serial no.: Year of production:	- 2006

The following results were obtained from a test of the thermal performance of a solar collector similar to **EN 12975-2:2006**. They apply to the collector described more precisely in the test report no. 97-10/KP and to the tests and procedures described herein.

Description of the collector			glazed / unglazed
Type	combi collector (solar thermal + photovoltaic)	Aperture area	1.222 m² / 1.219 m²
		Absorber area	1.200 m² / 1.219 m²
Length/Width/Height	1551 / 707 / 107 mm	Gross area	1.383 m² / 1.378 m²

Test results

Coefficients of efficiency glazed:
(determined in the sun simulator SUSI I) electrical in MPP, wind 1.2 m/s

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

Based on:	aperture area	absorber area
η_0 =	0.500	0.510
a_1 =	4.58 W/m²K	4.67 W/m²K
a_2 =	0.0135 W/m²K²	0.0137 W/m²K²

Coefficients of efficiency unglazed:
(determined in the sun simulator SUSI I) electrical in MPP, wind 1.2 m/s

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

Based on:	aperture area	absorber area
η_0 =	0.377	0.377
a_1 =	7.65 W/m²K	7.65 W/m²K
a_2 =	0.0131 W/m²K²	0.0131 W/m²K²

Power output per collector unit

	$T_m - T_a$	Irradiance 400 W/m²	700 W/m²	1000 W/m²
glazed:	10 K	187 W	370 W	554 W
	30 K	62 W	245 W	428 W
	50 K	-77 W	107 W	290 W

Power output per collector unit

	$T_m - T_a$	Irradiance 400 W/m²	700 W/m²	1000 W/m²
unglazed:	10 K	89 W	227 W	364 W
	30 K	-110 W	27 W	165 W
	50 K	-322 W	-184 W	-47 W

Peak power output per collector unit glazed: **611 W_{peak} at G = 1000 W/m² and t_m-t_a = 0 K**

Peak power output per collector unit unglazed: **459 W_{peak} at G = 1000 W/m² and t_m-t_a = 0 K**

Stagnation temperature t_{stg} = 142.2 °C glazed at G_S = 1000 W/m² and t_{as} = 30 °C

Emmerthal, 30.04.2010

Dipl.-Ing. M. Kirchner, Assisting Head of Test Centre FE

2. Description of the Collectors

2.1. Collector

	glazed / unglazed
Manufacturer	Holtkamp SES
Type	Volther Hybrid Collector glazed, PVT unglazed
Construction	combi collector (solar thermal + photovoltaic), Prototype
Year of production	2006
Serial number	-

2.2. Glazing

Number of glazings	one / none (the glazing of the PV module is not taken into account)
Material	with structure
Aperture area	1.556 m x 0.786 m = 1.222 m²

2.3. Absorber

Absorber material	copper fins + PV module
Material of fluid tubes	copper
Connection between absorber and tubes	ultrasound welding
Connection between copper absorber and PV module	thermal conductance paste, PV module and copper absorber are pressed together by pressure load
Hydraulic construction	two series-connected groups of 7 parallel tubes
Absorber layer	selective (type TiNOX)
Absorber dimensions	1.547 x 0.776 m² = 1.200 m² / 1.219 m²

2.4. Casing

Dimensions (L / W / H)	1551 / 707 / 107 mm
Material of frame	aluminium profiles
Material of back plate	aluminium sheet

2.5. Insulation

Insulation material	mineral wool, polystyrene between fluid tubes
Thickness	90 mm (mineral wool), 30 mm (polystyrene) / 120 mm (mineral wool)

2.6. Reference Areas

Absorber area	1.200 m² / 1.219 m²
Aperture area	1.222 m² / 1.219 m²
Gross area	1.383 m² / 1.378 m²

3. Photographs of the Collectors

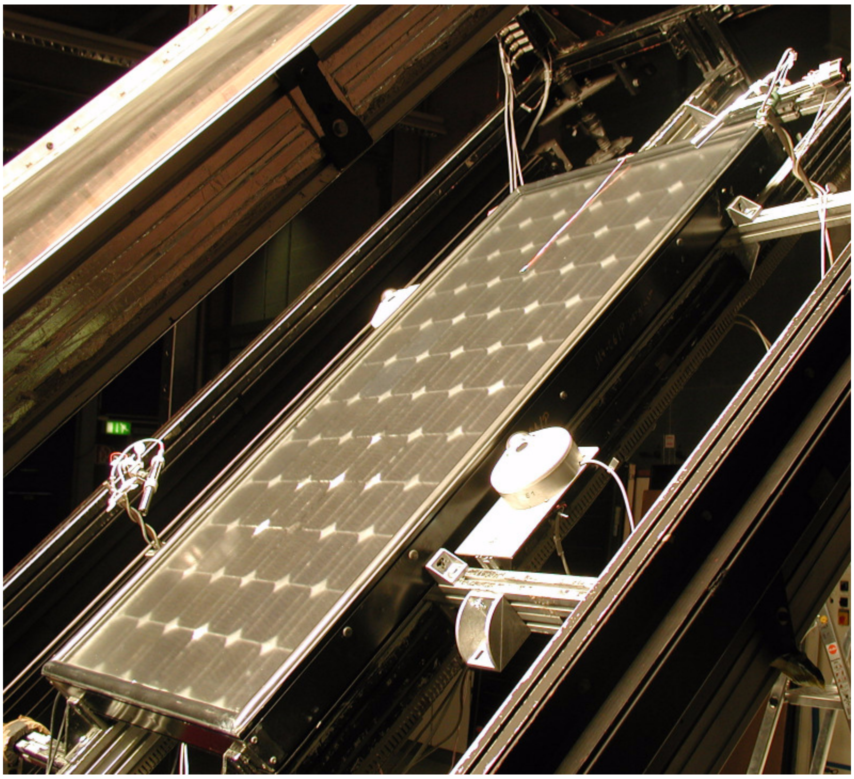


Fig. 3-1: Picture of the glazed collector, mounted in the sun simulator SUSI I

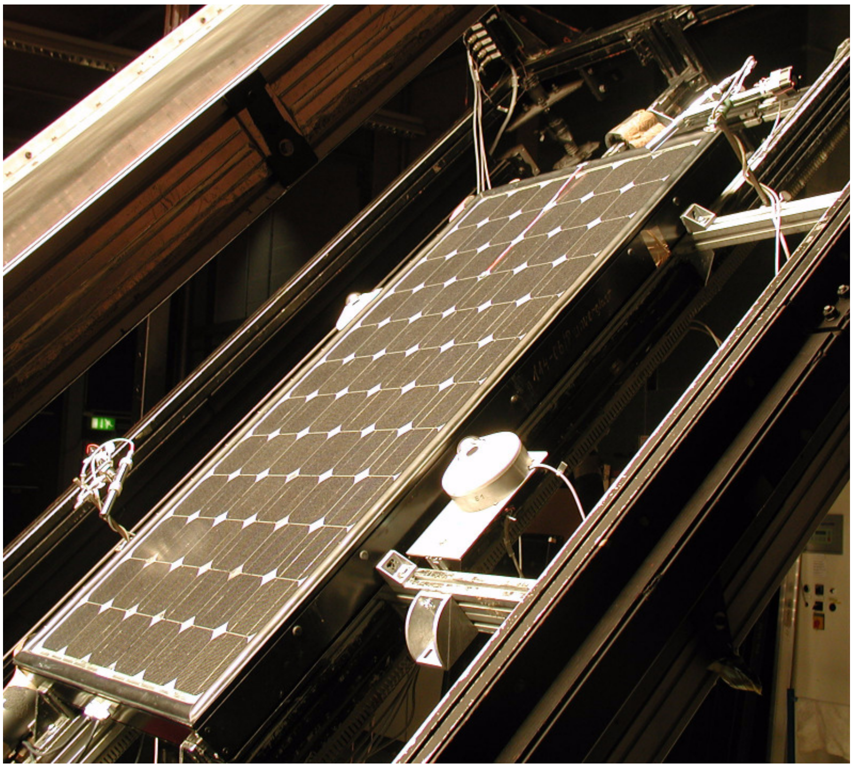


Fig. 3-2: Picture of the unglazed collector, mounted in the sun simulator SUSI I

4. General

The objective is to develop a new solarthermal plus photovoltaic hybrid collector (PVT). A glazed and an unglazed collector are tested. The aim of the test is to determine the enhanced thermal performance of the glazed collector.

The combined thermal and electrical performance test is done in parallel operation (MPP). As a partial test the glazed collector is exposed to irradiation to determine the stagnation temperature.

The tests are carried out in the sun simulator SUSI I. The radiation field has a spatial inhomogeneity so that the electrical performance is underestimated. Besides, the sun simulator does not fulfill the requirements for testing the efficiency of PV modules.

5. Test Procedure

In this chapter all tests are described.

5.1. Preparations

When the collectors arrive the actual condition is reported. The collectors are equiped with temperature sensors as descriped in chapter 7.

5.2. Determination of the Stagnation Temperature

The glazed collector is exposed to irradiation (approximatly 900 W/m² and 30 °C) for three and a half hours. The stagnation temperature is determined from this test.

5.3. Combined Thermal and Electrical Performance Test in MPP Operation

The thermal and electrical performance of the glazed and unglazed collector are measured in MPP operation at three different inlet temperatures of the fluid and an air speed of 1.2 m/s.

6. Documents; Collector Identification

The following labelling and documentation is required in DIN EN 12975-1 and IED 61215.

Labelling of the thermal module:	The test collector should have a visible and durable type label. The following details should be on the type label: * Name of manufacturer * Place of production * Serial number * Type * Year of production * Gross area of collector * Maximum operation pressure * Stagnation temperature (at 1000 W/m² and 30 °C) * Fluid content * Weight of empty collector * collector dimensions
Labelling of the electrical module:	The test collector should have a visible and durable type label. The following details should be on the type label: * Name of manufacturer * Type or model number * Serialnumber * polarity of terminals or leads (colour coding is permissible) * maximum system voltage
Installer instruction manual:	The following documents should be presented by the customer: * Installation instruction for mounting * Operating instructions The documents shall at least contain the following informations: * Dimensions and weight of the collector * Instructions about the transport and the handling of the collector * Description of the mounting procedure * Recommendations about lightning protection * Instructions about the coupling of the collectors to one another and the connection of the collector field to the heat transfer circuit * Dimensions of pipe connections for collector arrays up to 20 m² * Recommendations about the heat transfer media which may be used * Precautions to be taken during filling, operation and service * Maximum operation pressure * Details about the pressure drop of the collector * The maximum and minimum tilt angle * Maintenance requirements * maximum system voltage

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 not influence the results of the following tests. The temperatures measured are given in table A-3 and table A-4 in the appendix.

Name of the sensor	Position
t_{sm}	Absorber temperature sensor, at 2/3 of the height of the absorber, (as seen from the front side on the upright collector)
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

The glazed collector was exposed to irradiation and the stagnation temperature was determined .

Tab. 8-1: Test conditions during the exposure

Date: 24.01.2007 Test facility: SUSI I (indoor test with sun simulator) Inspector: Gerd Schiewe (employee of the Test centre) Test collector: Volther Hybrid Collector glazed		
	Conditions stipulated in EN 12975-2	Test conditions
Collector tilt angle	-	45 °
Solar irradiance	> 700 W/m²	908 W/m²
Ambient temperature, mean value	-	28.5 °C
Duration of exposure	> 5 h	3.5 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

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.

9.2. Test Conditions and Results

Date:	24.01.2007		
Test facility:	SUSI I (indoor test with sun simulator)		
Inspector:	Gerd Schiewe (employee of the Test centre)		
Collector tilt angle:	45°		
Test collector:	Volther Hybrid Collector glazed		
	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	908 W/m²	1000 W/m²	1100 W/m²
Surrounding air speed	< 1 m/s	< 1 m/s	< 1 m/s
Ambient temperature	28.5 °C	30 °C	40 °C
Measured absorber temperature (t_{sm})	132.9 °C		
Calculated stagnation temperature (t_{stg})		**142.2 °C glazed**	161.0 °C

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). During the performance test the PV modules are in MPP operation.

10.1.1.Special Note for the Test of the Unglazed Collector

The performance of an unglazed collector depends much more on the ambient air speed than the performance of a glazed collector. Furthermore, an unglazed collector has additional losses because of the direct radiation exchange between the absorber and the sky, because the sky temperature is lower than the ambient air temperature. That is why in EN 12975-2 the approach for the determination of the collector efficiency of an unglazed collector differs from the one of a glazed collector:

- the heat loss coefficient is not temperature dependent
- the heat loss coefficient and the conversion factor are wind dependent
- instead of the global irradiance the so called net irradiance G'' is used.

However, in order to be able to compare the results between the glazed and unglazed collector the results of the unglazed collector documented in the test report no. 114-06/P on hand are related to the global irradiance. Running a test in the sun simulator, the results for the coefficients are similar if they are based on the net irradiance because the effective sky temperature and the ambient air temperature do not differ much. In case of an outdoor test this is not applicable.

The specified conversion factor and heat loss coefficients are only valid for the ambient air speed during the test of u = 1.2 m/s, because for the unglazed collector these values are strongly dependent on the ambient air speed.

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.

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 and table 10-2. All measured data are given in table A-1, table A-2, table A-3 and table A-4 in the appendix.

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

Date:	25.01.2007		
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		
Test collector:	Volther Hybrid Collector glazed	Conditions stipulated in EN 12975-2	Test conditions
Operation mode PV module		-	MPP
Collector tilt angle		-	45°
Mean global irradiance		> 700 W/m²	911 W/m²
Mean thermal irradiance[1)]		≤ 498 W/m²	442 W/m²
Mean ambient temperature		-	25.8 °C
Mean air speed over the collector		3 m/s ± 1 m/s	1.2 m/s[2)]
Mass flow rate of the heat transfer fluid		0.02 kg/(m²s) or according to manufacturer	139.8 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.
2) To be able to compare the results with the results from the TÜV-Rheinland the ambient air speed was set to 1.2 m/s.

Tab. 10-2: Coefficients of the efficiency curve for the glazed collector, related to different areas (electrical MPP operation)

Related to area:	η_0	a_1	a_2
Aperture area (1.222 m²)	**0.500**	**4.58 W/m²K**	**0.0135 W/m²K²**
Absorber area (1.200 m²)	0.510	4.67 W/m²K	0.0137 W/m²K²
Gross area (1.383 m²)	0.422	4.05 W/m²K	0.0119 W/m²K²

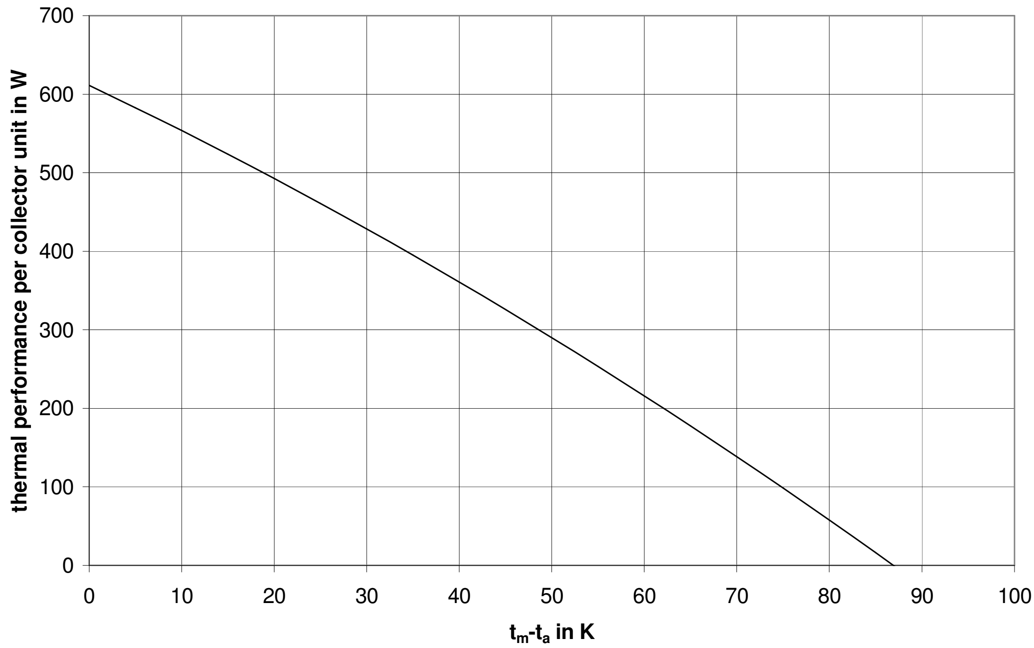


Fig. 10-1: Power curve for G = 1000 W/m² for the glazed collector, related to the collector unit (electrical MPP operation)

Tab. 10-3: Test conditions of the efficiency measurements for the unglazed collector in the sun simulator

Date:	26.01.2007		
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		
Test collector:	Volther Hybrid Collector unglazed	Conditions stipulated in EN 12975-2	Test conditions
Operation mode PV module		-	MPP
Collector tilt angle		-	45°
Mean global irradiance		> 700 W/m²	900 W/m²
Mean thermal irradiance 1)		≤ 496 W/m²	440 W/m²
Mean ambient temperature		-	25.5 °C
Mean air speed over the collector		3 m/s ± 1 m/s	1.2 m/s 2)
Mass flow rate of the heat transfer fluid		0.02 kg/(m²s) or according to manufacturer	139.9kg/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.
2) To be able to compare the results with the results from the TÜV-Rheinland the ambient air speed was set to 1.2 m/s.

Tab. 10-4: Coefficients of the efficiency curve for the unglazed collector, related to different areas (electrical MPP operation)

Related to area:	η_0	a_1	a_2
Aperture area (1.219 m²)	**0.377**	**7.65 W/m²K**	**0.0131 W/m²K²**
Absorber area (1.219 m²)	0.377	7.65 W/m²K	0.0131 W/m²K²
Gross area (1.378 m²)	0.332	6.74 W/m²K	0.0115 W/m²K²

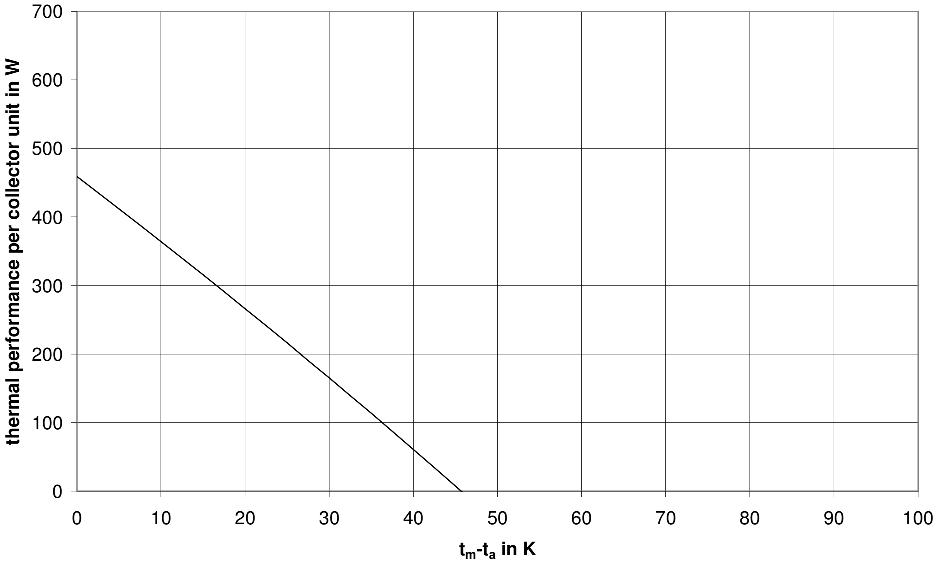


Fig. 10-2: Power curve for G = 1000 W/m² for the unglazed collector, related to the collctor unit (electrical in MPP operation)

Note:

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

11. Observations; Status of the Collector

Status of the collector after

* delivery: faultless
* exposure to irradiation: no change
* performance test: no change

After the performance test the cover of the unglazed collector was removed and it was observed that a great part of the copper absorber was thermally not connected to the PV module (see Figure 11-1).

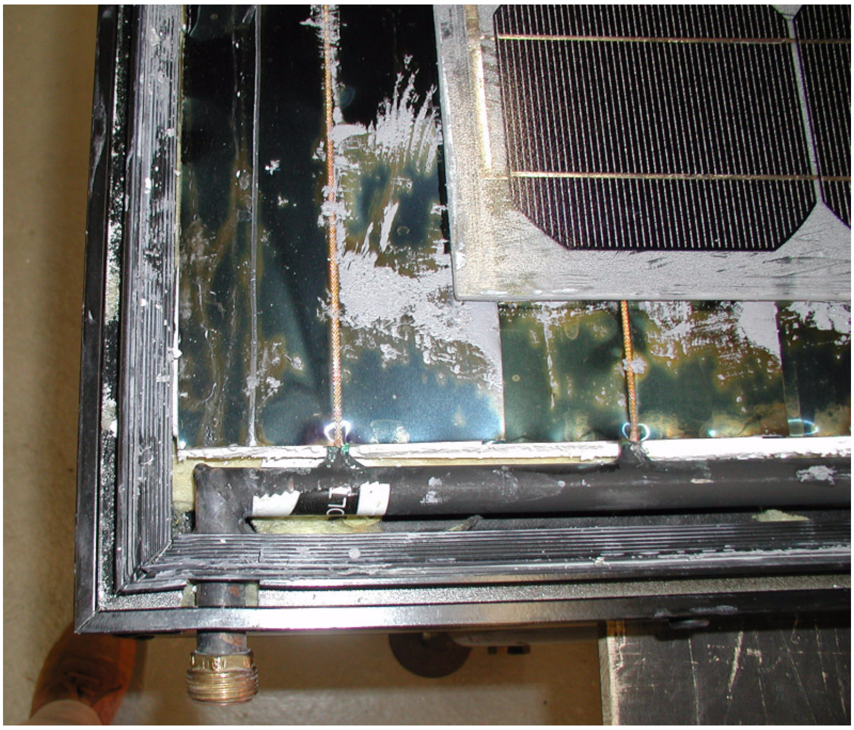


Fig. 11-1: Partial view of the opened, unglazed collector

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

12. Discussion of the Results

The comparison of the test results of the glazed and unglazed collector shows which impact the connection between copper absorber and PV module has on the collector efficiency.

For a glazed collector the optical efficiency is reduced because of the transmission of the glazing. However our results show that the conversion factor of the glazed collector (η_0 = 0.500) is much higher than the one of the unglazed collector (η_0 = 0.377).

If one assumes the same absorptance for both collectors this difference is caused by the collector efficiency factor F' (compare chapter 12.1). The heat loss coefficient of the glazed collector is much lower than the one of the unglazed collector, but this is not sufficient as an explanation. In fact we assume that the internal heat transfer coefficient k_{int} between the PV cells and the fluid is worse for the unglazed collector than the one of the glazed collector (compare chapter 12.1). To give a quantitative statement about this issue measurements of the absorptance are needed. Furthermore, we can not give any statement if the connection between copper absorber and PV moduel for the glazed collector was already nearly optimal.

Another influencing factor, although of minor relevance, is that the unglazed collector has a higher electrical efficiency than the glazed collector (two percentage points, see appendix).

With a better connection between the copper absorber and the PV module the internal heat transfer between PV module and fluid can be improved and this leads to a better collector efficiency factor F' and conversion factor (see chaper 12.1).

The coated copper absorber area is much smaller (1.089 m²) than the total absorber area of the module (the total absorber area is equivalent to the visible PV area (1.219 m²)). The internal heat transfer can be improved if the copper absorber area is enlarged to the size of the total absorber area.

Furthermore, the long-term stability of the construction should be tested. In particular the connection between copper absorber and PV module should be tested, because it is possible that the thermal conductance paste drys up and the pressure load of the heat insulation abates.

For further orders it is reasonable to do measurements of the absorptance to be able to make more detailed analyses.

For the interpretation of the results of the electrical performance it is important to keep in mind that no current-voltage-characteristics were tested and the MPP was adjusted (manually) for each operation point. It was not an objective of the test to make an extensive analyse of the electrical properties of the PV module.

12.1. Correlation between Collector Efficiency and Conversion Factor

For the unglazed collector the mathematical correlation between collector efficiency factor F' and conversion factor is given by:

$$\eta_0 = \alpha \cdot F' \qquad \text{Gl. (12.1)}$$

η_0 = collector efficieny at $t_m - t_a = 0$ (conversion factor)
α = absorption coefficient

The collector efficiency factor F' can be estimated by the following formula:

$$F' \approx \frac{k_{int}}{k_{int} + a_1} \qquad \text{Gl. (12.2)}$$

F' = collector efficieny factor

k_{int} = internal heat transfer coefficient in W/m²K

a_1 = „linear" heat loss coefficient of the collector in W/m²K

For the glazed collector the correlation between collector efficiency factor and conversion factor is given by:

$$\eta_0 \approx (\tau\alpha)_{eff} \cdot F' \qquad \text{Gl. (12.3)}$$

τ = transmission coefficient

13. Stipulations from the Test Centre

1. This test report is valid for the collector Volther Hybrid Collector glazed / Volther Hybrid Collector unglazed (description see section 2).
2. Prior to passing on to others or reproducing parts of this test report, permission must be obtained. Passing on the single pages 3, 23, 24, 25 and 26 or the coherent pages 1 to 18 or the complete test report is generally approved.

Test Centre for Solar Thermal

Components and Systems

Dipl.-Ing. M. Kirchner

Assisting Head of Test Centre FE

FK/30.04.2010
blg9710_engl.fm

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

Nr.	G	ṁ	t_{in}	t_e	t_e - t_{in}	t_m	t_a	t_m - t_a	T^*_m	η_a	P_{MPP} 1)	η_{el}
-	W/m²	kg/h	°C	°C	K	°C	°C	K	Km²/W	-	W	-
1	911.8	139.6	23.7	27.2	3.4	25.4	25.2	0.2	0.0002	0.499	83.8	0.075
2	912.4	139.5	23.8	27.2	3.4	25.5	25.4	0.1	0.0001	0.499		
3	911.1	139.4	23.7	27.2	3.4	25.5	25.5	0.0	0.0000	0.501		
4	910.1	140.5	45.4	48.1	2.7	46.7	25.8	20.9	0.0230	0.389	78.2	0.070
5	909.7	140.4	45.4	48.1	2.6	46.7	25.9	20.9	0.0229	0.388		
6	909.7	140.3	45.4	48.1	2.7	46.8	25.9	20.9	0.0229	0.389		
7	910.3	139.6	65.3	67.2	1.9	66.2	26.0	40.2	0.0442	0.274	73.1	0.066
8	911.2	139.6	65.3	67.2	1.9	66.2	26.1	40.1	0.0440	0.274		
9	911.2	139.6	65.3	67.2	1.9	66.2	26.2	40.1	0.0440	0.275		

1) The tests are carried out in the sun simulator SUSI I. The radiation field has a spatial inhomogeneity so that the electrical performance is underestimated. Besides, the sun simulator does not fulfill the requirements for testing the efficiency of PV modules. For the interpretation of the results of the electical performance it is important to keep in mind that no current-voltage-characteristics were tested and the MPP was adjusted (manually) for each operation point. It was not an objective of the test to make an extensive analyse of the electrical properties of the PV module.

Nomenclature:

G	W/m²	hemispherical (= global) solar irradiance in the collector plane
ṁ	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
P_{MPP}	W	performance of the PV module in MPP operation
η_{el}	-	collector electrical efficiency, related to the aperture area

Table A-2: Measured and Calculated Data from the Efficiency Tests for the Unglazed Collector, Related to the Aperture Area

Nr.	G	ṁ	t_{in}	t_e	t_e - t_{in}	t_m	t_a	t_m - t_a	T^*_m	η_a	P_{MPP} 1)	η_{el}
-	W/m²	kg/h	°C	°C	K	°C	°C	K	Km²/W	-	W	-
1	900.9	140.1	23.7	26.2	2.6	25.0	25.3	-0.3	-0.0003	0.380	107.6	0.098
2	901.0	140.1	23.7	26.2	2.6	25.0	25.2	-0.2	-0.0002	0.378		
3	900.3	140.1	23.7	26.3	2.6	25.0	25.3	-0.3	-0.0003	0.379		
4	900.1	139.9	45.4	46.8	1.3	46.1	25.7	20.4	0.0227	0.197	102.5	0.094
5	899.8	139.8	45.4	46.8	1.3	46.1	25.7	20.4	0.0227	0.198		
6	900.4	139.8	45.4	46.8	1.3	46.1	25.7	20.4	0.0227	0.197		
7	900.8	139.9	65.3	65.4	0.1	65.3	25.6	39.8	0.0441	0.016	97.8	0.089
8	899.0	140.0	65.3	65.4	0.1	65.3	25.7	39.7	0.0441	0.016		
9	899.4	139.9	65.3	65.4	0.1	65.3	25.7	39.6	0.0441	0.017		

1) The tests are carried out in the sun simulator SUSI I. The radiation field has a spatial inhomogeneity so that the electrical performance is underestimated. Besides, the sun simulator does not fulfill the requirements for testing the efficiency of PV modules. For the interpretation of the results of the electical performance it is important to keep in mind that no current-voltage-characteristics were tested and the MPP was adjusted (manually) for each operation point. It was not an objective of the test to make an extensive analyse of the electrical properties of the PV module.

Nomenclature:

G	W/m²	hemispherical (= global) solar irradiance in the collector plane
ṁ	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
P_{MPP}	W	performance of the PV module in MPP operation
η_{el}	-	collector electrical efficiency, related to the aperture area

Table A-3: Temperatures at Different Positions of the Glazed 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	23.7	27.2	25.4	25.2	23.7	38.2	25.2	39.8	1.2
2	23.8	27.2	25.5	25.4	23.8	38.3	25.3	39.8	1.2
3	23.7	27.2	25.5	25.5	23.7	38.5	25.4	39.8	1.2
4	45.4	48.1	46.7	25.8	23.9	44.4	26.5	57.8	1.2
5	45.4	48.1	46.7	25.9	24.0	44.4	26.7	57.9	1.2
6	45.4	48.1	46.8	25.9	24.0	44.5	26.7	57.9	1.2
7	65.3	67.2	66.2	26.0	24.3	50.1	27.6	74.5	1.2
8	65.3	67.2	66.2	26.1	24.3	50.1	27.8	74.6	1.2
9	65.3	67.2	66.2	26.2	24.3	50.2	27.9	74.6	1.2

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

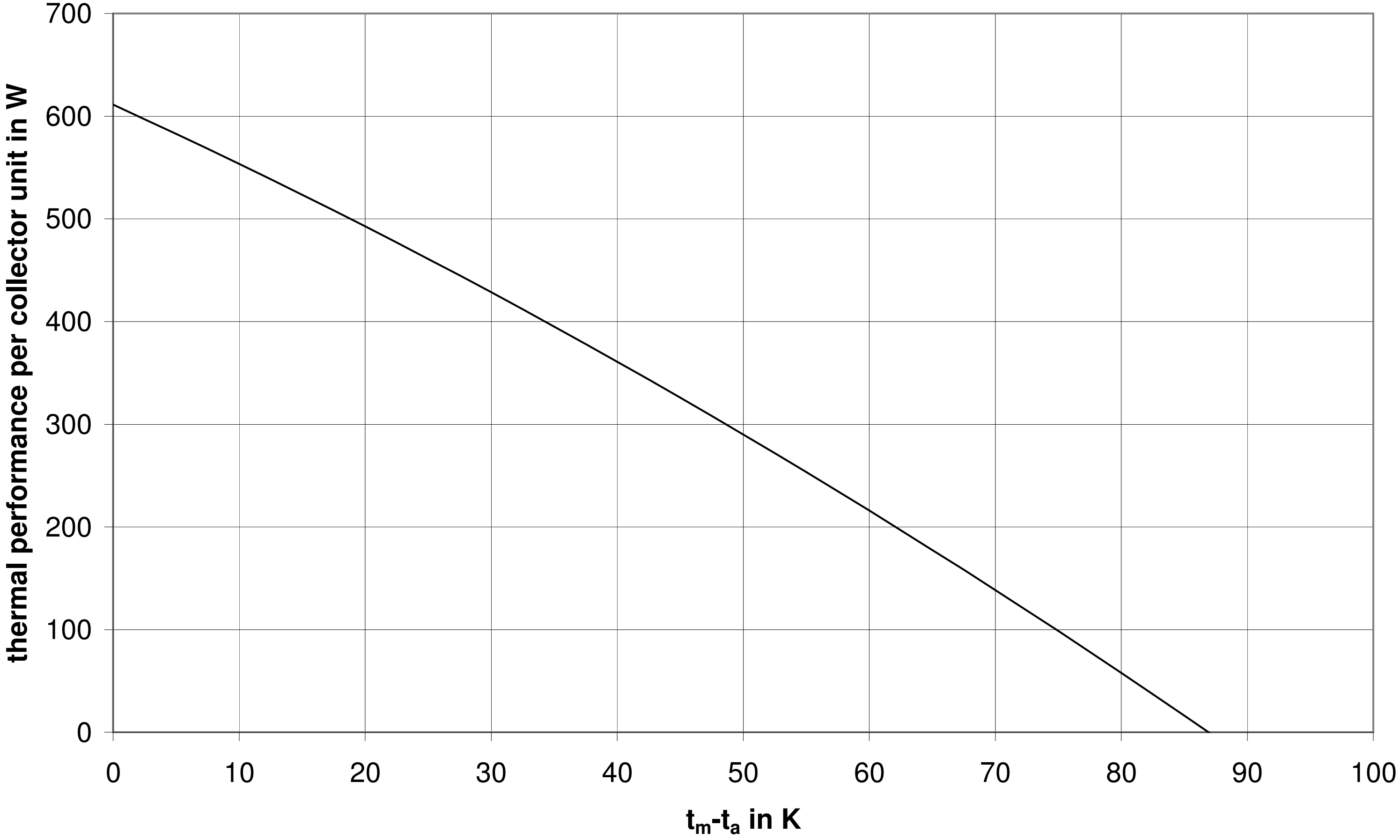
Table A-4: Temperatures at Different Positions of the Unglazed Collector, Meteorological Quantities

No.	t_{in}	t_e	t_m	t_a	t_s	t_{smglas}	t_{back}	t_{sm}	u
-	°C	°C	°C	°C	°C	°C	°C	°C	m/s
1	23.7	26.2	25.0	25.3	23.6	41.5	24.6	35.4	1.2
2	23.7	26.2	25.0	25.2	23.6	41.5	24.5	35.3	1.2
3	23.7	26.3	25.0	25.3	23.6	41.5	24.6	35.3	1.2
4	45.4	46.8	46.1	25.7	23.8	53.3	25.6	52.2	1.2
5	45.4	46.8	46.1	25.7	23.8	53.3	25.6	52.2	1.2
6	45.4	46.8	46.1	25.7	23.7	53.3	25.6	52.2	1.2
7	65.3	65.4	65.3	25.6	23.6	63.7	26.2	67.5	1.2
8	65.3	65.4	65.3	25.7	23.6	63.7	26.2	67.4	1.2
9	65.3	65.4	65.3	25.7	23.6	63.7	26.2	67.4	1.2

Nomenclature:

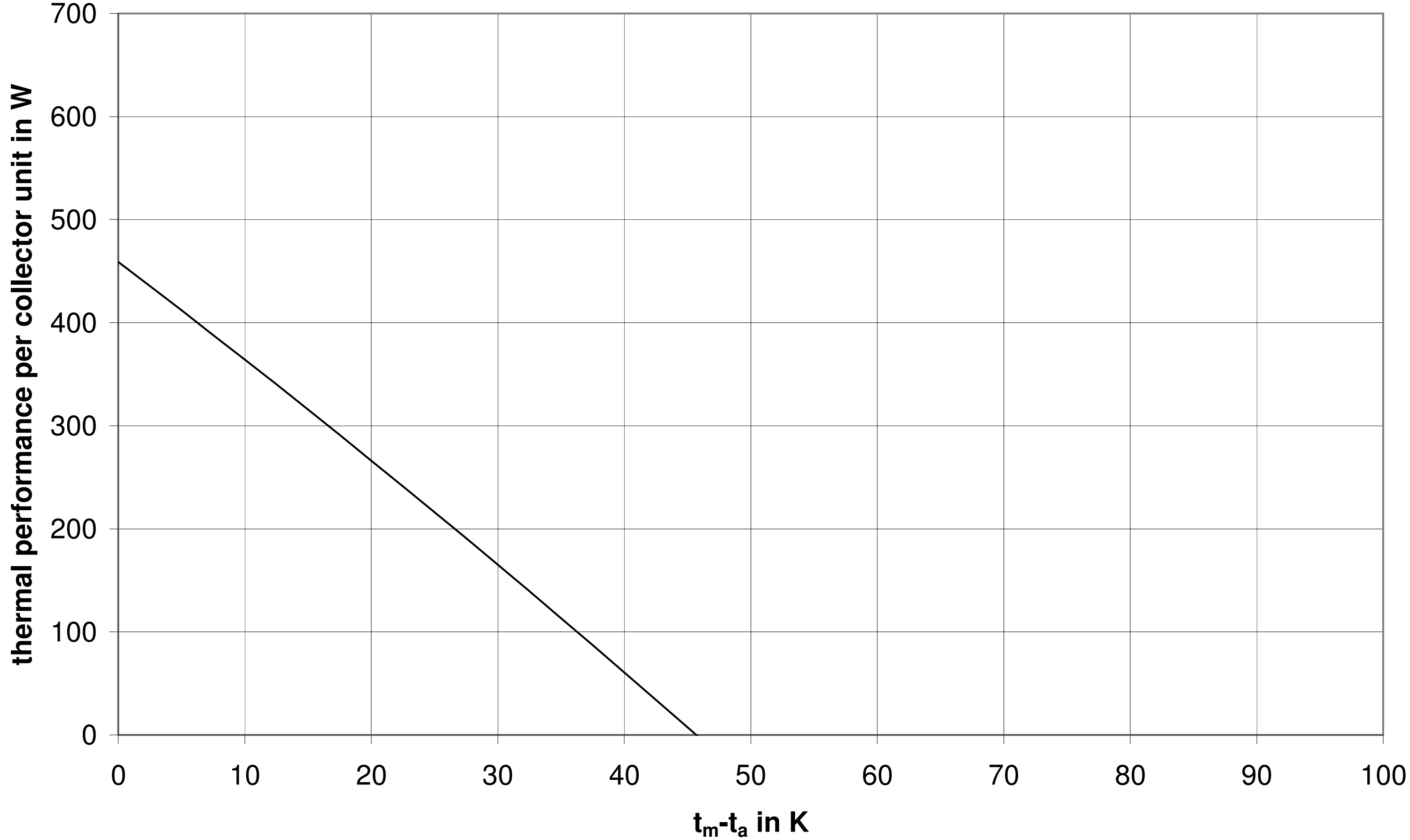
t_{in}, t_e	°C	collector inlet temperature and collector outlet (exit) temperature
t_m	°C	mean temperature of heat transfer fluid, $t_m := (t_{in} + t_e)/2$
t_a	°C	ambient temperature
t_s	°C	sky temperature
$t_{sm,glas}$	°C	temperature of the PV glazing
t_{back}	°C	temperature of the backside of the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

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



Company: Solimpeks Collector type: Volther Hybrid Collector glazed Serial No.: - Aperture area: 1.222 m²	Solar collector test similar to EN 12975-2:2006 electrical in MPP operation	ISFH	Report date: 30.04.2010 Report no.: 97-10/KP Page 23 of 26

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

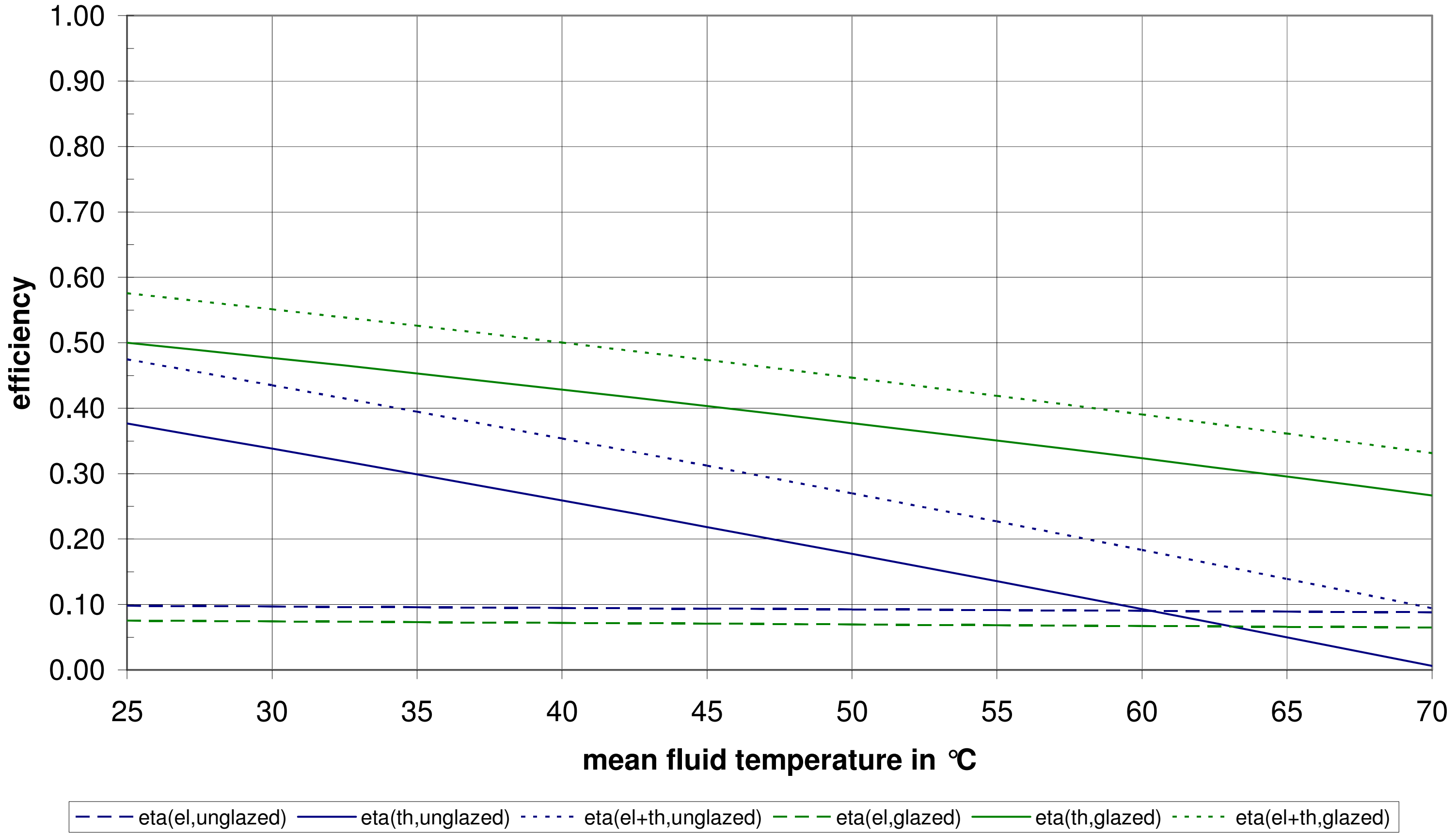


Company:	Solimpeks	Solar collector test	Report date: 30.04.2010
Collector type:	Volther Hybrid Collector unglazed	similar to EN 12975-2:2006	Report no.: 97-10/KP
Serial No.:	-	electrical in MPP operation	Page 24 of 26
Aperture area:	1.219 m²		

ISFH

Thermal and Electrical Efficiency Curve for the Glazed and Unglazed Collector

Reference value: irradiance 1000 W/m², ambient air temperature 25 °C, related to the aperture area



Company:	Solimpeks
Collector type:	Volther Hybrid Collector glazed / Volther Hybrid Collector unglazed
Serial No.:	-
Aperture area:	1.222 m² / 1.219 m²

Solar collector test

similar to EN 12975-2:2006

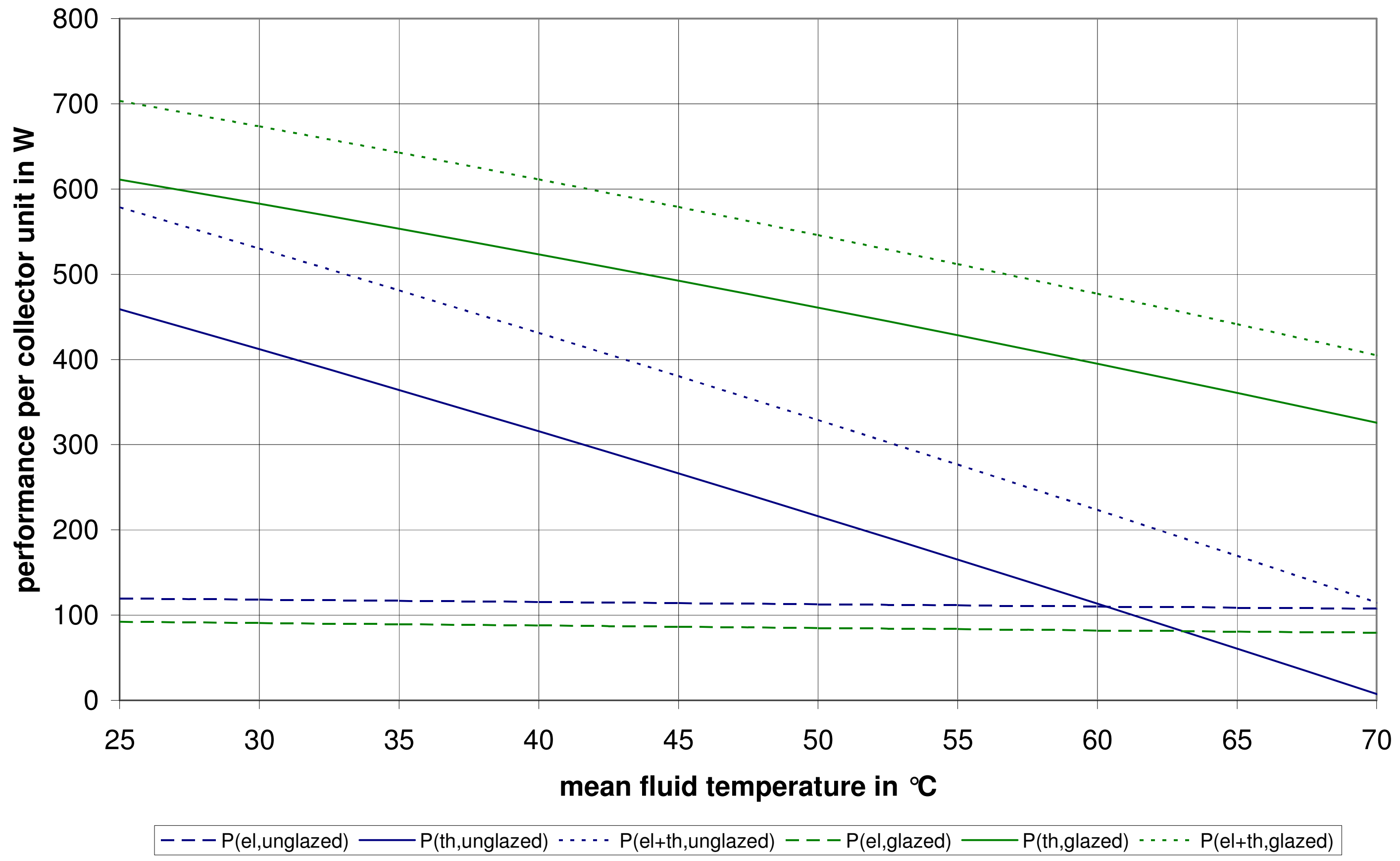
electrical in MPP operation

Report date: 30.04.2010

Report no.: 97-10/KP

Thermal and Electrical Performance Curve for the Glazed and Unglazed Collector

Reference value: irradiance 1000 W/m², ambient air temperature 25 °C, related to the aperture area



Company:	Solimpeks	Solar collector test	Report date: 30.04.2010
Collector type:	Volther Hybrid Collector glazed / Volther Hybrid Collector unglazed	similar to EN 12975-2:2006	Report no.: 97-10/KP
Serial No.:	-	electrical in MPP operation	Page 26 of 26
Aperture area:	1.22 m² / 1.219 m²		