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

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Test Basis

Test similar to	EN 12975-2:2006 Section 6

Test Report

Number	114-06/P-5
Date	05.06.2007
Number of pages	22

Customer

Address	Holtkamp SES Sandstr. 1 - 5 D- 48465 Schüttorf Germany
Contact person	Mr. Hoek Tel.: +49 (0)5923/994494, Fax: -994495

Test Collector

Type	PVT glazed
Manufacturer	Holtkamp SES
Serial- or Prototype	Prototype
Year of production	2006
Serial number	-

Contents

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1. Summary of the Prototype Results

Company:	**Holtkamp SES** Sandstr. 1 - 5 D- 48465 Schüttorf, Germany	Report no.: Report date:	114-06/P-5 05.06.2007
Type:	**PVT glazed**	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. 114-06/P-5 and to the tests and procedures described herein.

Description of the collector

Type	combi collector (solar thermal + photovoltaic)	Aperture area	1.222 m²
		Absorber area	1.200 m²
Length/Width/Height	1551 / 707 / 107 mm	Gross area	1.383 m²

Test results

Coefficients of efficiency
(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

thermal power output per collector unit

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

thermal peak power output per collector unit **611 $W_{peak,th}$ at G = 1000 W/m² and t_m-t_a = 0 K**

Electrical coefficients (module data for STC-conditions, G = 1000 W/m², T_{Module} = 25 °C)

Pmpp	Uoc	Isc	Umpp	Impp	FF	module efficiency
141.2 W	40.9 V	4.8 A	32.3 V	4.4 A	72 %	10.9 %

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

Emmerthal, 05.06.2007 pp J. Scheuren

J. Scheuren, head of Test Centre-FE

2. Description of the Collectors

2.1. Collector

Manufacturer	Holtkamp SES Sandstr. 1 - 5, D- 48465 Schüttorf
Type	PVT glazed
Construction	combi collector (solar thermal + photovoltaic), Prototype
Year of production	2006
Serial number	-

2.2. Glazing

Number of glazings	one
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

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)

2.6. Reference Areas

Absorber area	1.200 m²
Aperture area	1.222 m²
Gross area	1.383 m²

3. Photograph of the Collector

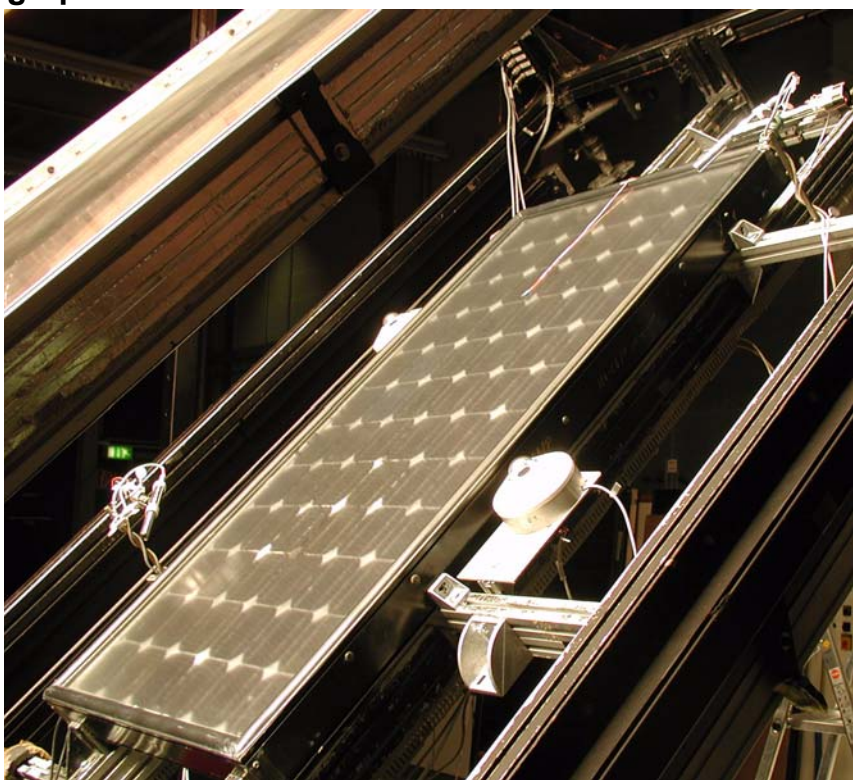


Fig. 3-1: Picture of the collector, mounted in the sun simulator SUSI I

4. General

The objective is to develop a new solarthermal plus photovoltaic hybrid collector (PVT). The combined thermal and electrical performance test is done in parallel operation (MPP). As a partial test the 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 collector arrives the actual condition is reported. The collector is equiped with temperature sensors as descriped in chapter 7.

5.2. Determination of the Stagnation Temperature

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

5.4. Electrical Performance Test

In a separate Flasher performance test the electrical perfomance is measured once more.

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-2 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 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)		
	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

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

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.

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: 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 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**	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 module is in MPP operation.

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 and table A-2 in the appendix.

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

	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, 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

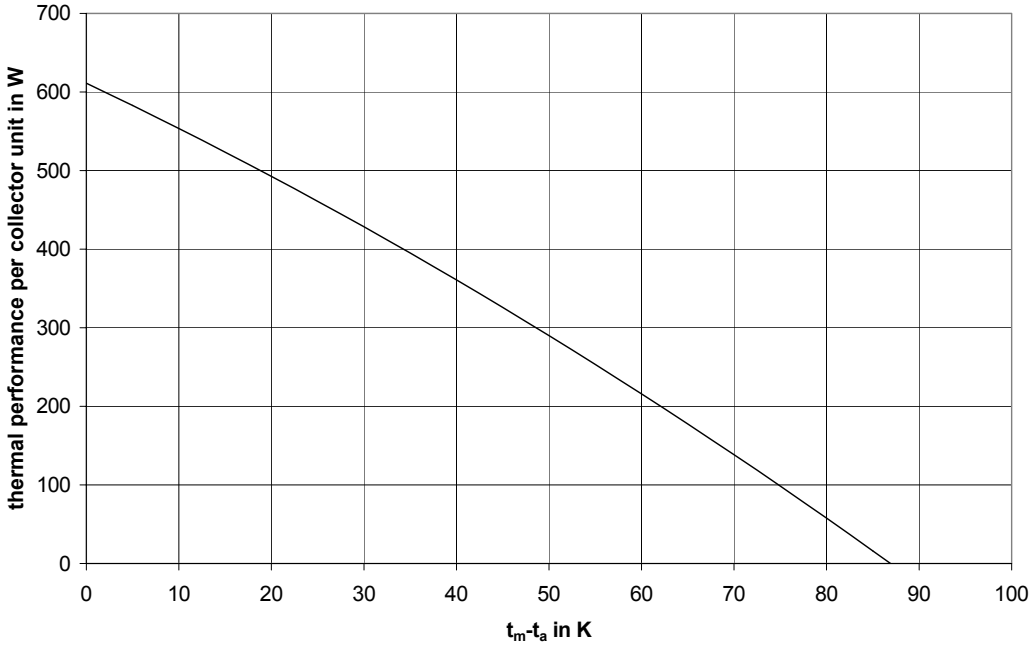


Fig. 10-1: Power curve for G = 1000 W/m², related to the collector unit (electrical MPP operation)

Note:

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

11. Determination of the electrical variables

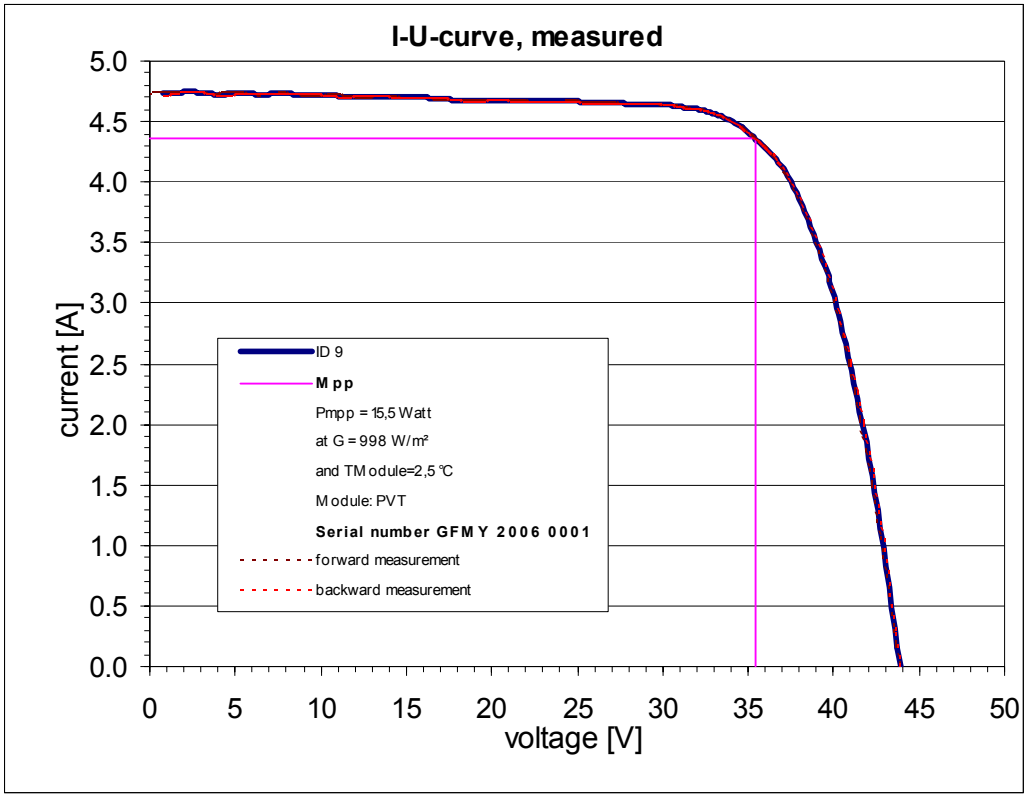
Data of the module	
Manufacturer:	Holtkamp SES
Module type:	**PVT**
Serial number:	**GFMY 2006 0001**
Cell type:	mono
Cell dimensions:	12,5 x 12,5 ps. Sq.
Number of seriel cells:	72
Strings parallel:	1
Total number of cells:	72
Colour backsheet:	white
Frame:	aluminium
Total length [mm]	1587
Total width [mm]	815
Module area [m²]	1.293405
Net power [W]	180

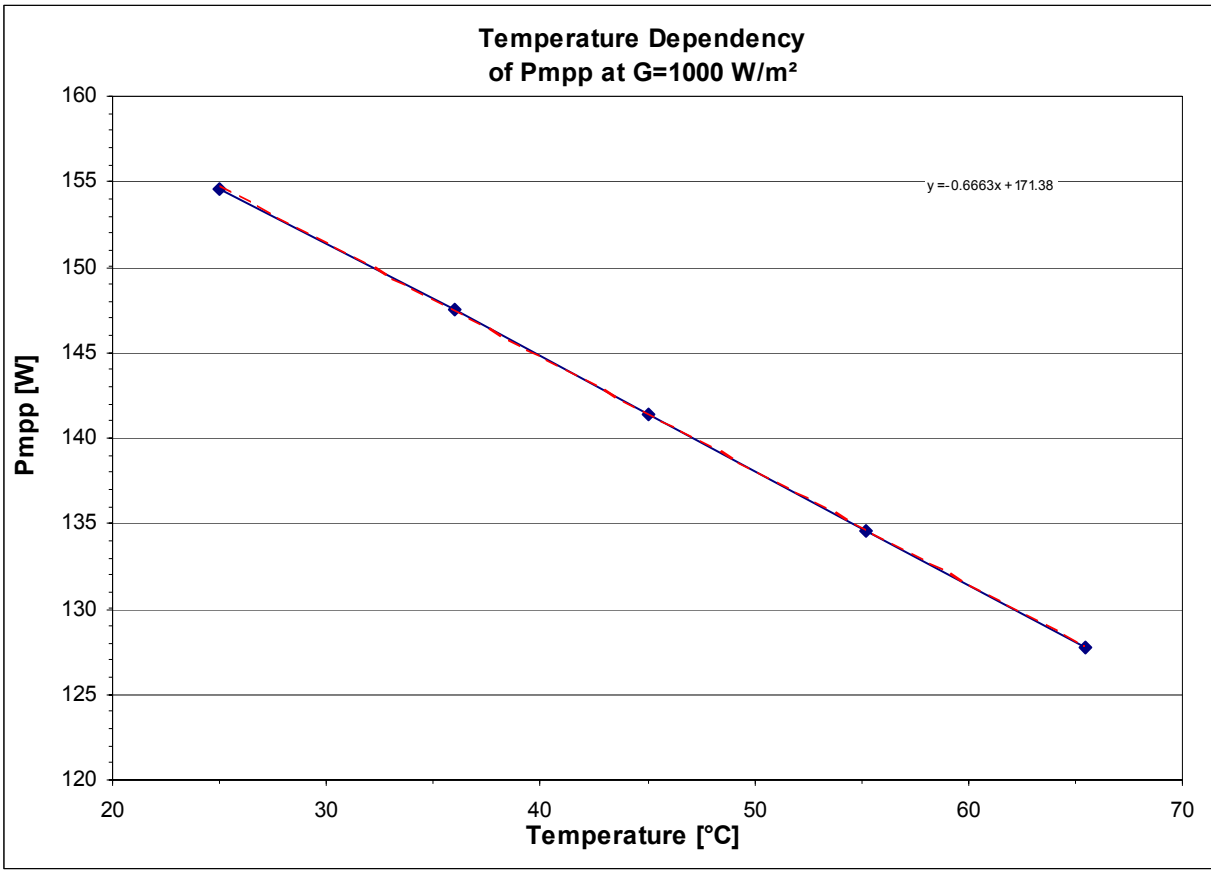
Measurements	
Date:	17.04.2007
Inspector:	Iris Kunze

Measured characteristic curve (Indoor)	
Data file (ID):	9
Time	18:08:41
G [W/m²]	998
Pmpp [W]	154.6
Uoc [V]	43.92
Isc [A]	4.74
Umpp [V]	35.5
Impp [A]	4.36
FF [%]	74.3
T [°C]	25.0

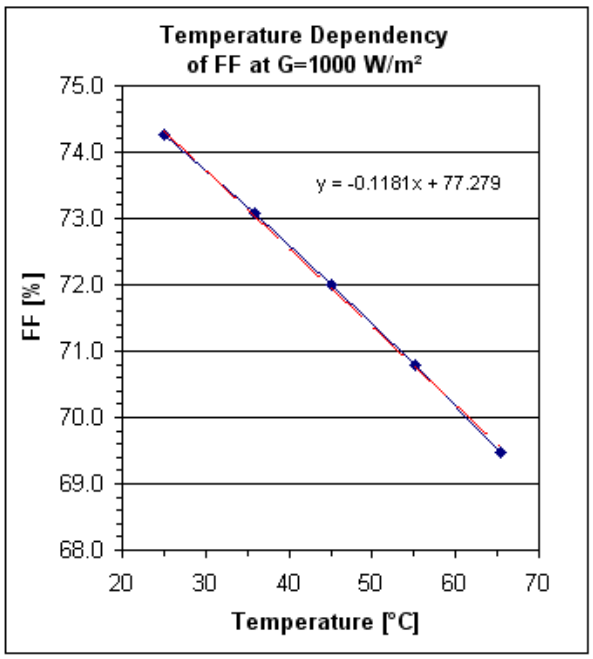
Calculated module data for STC- conditions (G=1000 W/m²; T_Modul=25°C)	
Pmpp [W]	**141.2**
0	40.9
Isc [A]	4.8
Umpp [V]	32.3
Impp [A]	4.4
FF [%]	72.0
Module efficiency	10.9%

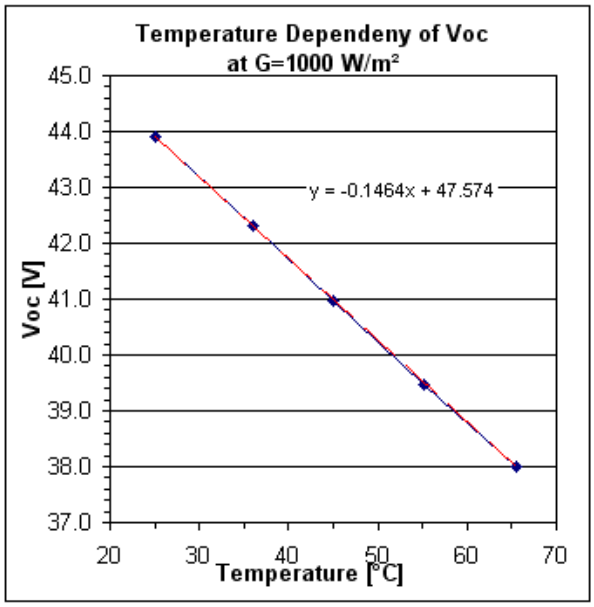
Basis of calculation:
Linear increase of Pmpp with G
and linear loss of performance of 0.16%
per °C temperature increase of the module
Measuring accurancy Pmpp +- 4 %
Measuring accurancy temperature coefficients +- 2 %

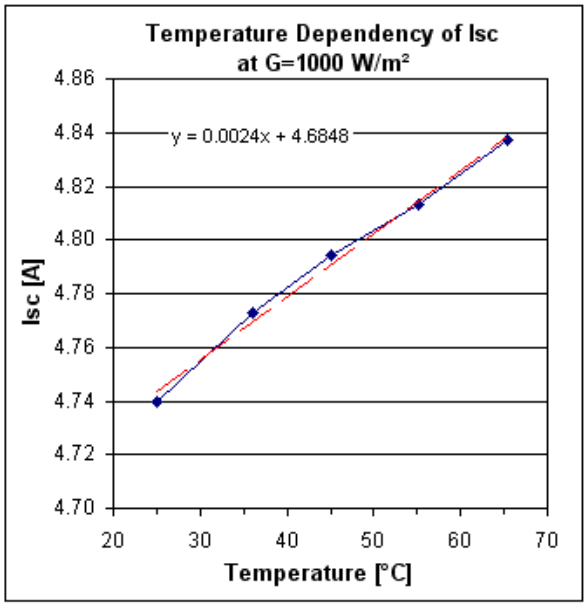

I-U-curve, measured
current [A]
voltage [V]
ID 9
Mpp
Pmpp = 15,5 Watt
at G = 998 W/m²
and TModule=2,5 °C
Module: PVT
Serial number GFMY 2006 0001
forward measurement
backward measurement


Temperature Dependency
of Pmpp at G=1000 W/m²
Pmpp [W]
Temperature [°C]
y = -0.6663x + 171.38

Temperature coefficient	[1]: gemessen
Tk Pmpp [W/°C]	-0.220
Tk Uoc [V/°C]	-0.048
Tk Isc [A/°C]	0.001
Tk Umpp [V/°C]	-0.051
Tk Impp [A/°C]	0.000
delta Pmpp [%/°C]	-0.002
delta Uoc [mV/°C per Cell]	-0.672
delta Isc [mA/°C per String]	0.778







12. Observations; Status of the Collector

Status of the collector after

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

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

13. Comment about the Results

For the interpretation of the results of the electrical performance (see table A-1) 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.

14. Stipulations from the Test Centre

1. This test report is valid for the collector PVT glazed (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 and 19 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.-Phys. J. Scheuren

Head of Test Centre-FE

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

Nr.	G	$\dot{m}$	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
$\dot{m}$	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
P_{MPP}	W	performance of the PV module in MPP operation
η_{el}	-	collector electrical efficiency, related to the aperture area

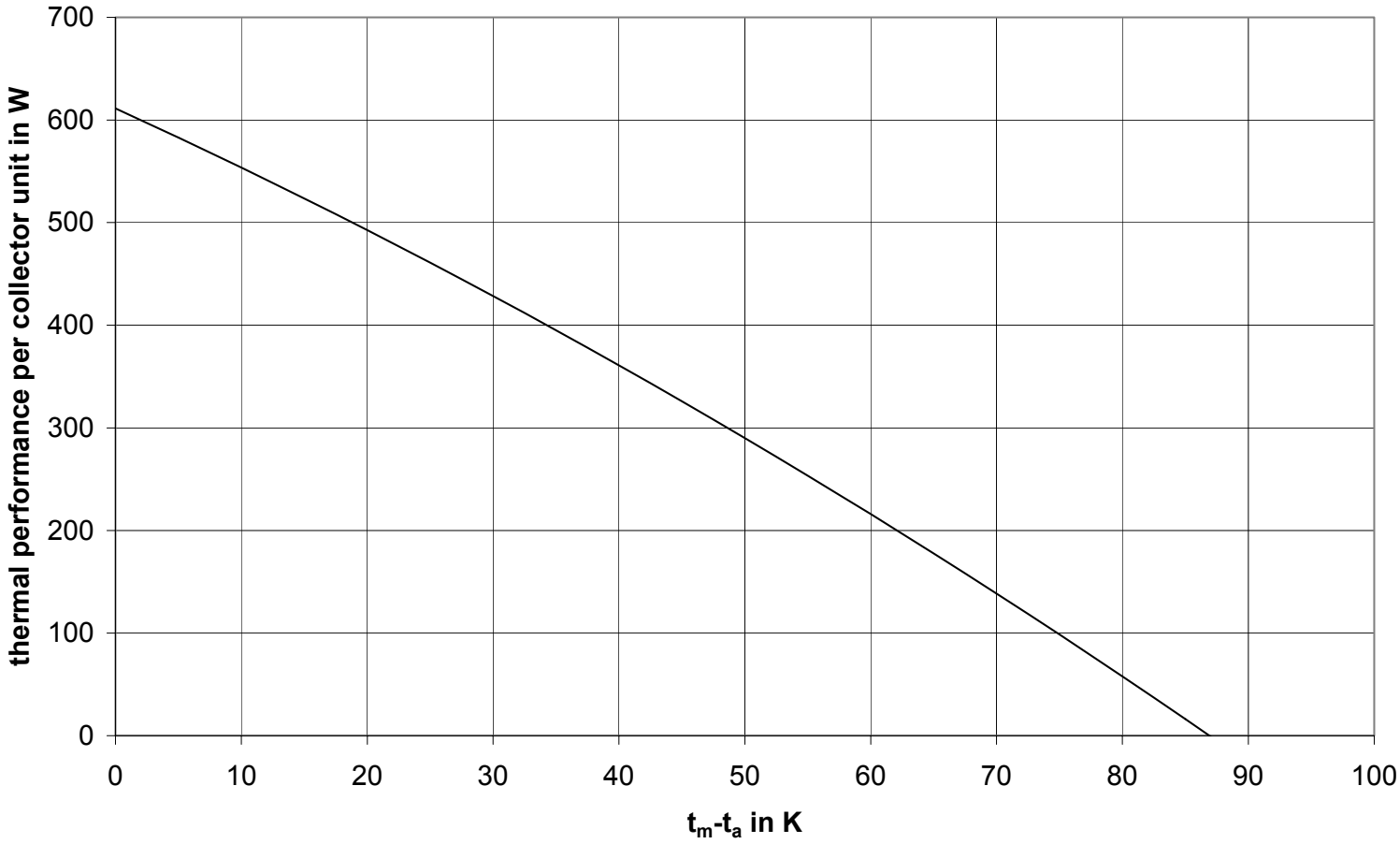
Table A-2: Temperatures at Different Positions, Meteorological Quantities

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:

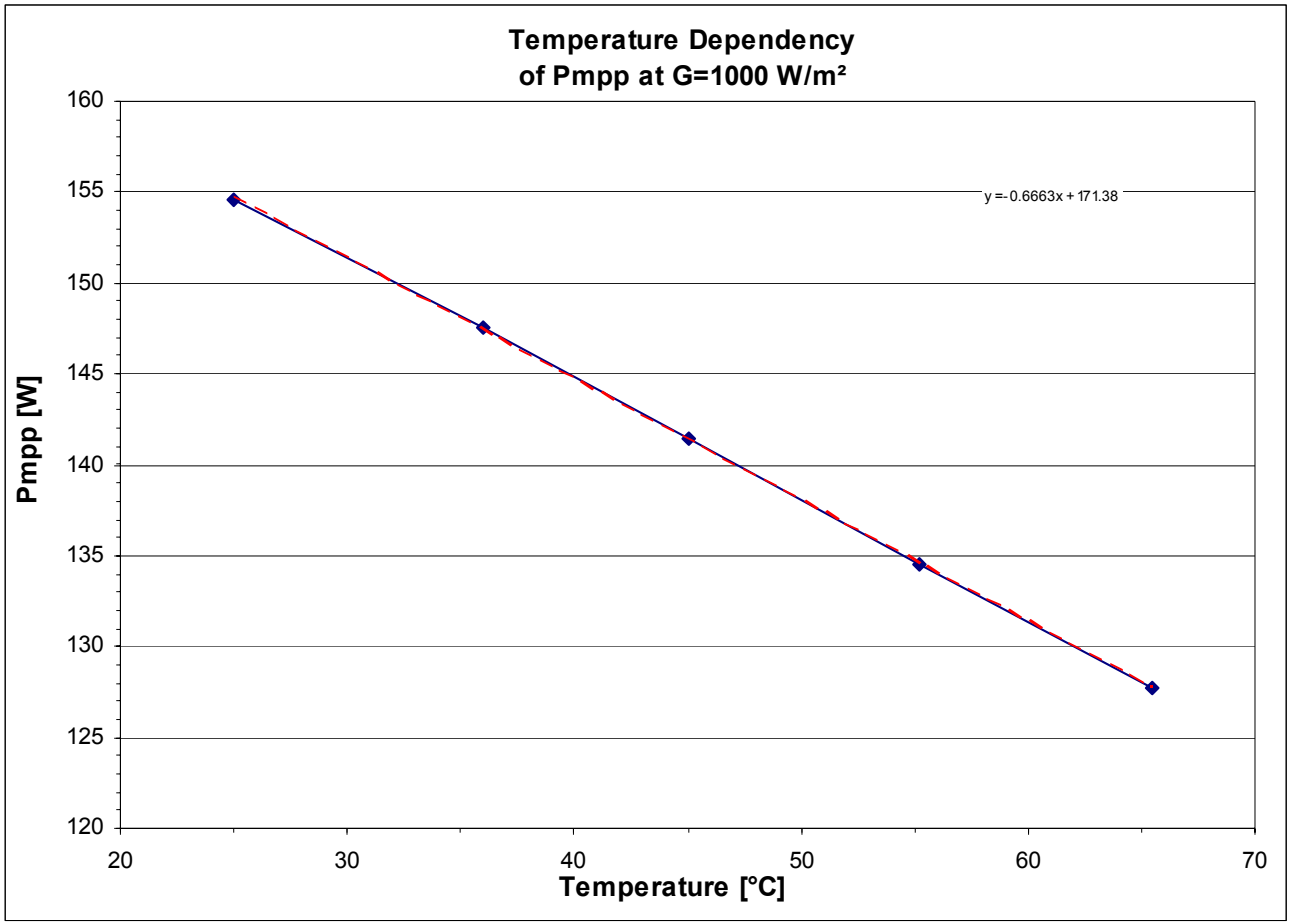
t_{in}, t_e	°C	collector inlet temperature and collector outlet (exit) temperature
t_m	°C	mean temperature of heat transfer fluid, t_m: = $(t_{in} + t_e)/2$
t_a	°C	ambient temperature
t_s	°C	sky temperature
t_{glas}	°C	temperature of the transparent cover
t_{back}	°C	temperature of the backside of the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

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



Company:	Holtkamp SES	Solar collector test	Report date: 05.06.2007
Collector type:	PVT glazed	similar to EN 12975-2:2006	Report no.: 114-06/P-5
Serial No.:	-	electrical in MPP	Page 19 of 22
Aperture area:	1.222 m²		

Temperature Dependency of Pmpp at G = 1000 W/m²



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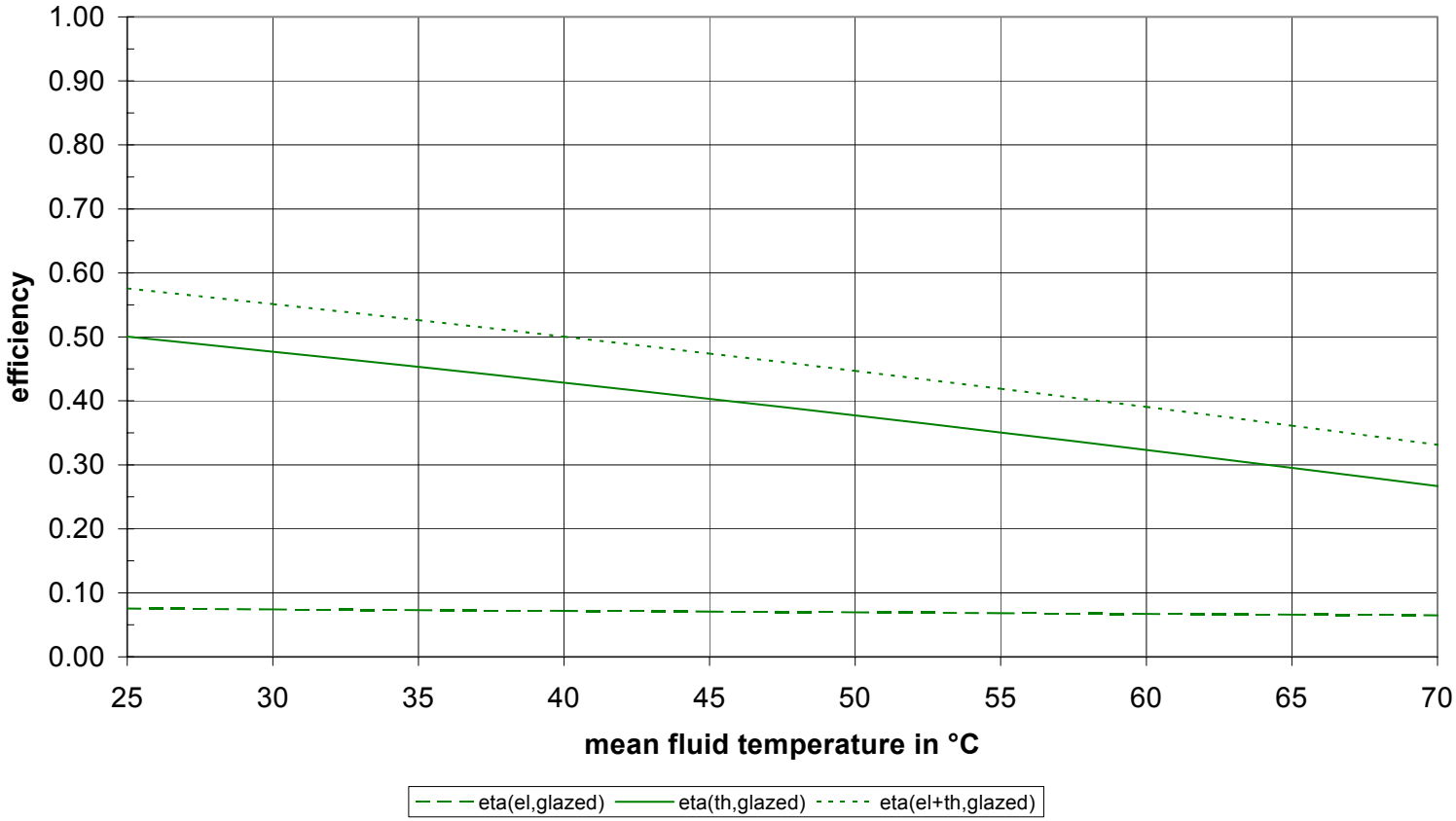
Aperture area:	1.222 m²		

Thermal and Electrical Efficiency Curves



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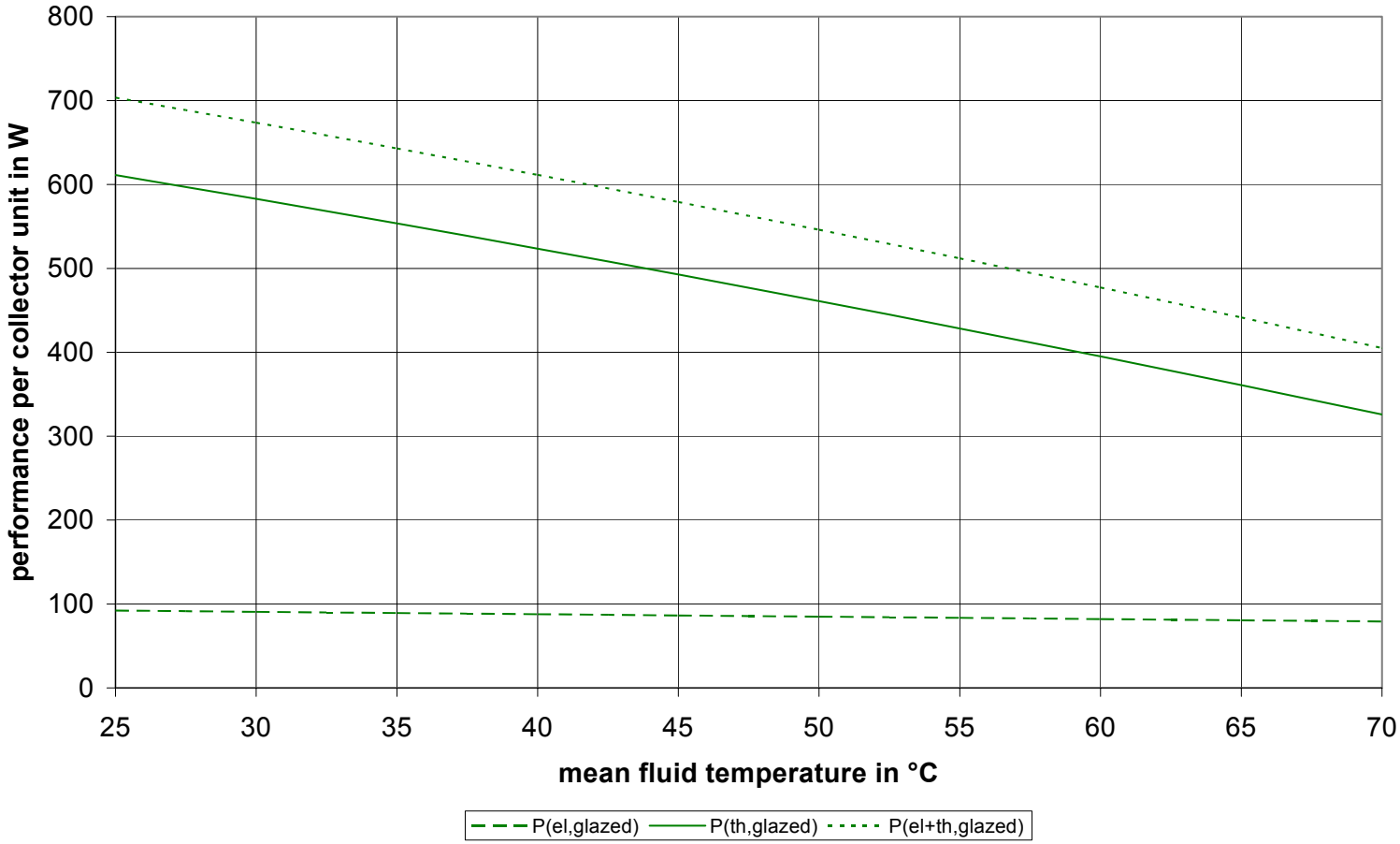
Aperture area:	1.222 m²		

Thermal and Electrical Performance Curves



Company:	Holtkamp SES
Collector type:	PVT glazed
Serial No.:	-
Aperture area:	1.222 m²

Solar collector test

similar to EN 12975-2:2006

electrical in MPP

Report date: 05.06.2007

Report no.: 114-06/P-5