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**TÜV Rheinland (Shanghai) Co., Ltd**
Solar/ Fuelcell Technologies

# Test Report

Qualification of a Solar Collector in accordance with
DIN EN 12975-1: 2011; DIN EN 12975-2: 2006

**TÜV Report No.: 154026306a_EN_30_Report_Gao**

**Shanghai, 05 December 2013**

DAkkS
Deutsche
Akkreditierungsstelle
D-PL-11097-02-01



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on

Qualification of a Solar Collector in accordance with

DIN EN 12975-1: 2011; DIN EN 12975-2: 2006

| | |
|---|---|
| Client: | Haining Onosi New Energy Co.,ltd.<br>Xinkai River No.2 Bridge,Wanshou Village<br>314412, Yanguan Town, Haining City<br>Zhejiang Province<br>P.R. China |
| TÜV Quotation No.: | 52081164 |
| TÜV Order No.: | 154026306 |
| Order of: | 13 May 2013 |
| Date of Receipt of Test Item: | 13 June 2013 |
| Commencement of Test: | 14 June 2013 |
| TÜV Client No.: | 486540 |
| Inspector: | P.Gao +86 (0)21 60811633 |
| Business Field: | Solar Energy |
| No of Pages: | 30 |
| Appendix: | 22 to 30 |

**Summary of collector performance test results:**

| | | | |
|---|---|---|---|
| Manufacturer | Haining Onosi New Energy Co.,Ltd | | |
| Brand | ONOSI | | |
| Collector type | ONS-HPC-30 | | |
| Year of manufacture | 2013 | | |
| Length | 2020 mm | Absorber area | 2.42 m² |
| Width | 2315 mm | Aperture area | 2.84 m² |
| Height | 158 mm | Gross area | 4.68 m² |
| Weight (empty) | 103 Kg | Mass flow | 0.021 kg/(m²s) |
| Heat transfer medium | Water | Test pressure: | 150 kPa |

**Thermal performance**

| | Aperture area ($A_a$) | Absorber area ($A_A$) |
|---|---|---|
| Conversion factor $\eta_0$ | 0.684 | 0.802 |
| Heat transfer coefficient $a_1$ | 1.001 W/(m²K) | 1.175 W/(m²K) |
| Temperature dependent heat transfer coefficient $a_2$ | 0.018 W/(m²K²) | 0.021 W/(m²K²) |

**Output power per collector unit**

| | Irradiation | | |
|---|---|---|---|
| $T_m - T_a$ in K | 400 W/m² | 700 W/m² | 1000 W/m² |
| 10 | 729 | 1300 | 1872 |
| 30 | 634 | 1205 | 1777 |
| 50 | 499 | 1071 | 1642 |

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## List of Contents – Appendix

# 1 Summary of test results

Qualification of a Solar Collector in accordance with

DIN EN 12975-1: 2011; DIN EN 12975-2: 2006

**Manufacturer** : Haining Onosi New Energy Co.,ltd.
Xinkai River No.2 Bridge,Wanshou Village
314412, Yanguan Town, Haining City
Zhejiang Province
P.R. China

**Brand** : ONOSI

**Collector type** : ONS-HPC-30

| Test | | Date | | Summary of main test results |
|---|---|---|---|---|
| | | Start | End | |
| Internal pressure | | 14 June 2013 | | No visual damages |
| High-temperature resistance | | 14 September 2013 | | No visual damages |
| Exposure | | 14 June 2013 | 27 August 2013 | No visual damages |
| External thermal shock | 1st | 15 July 2013 | | 893* W/m² No visual damages |
| | 2nd | 07 August 2013 | | 884* W/m² No visual damages |
| Internal thermal shock | 1st | 15 July 2013 | | 904* W/m² No visual damages |
| | 2nd | 15 August 2013 | | 954* W/m² No visual damages |
| Rain penetration | | 28 August 2013 | | No visual damages |
| Mechanical load | | 24 September 2013 | | No visual damages |
| Thermal performance | | 28 Septem-ber 2013 | 15 October 2013 | No visual damages |
| Final inspection | | 25 September 2013 | | No visual damages |

All above listed tests of the standard DIN EN 12975-2:2006 were passed successfully in accordance with the criteria.

# 2 Setting of tasks

A complete collector test in accordance with DIN EN 12975-2:2006 of the Haining Oupair-ineng Solar Water Heater Co.,Ltd collector ONS-HPC-30 should be performed with the aim of Solar Keymark certification.

# 3 Basis of testing

EN 12975-1:2011 *„Thermal solar systems and components – Collectors – Part 1: General requirements“*

EN 12975-2:2006 *“Thermal solar systems and components – Collectors – Part 2: Test procedure”*

Solar Keymark – Specific Scheme Rules v20.00 March 2013: *“Specific CEN Keymark Scheme Rules for Solar Thermal Products”*

**Shanghai, 05 December 2013**

**Responsible for collector testing**

Dipl.-Ing. Peng Gao

**Assistant Manager**

Dipl.-Ing. M. Kottwitz

# 4 Sampling

| | |
|---|---|
| Prototype samples | ○ |
| Samples from pilot production | ◙ |
| Samples from serial production | ○ |
| Selection of test samples acc. to Solar Keymark scheme rules | ◙ |
| Random selection of test samples acc. to SRCC scheme rules | ○ |

# 5 Description of the collector construction

| | |
|---|---|
| | Haining Onosi New Energy Co.,Ltd |
| Brand name | ONOSI |
| Collector Type | ONS-HPC-30 |
| Category | Evacuated tube-collector |
| Date of manufacture | 2013 |
| Serial number | ONS/HPC30-20130603011 ONS/HPC30-20130503001 |
| Drawing numbers | ON S-HPC-ZZ(1); ON S-HPC-ZZ(2); OPRN-C-TZ005(2); OPRN-C-TZ002(2); ONS-HPC-RG24 etc. |

Collector & construction:

| | |
|---|---|
| Gross dimensions l x w x t [mm] | 2020 x 2315 x 158 ① |
| Normative Absorber dimensions l x Øouter of inner tube [mm] x no. of tubes | 1725 X 47 x 30 ① |
| Physical Absorber dimensions l x Øouter of inner tube [mm] x no. of tubes | 1744 X 47 x 30 ① |
| Aperture dimensions l x Øinner of outer tube [mm] x no. of tubes | 1725 X 55 x 30 ① |
| Gross/ Aperture/ Absorber area [m²] | 4.68 ① / 2.84 ① / 2.42 ① |
| Weight empty [kg] | 103 ② |
| Fluid content [l] | 1.79 ③ |

Absorber:

| | |
|---|---|
| Construction type | Heat-pipe Sydney-Glass tube ② |
| Absorber Material | glass with aluminium heat transfer sheets ② |
| Absorber Grid | serial ② |
| Absorber thickness [mm] | 1.60 ② |
| Effective Surface | all around ② |

① Determinate by test laboratory
② reviewed manufacturer information
③ according to manufacturer information

| | |
|---|---|
| Surface treatment | CU/SS-N /AL ③ |
| Absorptance [ ] | 0.91 ③ |
| Emittance [ ] | 0.06 ③ |

Absorber Piping:

| | |
|---|---|
| Collector connection type / dimension / numbers | pipe / 22 mm / 2 ② |
| Header tube material / dimension | copper ② / 38 mm ② |
| Riser tube-header / tube-Absorber connection | brazed ② / mechanical ② |
| Riser tube material / $Ø_{outer}$ / thickness / overall length [mm] | copper / 24 / 1 / 67.2 ② |
| Number and Distance [mm] of riser tubes or fins on center position | 30 / 75 ② |

Cover:

| | | |
|---|---|---|
| Number of covers | 1 ② | |
| Glazing to absorber space [mm] | 3.7 ② | |
| | Glas 1 | Glas 2 |
| Length / $Ø_{outer}$ / thickness [mm] | 1800 / 58 / 1.6 ② | - |
| Material / surface and coating | Borosilicate glass / clear glass ③ | - |
| Transmittance factor [ ] | 0.910 ③ | - |

Casing:

| | | |
|---|---|---|
| Enclosure L x W x T [mm] | 2305 / 161 / 123 ② | |
| Enclosure material | aluminium alloy ② | |
| Enclosure backside material | not part of construction ② | |
| Frame fastening method | screws ② | |
| Insulation | Primary Material | Secondary Material |
| Material | Rock wool ② | - |
| Thickness [mm] | 20 / 56 ② | - |
| Material thermal conductivity [W/Km²] | 0.043 ③ | - |
| Lateral insulation | Primary Material | Secondary Material |
| Material | - | - |
| Thickness [mm] | - | - |
| Material thermal conductivity [W/Km²] | - | - |

① Determinate by test laboratory
② reviewed manufacturer information
③ according to manufacturer information

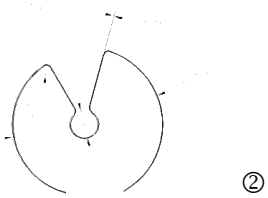
Sealing`s:

| | |
|---|---|
| Frame - Cover | not part of construction ② |
| Frame Corner or side caps | Silicon base ② |
| Frame - back sheet | not part of construction ② |
| Grommet header tube | Silicon base ② |
| Grommet evacuated tube | Silicon base ② |
| Evacuated tube closure | Silicon base ② |

Head pipe:

| | |
|---|---|
| total length [mm] | 1700 ② |
| Heating section length / -diameter [mm] | 1625 / 8 ② |
| Condenser length / -diameter [mm] | 75 / 24 ② |
| Material | copper ② |
| Fluid | water ③ |
| Fluid content [l] | 1.5 ③ |
| Filling pressure [kPa] | $1.3*10^{-6}$ ③ |

Heat conduction plate (HCP):

| | |
|---|---|
| HCP per tube | 1 ② |
| | Unit I |
| HCP Form |  ② |
| HCP material | aluminium ② |
| Number of HCP Parts per tube | 1 ② |
| HCP length / thickness [mm] | 1630 / 0.24 ② |

Limit values (given by manufacturer):

| | |
|---|---|
| Max. operating temperature [°C] | 185 |
| Maximum operating pressure [kPa] | 600 |
| Recommended Heat transfer medium | Water Glycol mixture |
| Recommended operating mass Flow [l/(m²h)] | Not mentioned |
| Tilt angle limits [°] | 30 to 70 |

① Determinate by test laboratory
② reviewed manufacturer information
③ according to manufacturer information

| | |
|---|---|
| Collector mounting | on roof and flat roof mounting in vertical position is possible |
| Other limitations | not mentioned |

Instruction/installation manual:
Installation manual the requirements of DIN EN 12975-1:2011

| | Comments | fulfilled |
|---|---|---|
| Dimensions and weight of the collector, instructions for transport and handling thereof | | Yes |
| Description of the assembly procedure | | Yes |
| Recommendations regarding lightning protection | | Yes |
| Instructions for connecting collectors to each other and for connection of the collector field to the heat transfer circuit as well as dimensions of tube connections in collector groups up to 20 m² | | Yes |
| Recommendations regarding the usable heat transfer media (also with regard to corrosion) as well as precautionary measures which are to be taken for filling, operation, servicing and maintenance | | Yes |
| Maximum operating pressure, pressure loss as well as largest and smallest tilt angles | | Yes |
| Permissible wind and snow load | | Yes |
| Maintenance requirements | | Yes |

Collector type plate:
Collector marking requirements of DIN EN 12975-1:2011

| | Comments | fulfilled |
|---|---|---|
| Name of the manufacturer | | Yes |
| Type of collector | | Yes |
| Serial number | | Yes |
| Year of manufacture | | Yes |
| Gross collector area | | Yes |
| Dimensions of the collector | | Yes |
| Maximum operating pressure | | Yes |
| Stagnation temperature, at 1000 W/m² and 30 °C | | Yes |
| Volume of the heat transfer fluid | | Yes |
| Empty weight of the collector | | Yes |
| Manufactured in: … | | Yes |
| Durability: | No problems detected during exposure test acc. to EN12975-2 | Yes |

① Determinate by test laboratory
② reviewed manufacturer information
③ according to manufacturer information

# 6 Execution and evaluation

## 6.1 Visual inspection

| Date | 14 June 2013 | Inspector | Reba Liu |
|---|---|---|---|
| Internal barcode no. | Serial no. | Description of defects | |
| 154026306-1 | ONS/HPC30-20130503001 | No visual damages | |
| 154026306-1 | ONS/HPC30-20130603011 | No visual damages | |

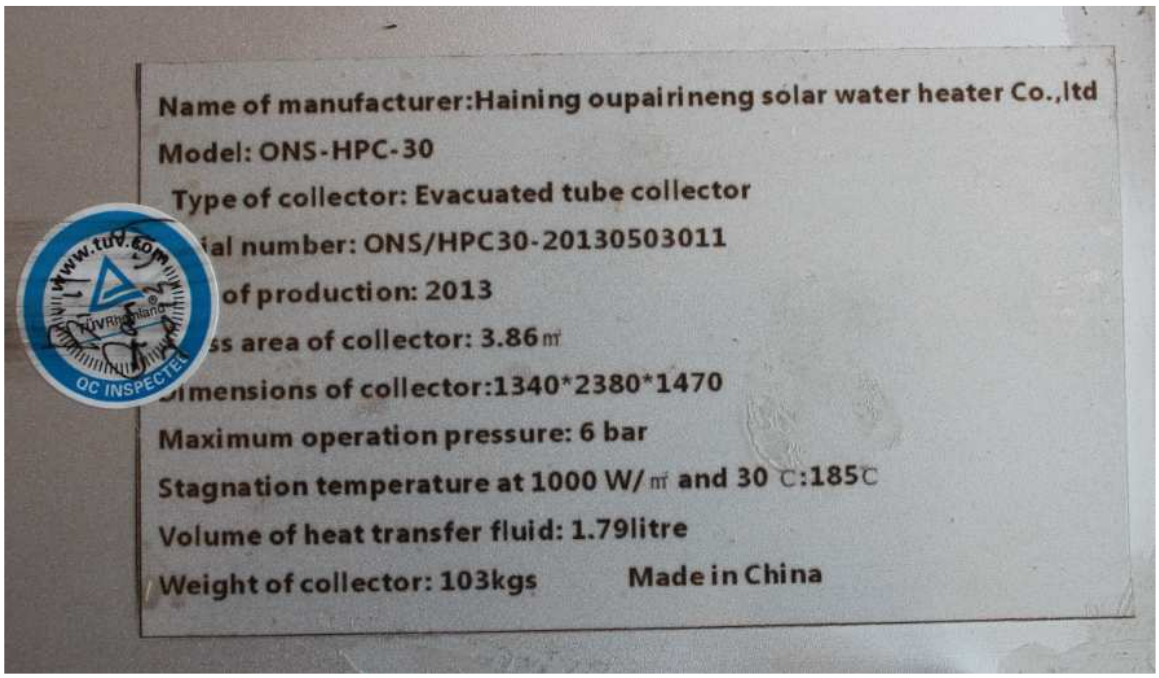



*Fig. 1: test sample label (random selection)*

## 6.2 Internal pressure test

### 6.2.1 Collector type

| | | |
|---|---|---|
| Absorber material | ◙ Inorganic | ○ Organic |
| Maximum collector operating pressure specified by manufacturer [kPa] | 600 | |
| Serial no. | ONS/HPC30-20130603011 | |

### 6.2.2 Test conditions;

| | | | |
|---|---|---|---|
| Date | 14 June 2013 | Inspector | Reba Liu |
| Test temperature [°C] | | 30 | |
| Test pressure [kPa] | | 953.5 | |
| Test duration [min] | | 15 | |
| Pressure difference [kPa] | | -15.6 | |

### 6.2.3 Test results

| |
|---|
| Details of any observed or measured leakage, swelling or distortion and problems which according to 5.2 of EN 12975-1:2011 are to be classified as “severe”. |
| No visual damages |

## 6.3 High temperature resistance test

| | | | |
|---|---|---|---|
| Serial no. | | ONS/HPC30-20130603011 | |
| Date | 14 September 2013 | Inspector | Reba Liu |

### 6.3.1 Method used to heat collector

| | |
|---|---|
| Test performed with outdoor exposure / solar simulator | Outdoor |

### 6.3.2 Conditions for testing high temperature resistance

| | |
|---|---|
| Collector tilt angle [° from horizontal] | 30 |
| Average irradiation during test [W/m²] | 1039 |
| Average ambient air temperature [°C] | 26.2 |
| Average ambient air speed [m/s] | 0.3 |
| Duration of test [min] | 60 |

### 6.3.3 Test results

| |
|---|
| Details of any observed or measured degradation, distortion, shrinkage or out gassing and problems which according to 5.3.4 of EN 12975-1:2011 are to be classified as “severe”. |
| No visual damages |

## 6.4 Stagnation temperature

| | | | |
|---|---|---|---|
| Serial no. | | ONS/HPC30-20130603011 | |
| Date | 14 September 2013 | Inspector | Reba Liu |

### 6.4.1 Method used to heat collector

| | |
|---|---|
| Test performed with outdoor exposure / solar simulator | Outdoor |

### 6.4.2 Conditions for testing stagnation temperature

| | |
|---|---|
| Collector tilt angle [° from horizontal] ◦ | 30 |
| Average irradiation during test [W/m²] | 1039 |
| Average ambient air temperature [°C] | 26.2 |
| Average ambient air speed [m/s] | 0.3 |
| Absorber temperature [°C] | 206.4 |

Requisite additional information for stagnation temperature:

### 6.4.3 Determination of stagnation temperature

| | |
|---|---|
| Stagnation temperature<br>for ambient conditions of 1000W/m² and 30°C<br>(determination acc. to EN 12975-2:2006, Annex C) | 201.9 |

### 6.4.4 Test remarks

| Requisite additional information for stagnation temperature: |
|---|
| Single pipe used for detection of stagnation temperature |

## 6.5 Exposure test

| | | |
|---|---|---|
| Serial no. | ONS/HPC30-20130603011 | |
| Date begin/ end | 14 June 2013 | 27 August 2013 |
| Inspector | Reba Liu | |

### 6.5.1 Test conditions

| | | |
|---|---|---|
| Collector tilt angle [° from horizontal] | 30 | |
| Total no. of test days and radiation energy [MJ/m²] | 74 | 1102.4 |
| No. of days with more than 14 MJ/m² | 31 | |
| No of rain days and total rainfall [mm] | 41 | 316.7 |
| Time period with G>850 W/m² & ta>10°C [h] | 54.8 | |
| | minimum value | maximum value |
| Ambient temperature of test days [°C] | 16.6 | 35.2 |
| Ambient temperature during high irradiation > 850 W/m² [°C] | 25.1 | 32.8 |
| Total daily rainfall [mm] | 0.0 | 38.9 |

### 6.5.2 Test results

| Details of any observed or measured problems or failures which according to B 5.5 of EN 12975-2:2006 are to be classified as “severe”. |
|---|
| No visual damages |

For more details about exposition test see Appendix 2: climate data.

## 6.6 External thermal shock test

### 6.6.1 Test conditions

| | 1st shock | | 2nd shock | |
|---|---|---|---|---|
| Test performed with outdoor exposure / solar simulator | Outdoor | | Outdoor | |
| Serial no. | ONS/HPC30-20130603011 | | | |
| Date | 15 July 2013 | | 07 August 2013 | |
| Inspector | Reba Liu | | Reba Liu | |
| Collector tilt angle [° from horizontal] | 30 | | 30 | |
| Irradiation $G^*_{min}$ & $G^*_{mean}$ [W/m²] | 893 | 918 | 884 | 984 |
| Ambient air temperature $t_{a\,min.}$ & $t_{a\,mean}$ [°C] | 28.3 | 28.9 | 29.6 | 30.3 |
| Period during which steady state conditions were maintained prior to shock [min] | 60 | | 60 | |
| Water spray mass flow rate [kg/(sm²)] | 0.031 | | 0.031 | |
| Water spray temperature [°C] | 20.2 | | 24.5 | |
| Spraying duration [min] | 15 | | 15 | |

### 6.6.2 Test results:

| Details of any observed or measured cracking, distortion, condensation, water penetration or loss of vacuum found and problems which according to 5.5.4 of EN 12975-1:2011 are to be classified as “severe”. |
|---|
| No visual damages |

## 6.7 Internal thermal shock test

### 6.7.1 Test conditions

| | 1st shock | | 2nd shock | |
|---|---|---|---|---|
| Test performed with outdoor exposure / solar simulator | Outdoor | | Outdoor | |
| Serial no. | ONS/HPC30-20130603011 | | | |
| Date | 15 July 2013 | | 15 August 2013 | |
| Inspector | Reba Liu | | Reba Liu | |
| Collector tilt angle [° from horizontal] | 30 | | 30 | |
| Irradiation $G^*_{min}$ & $G^*_{mean}$ [W/m²] | 904 | 912 | 954 | 976 |
| Ambient air temperature $t_{a\,min.}$ & $t_{a\,mean}$ [°C] | 29.9 | 30.4 | 27.7 | 28.1 |
| Period during which steady state conditions were maintained prior to shock [min] | 60 | | 60 | |
| Water spray mass flow rate [kg/(sm²)] | 0.024 | | 0.024 | |
| Water spray temperature [°C] | 21.6 | | 23.2 | |
| Spraying duration [min] | 5 | | 5 | |
| Absorber temperature after spraying [°C] | | | | |

Requisite additional information for internal thermal shock test:

| |
|---|
| |

### 6.7.2 Test results:

| Details of any observed or measured cracking, distortion, condensation, water penetration or loss of vacuum found and problems which according to 5.6.4 of EN 12975-1:2011 are to be classified as “severe”. |
|---|
| No visual damages |

## 6.8 Rain penetration test

| | |
|---|---|
| Serial no. | ONS/HPC30-20130603011 |
| Date | 28 August 2013 |
| Inspector | Reba Liu |

### 6.8.1 Test conditions

| | |
|---|---|
| Collector mounted on: | Open frame |
| Collector tilt angle [° from horizontal] | 30 |
| Detection of ingress of water: | by weighing the collector |
| Water spray flow rate [kg/(s*m²)] | 0.025 |
| Spraying duration [h] | 4 |

### 6.8.2 Test results;

| | |
|---|---|
| Area with visible water penetration [% of aperture area] | - |
| Location where water penetration is observed | - |
| Duration until visible water penetration has disappeared | - |

| Details of any problems which according to 5.7.4 of EN 12975-1:2011 are to be classified as “severe”.: |
|---|
| No visual damages |

## 6.9 Mechanical load test

| | |
|---|---|
| Serial no. | ONS/HPC30-20130603011 |
| Date | 24 September 2013 |
| Inspector | Reba Liu |

**Method used to apply pressure**

○ Suction cups ◙ Loading with water

### 6.9.1 Positive pressure test of the collector cover

| | |
|---|---|
| Maximum pressure load [Pa] | 2000 |
| Remaining deflection [mm] | 5.5 |

### 6.9.2 Negative pressure test of collector

| | |
|---|---|
| Maximum pressure load [Pa] | not applicable |
| Remaining deflection [mm] | - |

**Test results**

| |
|---|
| Details of any damage to the collector cover, cover fixings or mounting fixings and problems which according to 5.9 of EN 12975-1:2011 are to be classified as “severe”: |
| No visual damages |

## 6.10 Final Inspection

| | |
|---|---|
| Serial no. | ONS/HPC30-20130603011 |
| Date | 25 September 2013 |
| Inspector | Reba Liu |

**Test results**

| | Collector component | Potential problem | Evaluation |
|---|---|---|---|
| a) | Collector box, fasteners | Cracking, warping, corrosion, rain penetration | 0 |
| b) | Mountings, structure | Strength, safety | 1 |
| c) | Seals, gaskets | Cracking, adhesion, elasticity | 1 |
| d) | Cover, reflector | Cracking, crazing, buckling, delamination, warping, out gassing | 0 |
| e) | Absorber coating | Cracking, crazing, blistering | 0 |
| | Absorber tubes and headers | Deformation, corrosion, leakage, loss of bonding | 0 |
| | Absorber mounting | Deformation, corrosion | 0 |
| f) | Insulation | Water retention, out gassing, degradation | 1 |

Evaluate each potential problem according to the following scale:

0 No problem
1 Minor problem
2 Severe problem

- Inspection to establish the condition was not possible.

Requisite additional information for final inspection:

Minor deformation during mechanical load test;

Grommets between manifold and evacuated tubes get brittle;

Minor color changed;

# 7 Measuring results of thermal performance testing

## 7.1 Test method according to DIN EN 12975-2:2006 chapter 6.3

| | | |
|---|---|---|
| Serial no. | ONS/HPC30-20130503001 | |
| Date (Start/End) | 28 September 2013 | 15 October 2013 |
| Inspector | Reba Liu | |

## 7.2 Test conditions

| | |
|---|---|
| Latitude [°] | 26°04' |
| Longitude [°] | 101°40' |
| Collector tilt [° from horizontal] | 30 / 60 |
| Collector azimuth [° from south] | 0 |
| Orientation of absorber or pipes | vertical |
| Mass flow [kg/(m²s)] | 0.021 |
| Aperture area $A_a$ [m²] | 2.84 |

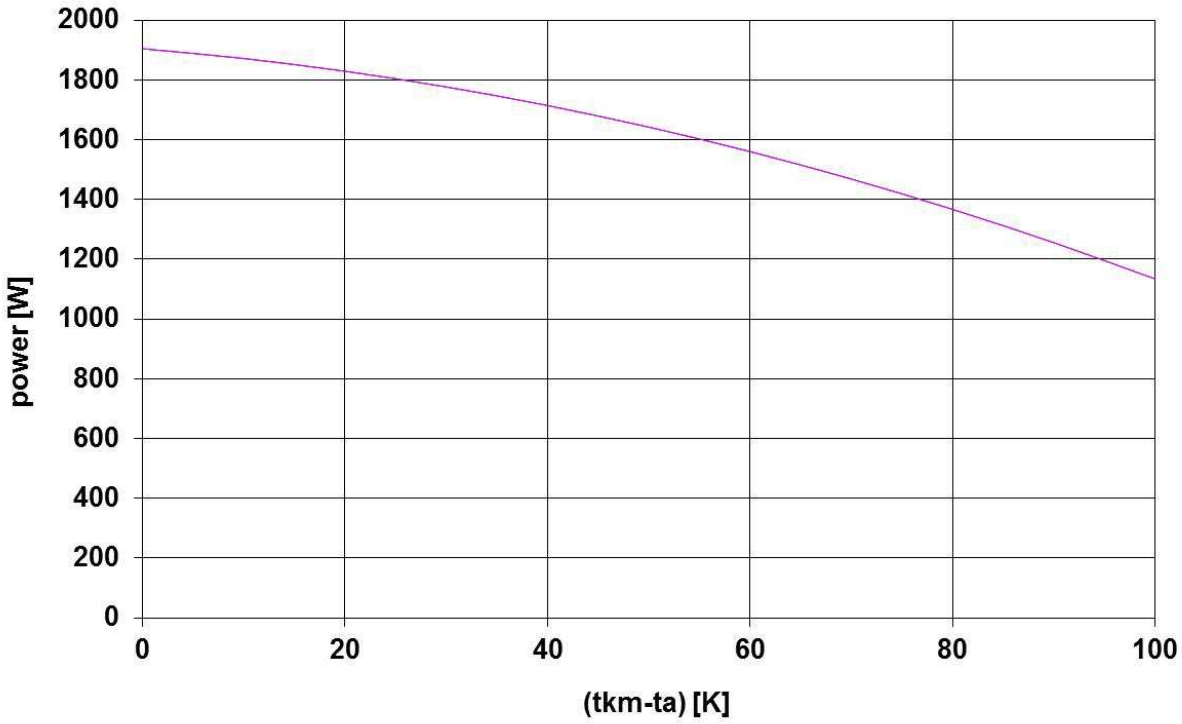
### *7.2.1 Test results thermal performance*

Second order fit to data

$$\dot{Q} = A \cdot G\left(\eta_0 - a_1 \frac{(t_m - t_a)}{G} - a_2 \frac{(t_m - t_a)^2}{G}\right)$$

| | |
|---|---|
| Conversion factor $\eta_{0a}$ [ ] | 0.684 (based on aperture area) |
| Heat transfer coefficient $a_{1a}$ [ W/(m²K)] | 1.001 (based on aperture area) |
| Temp. dependent heat transfer coefficient $a_{2a}$ [W/(m²K²)] | 0.018 (based on aperture area) |
| Incidence angle modifier $K_\theta$ (40.2°/ 40.2°) [ ] | 1.32 (based on aperture area) |
| Effective heat capacity c [kJ/(m²K)] | 97.969 (based on aperture area) |
| Time constant $\tau_c$[s] | Not necessary for quasi-dynamic test method |

***Power curve*** per collector unit (for G = 1000 W/m²)




| | |
|---|---|
| **Maximum power [$W_{peak}$]** (G=1000 W/m²) per collector unit | **1905** |

| Details of any damage and problems: |
|---|
| No visual damages |

For more details about thermal performance test see Appendix 1: Thermal performance test results.

# 8 General remarks

All results only refer to the test samples that were subjected to testing. Symbols are in accordance with ISO 9488 and ISO 9806-1 Annex A.

The extended total measuring uncertainty for the outdoor performance test is:

$\eta \leq \pm 2.45$ % (for irradiation levels above 700 W/m² and K=2)

To minimize back side reflectivity during thermal performance test, a black plastic film with low reflectivity (< 20%) was used!

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## Appendix 1: Thermal performance test results

Evaluation of quasi-dynamic collector test based on aperture area and mean temperature of heat transfer fluid (multi linear regression/ simulation)

| **Based on aperture area:** | | |
|---|---|---|
| Aperture collector area used for curve: | 2.84 m² | |
| The quasi-dynamic collector model is defined by | | |
| $Q/A_a = F'(\tau\alpha)_{en} K_{\theta b}(\theta) G_b + F'(\tau\alpha)_{en} K_{\theta d}(\theta) G_d - c_6 uG^* - c_1(t_m-t_a) - c_2(t_m-t_a)^2 - c_3 u(t_m-t_a) - c_4(E_L-\sigma T_a^4) - c_5 dt_m/dt$ | | |
| | | |
| Mass flow during test [kg/(m²s)] | 0.021 | |
| Operating pressure during test [kPa] | 150 | |
| | | |
| Based on aperture area | | |
| | Value | Unit |
| $F'(\tau\alpha)_{en}$ | 0.662 | [ ] |
| $K_{\theta d}$ | 1.219 | [ ] |
| $b_0(\theta)$ | 0.060 | [ ] |
| $c_1$ | 1.001 | [W/(m²K)] |
| $c_2$ | 0.018 | [W/(m²K²)] |
| $c_3$ | not determined | [J/(m³K)] |
| $c_4$ | not determined | [W/(m²K)] |
| $c_5$ | 97.969 | [kJ/(m²K)] |
| $c_6$ | not determined | [s/m] |

| Angle [°] | 10 | 20 | 30 | 40 | 50 | 60 | 70 |
|---|---|---|---|---|---|---|---|
| $K_{\theta b\,longi}$ () [ ] | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.94 | 0.88 |
| $K_{\theta b\,trans}$ () [ ] | 1.03 | 1.07 | 1.20 | 1.34 | 1.50 | 1.53 | 1.51 |
| **Incidence angle modifier $K_\theta$ (40.2°/ 40.2°) [ ]** | **1.32** (based on aperture area) | | | | | | |

**Comparison between measurement and regression (see Figure A1.4):**

| | |
|---|---|
| Total energy deviation [%] | -0.12 |
| Objective [%] | 2.72 |

The “objective” describes the ratio of the integrated absolute energy difference between measurement and simulation/ regression to the total measured energy during the complete test sequence.

**Calculation of collector parameters**

| | |
|---|---|
| Conversion factor $\eta_0$ | = $F'(\tau\alpha)_{en}$ $K_{\theta b}(\theta_{l,t}=15.0°)$ 0.85 + $F'(\tau\alpha)_{en}$ $K_{\theta d}(\theta)$ 0.15 |
| Heat transfer coefficient $a_1$ | = c1 |
| Temperature dependent heat transfer coefficient $a_2$ | = c2 |
| Effective heat capacity c | = c5 |

**Presentation of the used data set for regression**

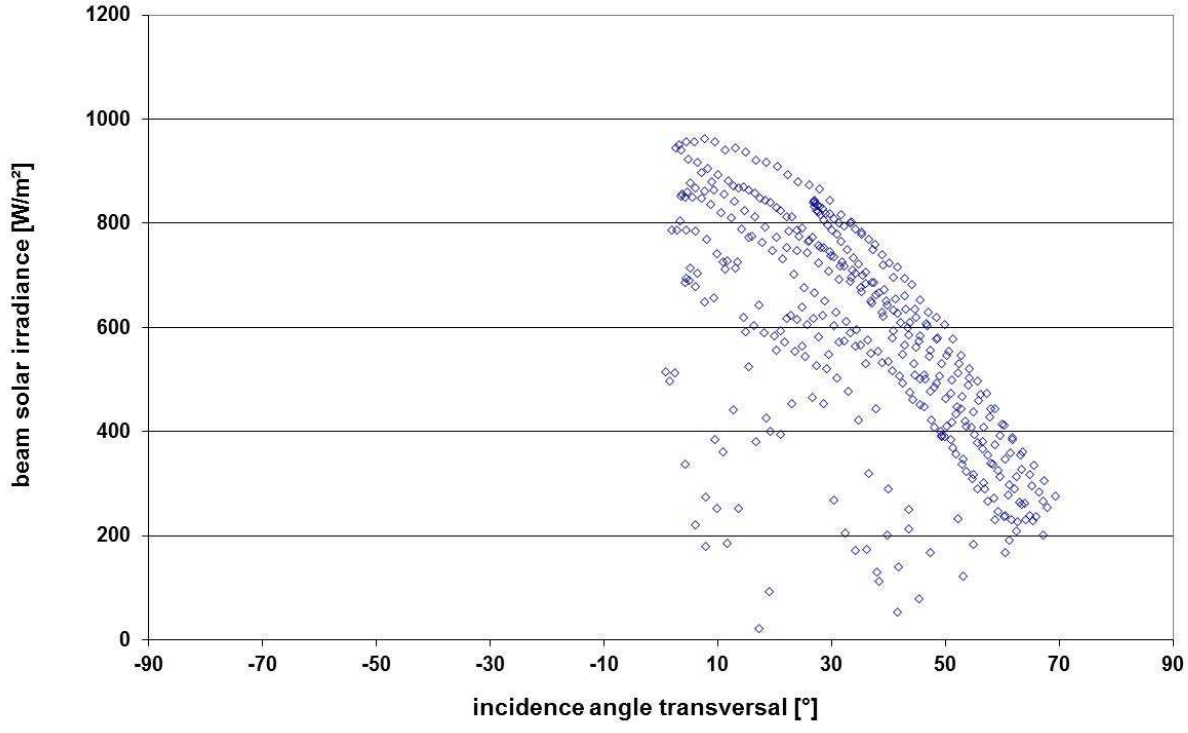


Figure A1.1: Direct solar irradiance over its incidence angle

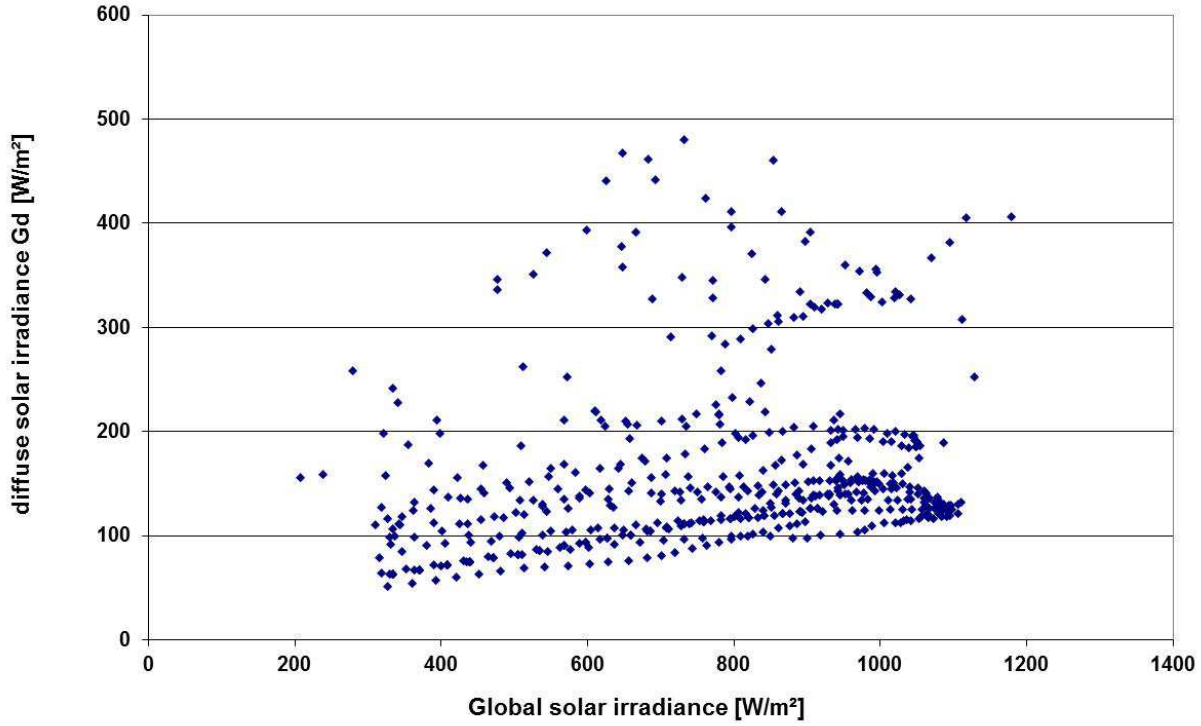


Figure A1.2: Diffuse solar irradiance over global irradiance

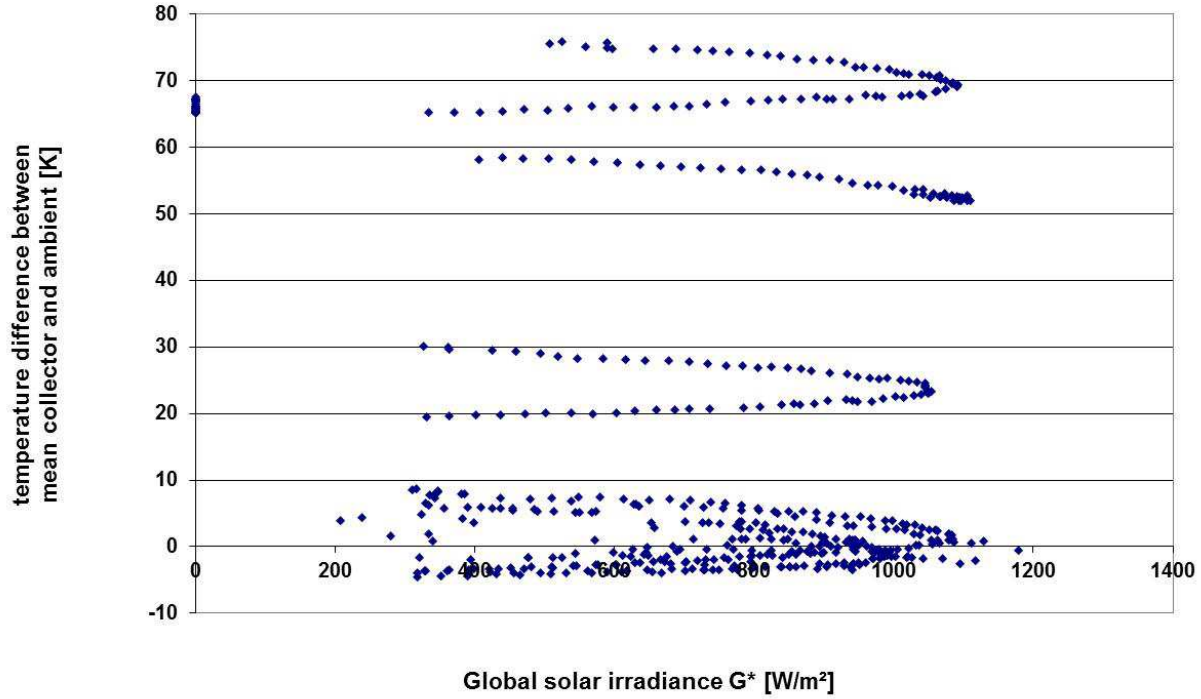


Figure A1.3: Temperature difference between mean collector and ambient temperature over global irradiance

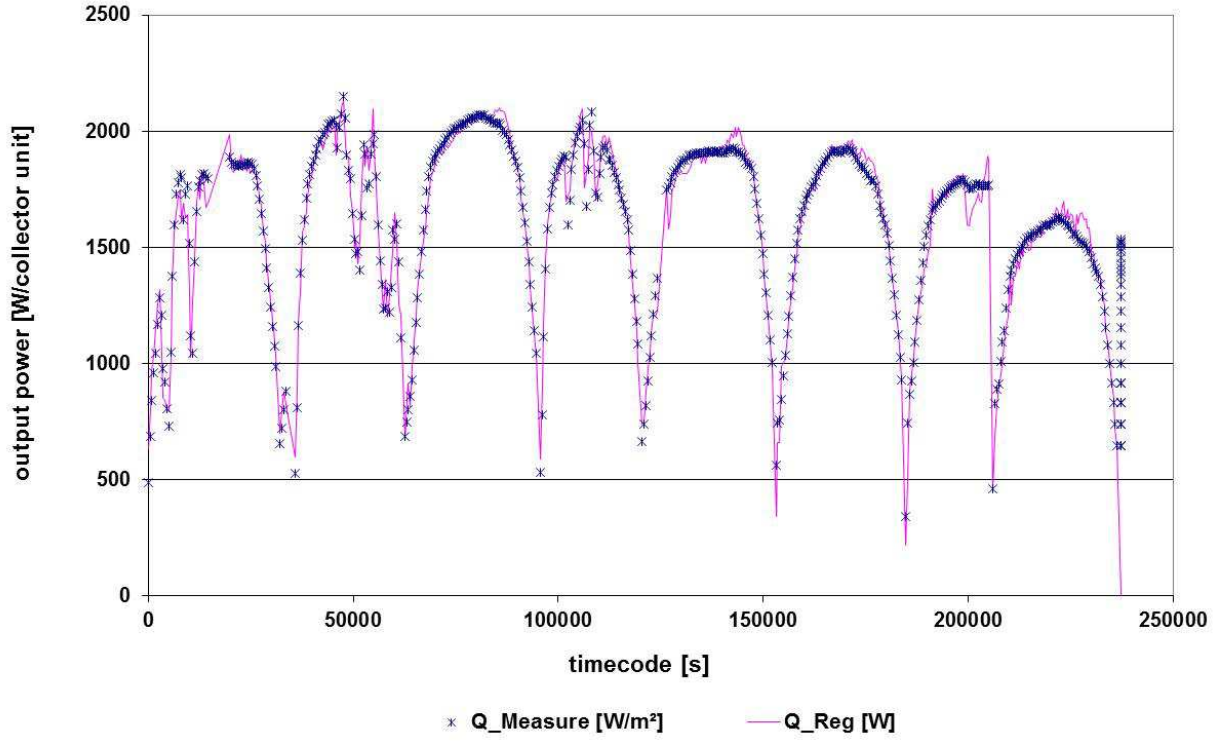


Figure A1.4: Measured and calculated power over time (full data set)

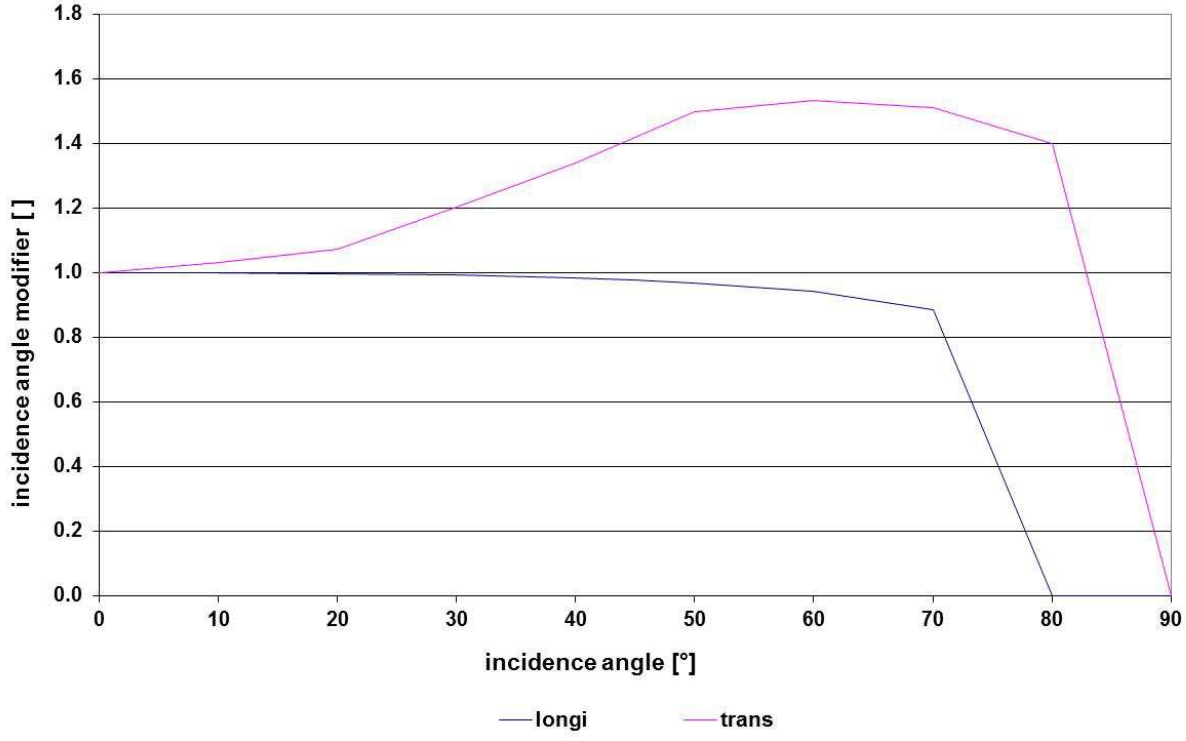


Figure A1.5: incidence angle modifier over incidence angle

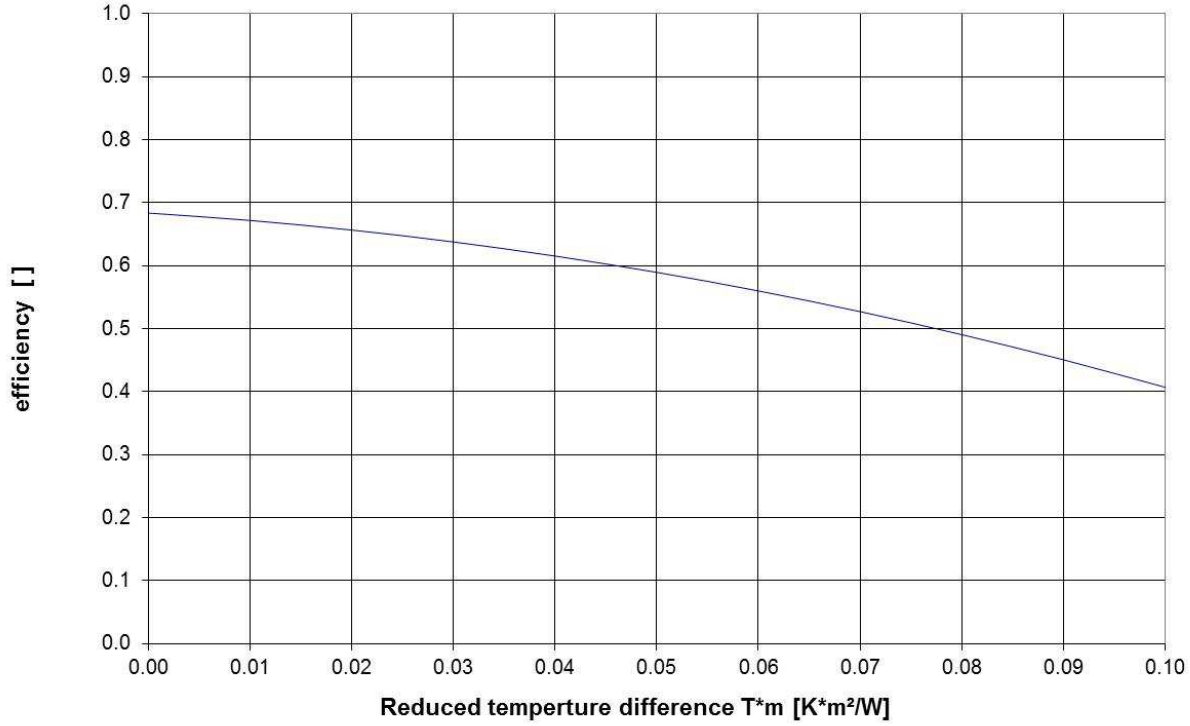


Figure A1.6: efficiency curve over reduced temperature difference at 1000W/m² irradiation

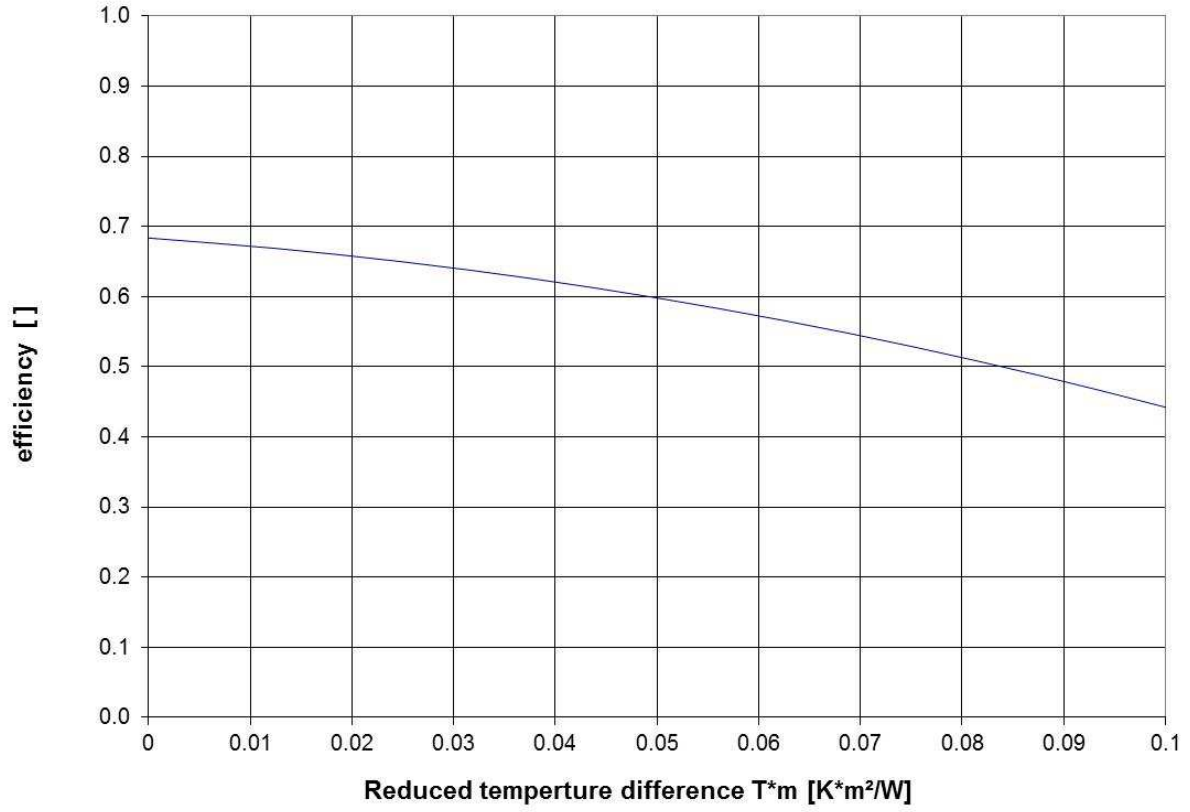


Figure A1.7: efficiency curve over reduced temperature difference at 800W/m² irradiation

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## Appendix 2: climate data

| Date | time (G*>850W/m²) | ta (G*>850W/m²) | H | min ta | max. ta | mean ta | Rain | Comments |
|---|---|---|---|---|---|---|---|---|
| | min | °C | MJ | °C | °C | °C | l/m² | |
| 2013-06-14 | 190 | 30.1 | 25.2 | 17.5 | 33.3 | 28.4 | 0.0 | |
| 2013-06-15 | 110 | 32.3 | 13.4 | 17.6 | 33.1 | 27.8 | 0.0 | |
| 2013-06-16 | | | | | | | | interim failure |
| 2013-06-17 | | | | | | | | interim failure |
| 2013-06-18 | | | | | | | 0.0 | |
| 2013-06-19 | 80 | 31.5 | 21.9 | 26.1 | 35.2 | 32.0 | 0.0 | |
| 2013-06-20 | 65 | 32.8 | 13.4 | 28.7 | 34.4 | 32.1 | 0.0 | |
| 2013-06-21 | | | 14.3 | 18.9 | 27.9 | 23.2 | 20.7 | |
| 2013-06-22 | | | 17.2 | 18.9 | 28.6 | 25.1 | 31.8 | |
| 2013-06-23 | | | 15.8 | 20.8 | 31.4 | 25.7 | 11.9 | |
| 2013-06-24 | 120 | 29.2 | 20.2 | 19.6 | 30.3 | 26.6 | 0.0 | |
| 2013-06-25 | | | 13.1 | 20.8 | 29.0 | 25.4 | 0.0 | |
| 2013-06-26 | 30 | 29.8 | 19.5 | 20.1 | 32.2 | 27.8 | 25.9 | |
| 2013-06-27 | | | 9.0 | 17.5 | 22.6 | 20.3 | 3.1 | |
| 2013-06-28 | | | 21.6 | 16.6 | 28.2 | 24.0 | 0.0 | |
| 2013-06-29 | 105 | 29.8 | 22.4 | 20.8 | 31.1 | 27.5 | 0.0 | |
| 2013-06-30 | | | 14.3 | 22.0 | 30.7 | 26.9 | 0.0 | |
| 2013-07-01 | | | 11.3 | 21.1 | 27.5 | 25.3 | 0.2 | |
| 2013-07-02 | | | 16.6 | 19.4 | 29.9 | 26.2 | 12.0 | |
| 2013-07-03 | | | 16.5 | 21.2 | 30.2 | 26.9 | 0.0 | |
| 2013-07-04 | | | 12.1 | 22.2 | 28.3 | 25.6 | 0.0 | |
| 2013-07-05 | | | 7.1 | 19.9 | 25.7 | 23.0 | 8.9 | |
| 2013-07-06 | | | 7.9 | 19.2 | 23.0 | 21.4 | 13.7 | |
| 2013-07-07 | | | 15.7 | 19.7 | 27.8 | 24.7 | 2.8 | |
| 2013-07-08 | | | 15.4 | 21.1 | 29.1 | 25.4 | 0.0 | |
| 2013-07-09 | | | 14.4 | 19.4 | 26.3 | 23.7 | 0.3 | |
| 2013-07-10 | | | 15.7 | 21.2 | 29.0 | 25.6 | 0.0 | |
| 2013-07-11 | | | 16.4 | 22.0 | 29.2 | 25.6 | 0.7 | |
| 2013-07-12 | | | 16.6 | 19.2 | 29.3 | 24.7 | 23.8 | |
| 2013-07-13 | | | 19.3 | 20.1 | 30.3 | 26.2 | 0.5 | |
| 2013-07-14 | 205 | 29.0 | 25.2 | 19.5 | 31.7 | 27.3 | 0.0 | |

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| Date | time (G*>850W/m²) | ta (G*>850W/m²) | H | min ta | max. ta | mean ta | Rain | Comments |
|---|---|---|---|---|---|---|---|---|
| | min | °C | MJ | °C | °C | °C | l/m² | |
| 2013-07-15 | 180 | 29.5 | 22.7 | 24.6 | 32.5 | 29.4 | 0.0 | |
| 2013-07-16 | 50 | 32.2 | 14.6 | 20.8 | 33.1 | 28.4 | 0.0 | |
| 2013-07-17 | | | 17.5 | 26.4 | 31.4 | 28.6 | 0.0 | |
| 2013-07-18 | | | 7.7 | 19.6 | 26.5 | 23.6 | 2.4 | |
| 2013-07-19 | | | 12.3 | 19.6 | 26.7 | 21.3 | 5.1 | |
| 2013-07-20 | | | 16.5 | 19.9 | 29.2 | 23.3 | 0.1 | |
| 2013-07-21 | | | 13.5 | 19.9 | 28.4 | 22.7 | 5.4 | |
| 2013-07-22 | | | | | | | | |
| 2013-07-23 | | | 7.0 | 19.9 | 28.9 | 21.7 | 3.2 | |
| 2013-07-24 | | | | | | | | interim failure |
| 2013-07-25 | | | | | | | | interim failure |
| 2013-07-26 | | | | | | | | interim failure |
| 2013-07-27 | 220 | 30.3 | 24.0 | 19.2 | 32.7 | 27.7 | 0.4 | |
| 2013-07-28 | | | 13.1 | 21.0 | 30.1 | 25.9 | 0.4 | |
| 2013-07-29 | | | 15.8 | 19.7 | 30.5 | 28.3 | 0.0 | |
| 2013-07-30 | | | | | | | | interim failure |
| 2013-07-31 | | | 6.4 | 28.6 | 31.8 | 30.4 | 0.0 | |
| 2013-08-01 | | | 12.6 | 18.7 | 27.6 | 22.8 | 5.4 | |
| 2013-08-02 | 150 | 25.7 | 18.6 | 18.5 | 28.0 | 23.2 | 5.5 | |
| 2013-08-03 | 35 | 29.1 | 23.7 | 18.2 | 32.6 | 27.0 | 5.7 | |
| 2013-08-04 | | | 5.5 | 19.2 | 21.3 | 20.4 | 2.5 | |
| 2013-08-05 | | | 14.8 | 18.2 | 27.0 | 23.8 | 2.5 | |
| 2013-08-06 | 40 | 28.8 | 21.7 | 17.1 | 31.1 | 26.4 | 7.7 | |
| 2013-08-07 | 210 | 29.2 | 25.7 | 20.0 | 32.2 | 27.7 | 5.2 | |
| 2013-08-08 | 85 | 28.2 | 19.7 | 18.1 | 30.3 | 25.0 | 5.5 | |
| 2013-08-09 | 30 | 26.5 | 18.2 | 21.3 | 28.2 | 25.7 | 0.6 | |
| 2013-08-10 | 30 | 27.4 | 18.8 | 18.5 | 28.9 | 25.1 | | |
| 2013-08-11 | | | 16.3 | 19.9 | 27.1 | 23.8 | | |
| 2013-08-12 | | | 10.9 | 17.5 | 24.7 | 20.8 | 0.7 | |
| 2013-08-13 | 60 | 25.1 | 19.2 | 17.7 | 27.8 | 23.1 | 2.2 | |
| 2013-08-14 | 30 | 26.8 | 17.3 | 18.6 | 29.5 | 24.4 | | |

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| Date | time (G*>850W/m²) | ta (G*>850W/m²) | H | min ta | max. ta | mean ta | Rain | Comments |
|---|---|---|---|---|---|---|---|---|
| | min | °C | MJ | °C | °C | °C | l/m² | |
| 2013-08-15 | 205 | 28.8 | 25.8 | 17.4 | 31.8 | 26.9 | 0.0 | |
| 2013-08-16 | 130 | 27.3 | 22.1 | 18.0 | 29.8 | 24.4 | 9.5 | |
| 2013-08-17 | 55 | 28.4 | 17.7 | 17.6 | 29.4 | 24.8 | 0.0 | |
| 2013-08-18 | | | 12.0 | 17.6 | 28.1 | 23.4 | 0.0 | |
| 2013-08-19 | 100 | 28.1 | 22.7 | 17.5 | 31.5 | 25.9 | 7.5 | |
| 2013-08-20 | | | 16.5 | 18.2 | 30.5 | 26.0 | 0.0 | |
| 2013-08-21 | 130 | 28.8 | 22.7 | 18.6 | 30.7 | 25.8 | 1.1 | |
| 2013-08-22 | 90 | 26.1 | 20.2 | 19.0 | 30.5 | 25.1 | 33.0 | |
| 2013-08-23 | 200 | 29.3 | 24.9 | 18.1 | 32.1 | 27.1 | 38.8 | |
| 2013-08-24 | 200 | 31.5 | 24.3 | 18.8 | 34.0 | 28.7 | 0.0 | |
| 2013-08-25 | | | 5.6 | 21.0 | 26.0 | 22.7 | 10.0 | |
| 2013-08-26 | 165 | 26.5 | 22.6 | 18.7 | 29.3 | 24.7 | 0.0 | |
| 2013-08-27 | 180 | 28.7 | 25.1 | 17.9 | 31.0 | 26.7 | 0.0 | |

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## Appendix 3: Photo documentation

*Fig. 2: incoming inspection*

*Fig. 3: internal shock test*

*Fig. 4: thermal performance test*

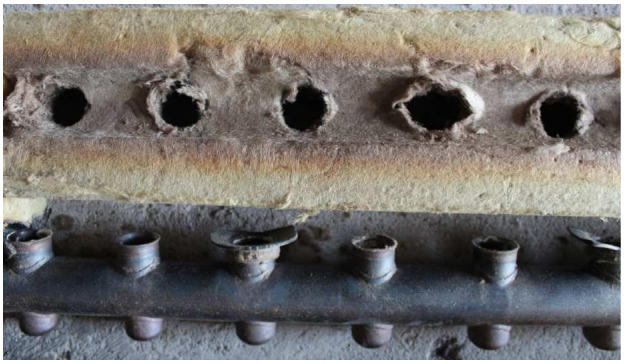

*Fig. 5: final inspection*