Thermal Testing of Solar Collectors an Systems

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TestLab Solar Thermal Systems

Fraunhofer ISE

Focused item

Relevant Test Standards

- EN ISO 9806:2014
- ISO 9459-2,5
- EN 12977-3,4,5

Innovative Products – Innovative Methods

- PVT
- BIST

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RELEVANT TEST STANDARDS

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Relevant Test Standards and Certificates for Collectors

Norm/Certificate \ Scope	liquid-heating collectors	PVT collectors	air-heating collectors	concentrating collectors
EN 12975-1,2:2006-A1:2011	✓	✓	✗	✓
ISO 9806-1:1994 a. -2,3:1995	✓	✗	✗	✗
EN ISO 9806:2014	✓	✓	✓	✓
Q-Mark*	✓	✓	✓	✓
SKM	✓	✓	✓	✓
SRCC	✓	✓	✓	✓
hEN 12975-1:2014*	✓	✓	✓	✓
CE (to CPR)	✓	✓	✓	✓

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Relevant Test Standards for Solar Systems

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ISO/FDIS 9806:2013(E) and EN 12975-2:2006-A1:2012
Scope (1)

This International Standard specifies test methods for assessing the durability, reliability and safety for fluid heating collectors.

This International Standard also includes test methods for the thermal performance characterization of fluid heating collectors, namely steady-state and quasi-dynamic thermal performance of glazed and unglazed liquid heating solar collectors and steady-state thermal performance of glazed and unglazed air heating solar collectors (open to ambient as well as closed loop).

This International Standard is also applicable to hybrid collectors generating heat and electric power. However it does not cover electrical safety or other specific properties related to electric power generation.

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ISO/FDIS 9806:2013(E) and EN 12975-2:2006-A1:2012
Scope (2)

This International Standard is also applicable to collectors using external power sources for normal operation and/or safety purposes.

This International Standard is not applicable to those collectors in which the thermal storage unit is an integral part of the collector to such an extent that the collection process cannot be separated from the storage process for the purpose of making measurements of these two processes.

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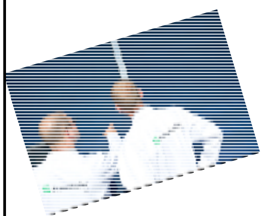
Test methods list



Sub clause	Test
6	Internal pressure test for fluid channels
7	Leakage test
8	Rupture and collapse test
9	High-temperature resistance
11	Exposure test
12	External thermal shock test
13	Internal thermal shock test
14	Rain penetration test
15	Freeze resistance test
16	Mechanical load test
17	Impact resistance test
20	Thermal performance test
28	Pressure drop measurement
18	Final Inspection

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Performance test procedures
Measuring methods

Typically one of the two following measuring methods is used:

- Steady-state method
(indoor available with a Solar Simulator)
- Quasi-dynamic test method

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Area definitions (ISO 9488)
Flat plate collectors

Attention: **different module sizes** have a **different power output**

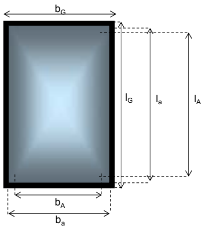
The area reference at the comparison with efficiency curves have to be considered. The area definitions change.

Area definitions:

Gross area $A_G = b_G l_G$

Aperture area $A_a = b_a l_a$

Absorber area $A_A = b_A l_A$



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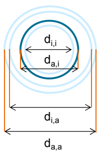
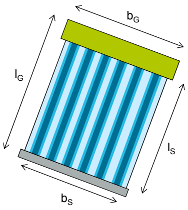
Area definitions (ISO 9488)
Vacuum tube collectors



Brutto area $A_G = b_G l_G$

If a mirror exists:
Aperture area $A_a = b_S l_S$
Absorber area $A_A = d_{a,i} \pi \, l_{eff} \, n$

If no mirror exists:
Aperture area $A_a = d_{i,a} l_{eff} \, n$
Absorber area $A_A = d_{a,i} l_{abs} \, n$



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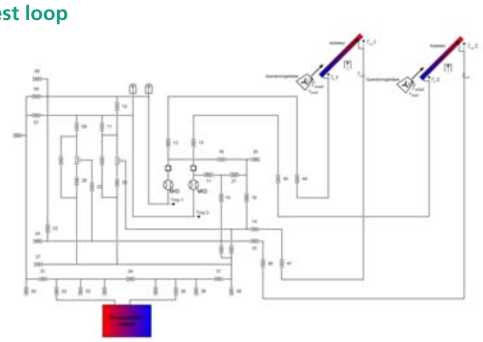
Stationary method
Test loop



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Testing conditions (EN 12975-2)

Perpendicular irradiance in the collector plane > 700 W/m²
Fluctuations during measurement:

- Ambient air +/- 1,5 K
- Mass flow +/- 1%
- Fluid temperature at collector inlet +/- 0,1K
- Irradiance +/- 50 W
- Wind speed +/- 0,5 m/s

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Testing conditions (ISO 9806)

Parameter	Permitted deviation from the mean value		
	Glazed collector	Air heating collector	Unglazed collector
(Global)Test solar irradiance	± 50 W/m²	± 50 W/m²	± 50 W/m²
Total short wave solar irradiance	-	-	± 50 W/m²
Thermal irradiance	-	-	± 20 W/m²
Surrounding air temperature	± 1,5 K	± 1,5 K	± 1,5 K
Fluid mass flow rate	± 1 %	± 2 %	± 1 %
Fluid temperature at the collector inlet	± 0,1 K	± 1,5 K	± 0,1 K
Fluid temperature at the collector outlet	± 0,5 K	± 1.5 K	± 0,5 K
Surrounding air speed	-	-	± 0,5 m/s but ±1,0 m/s for up to 10 % of the measurement period

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Testing conditions (ISO 9806 and EN 12975-2)
Solar Simulator

Additional measurements during tests in solar simulators:

- Measurement of simulated solar irradiance
  - Grid of maximum spacing 150 mm
  - Spatial mean value
- Measurement of thermal irradiance in simulators
- Ambient air temperature in simulators
  - Outlet temperature of wind generators for calculations of collector performance

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Steady-state method

η

Measurement points under steady-state conditions

⬇

determination of the efficiency curve by regression with method of least squares

$\frac{\Delta T}{G}$

with

$\Delta T = T_m - T_{amb}$

$G = I_h$

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Instantaneous efficiency factor (EN 12975-2)

$\eta_{0a} =$ Conversion factor

$a_{1a} =$ Linear thermal loss coefficient

$a_{2a} =$ Quadratic thermal loss coefficient

$$\eta = \eta_0 - a_1 \frac{t_m - t_{amb}}{I_h} - a_2 I_h \left(\frac{t_m - t_{amb}}{I_h} \right)^2$$

Indices:

- ***a*** - results refer to the **aperture** area
- ***A*** - results refer to the **absorber** area

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Computation of the collector parameters (ISO 9806)
Liquid heating collectors (1)

Steady state glazed liquid heating collectors

$$\eta_{hem} = \eta_{0,hem} - a_1 \frac{\vartheta_m - \vartheta_a}{G} - a_2 \cdot G \left(\frac{\vartheta_m - \vartheta_a}{G} \right)^2$$

$$\dot{Q} = A \cdot G \cdot \left(\eta_{0,hem} - a_1 \frac{\vartheta_m - \vartheta_a}{G} - a_2 \cdot G \left(\frac{\vartheta_m - \vartheta_a}{G} \right)^2 \right)$$

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Computation of the collector parameters (ISO 9806)
Liquid heating collectors (2)

Steady state unglazed liquid heating collectors

$$\eta_{hem} = \eta_{0,hem}\left(1-b_u u\right)-\left(b_1-b_2 u\right)\frac{\vartheta_m-\vartheta_a}{G''}$$

with $G''=G+\frac{\varepsilon}{\alpha}\left(E_L-\sigma T_a^4\right)$

$$\dot{Q} = A\cdot G''\left(\eta_{0,hem}\left(1-b_u u\right)-\left(b_1-b_2 u\right)\frac{\vartheta_m-\vartheta_a}{G''}\right)$$

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Computation of the collector parameters (ISO 9806)
Air heating collectors (1)

Steady state air heating collectors

$$\eta_{hem} = \frac{\dot{Q}}{A\cdot G} = \frac{(\dot{m}_{p_e}\cdot c_{f,e}\cdot\vartheta_e)-(\dot{m}_{p_i}\cdot c_{f,i}\cdot\vartheta_i)-((\dot{m}_{p_e}-\dot{m}p_i)\cdot c_{f,a}\cdot\vartheta_a)}{A\cdot G}$$

Modelling like glazed liquid heating collectors

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Computation of the collector parameters (ISO 9806)
Air heating collectors (2)

Open to ambient collectors having a measurable wind speed dependency (e.g. **unglazed air heating collectors**)

$$\frac{\dot{Q}_m}{A\cdot G''} = \eta_{\max,0m/s} - b_u\cdot u$$

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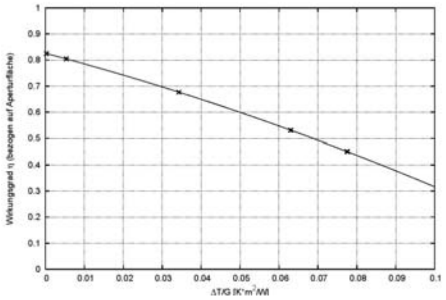
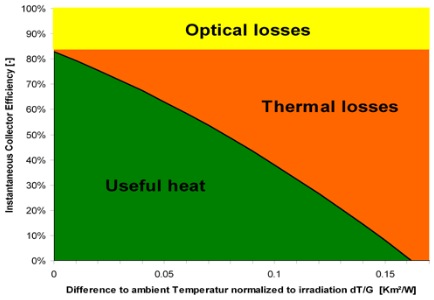
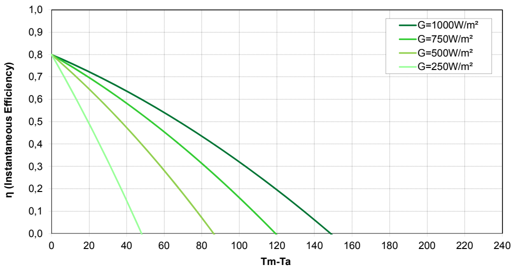
Efficiency curve



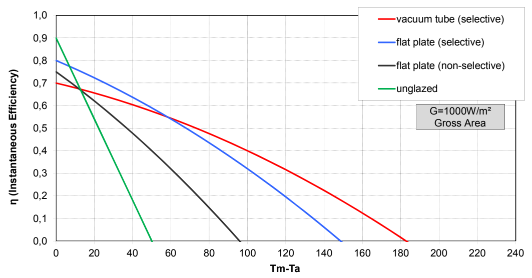
Efficiency equation



Efficiency equation



Comparison of different efficiency curves



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Quasi-Dynamic test procedure (QDT) not applicable for a standard solar simulator

- Measurement of the collector at 4 evenly distributed operating temperature levels
- there have to be days, with high and low diffuse irradiance fraction, with windless and windy days and they have to contain measurement data with different irradiance angles including values with varying incidence angle 60° .

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QDT

$$\frac{\dot{Q}}{A} = F'(\tau\alpha)_{en} K_{\theta b}(\theta) I_b + F'(\tau\alpha)_{en} K_{\theta d} I_d - c_6 u I_h - c_1 (t_m - t_{amb}) - c_2 (t_m - t_{amb})^2 - c_3 u (t_m - t_{amb}) + c_4 (E_L - \sigma T_a{}^4) - c_5 \frac{dt_m}{dt}$$

mit

$K_{\theta b}(\theta)$ = incident angle correction factor of direct irradiance
$K_{\theta d}$ = incident angle correction factor of diffuse irradiation
c_1 = heat transition coefficient = $F'U_0$
c_2 = heat dependance of $c_1 = F'U_1$
c_3 = Wind dependance of $c_1 = F'U_u$
c_4 = Sky temperature dependance $c_1 = F'\varepsilon$
E_L = long wave irradiation in the colletor plane
c_5 = thermal capacity = $\frac{C}{A}$
c_6 = wind dependance of the convertion factor

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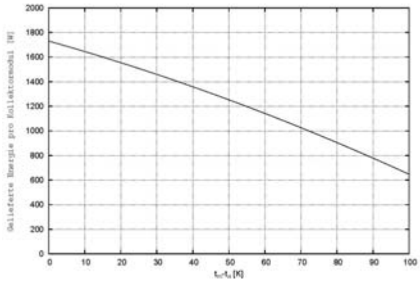
Power output
Curve



Irradiance: 1000 W/m²

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Power output
Table listing

Tm - Ta in K	400 W/m2	700 W/m2	1000 W/m2
0	693	1212	1731
10	607	1127	1646
30	421	941	1460
50	215	734	1253

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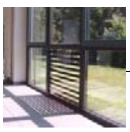
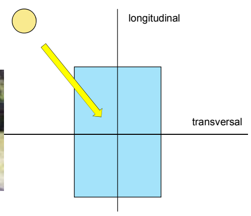
IAM
Bi-dimensional modelling

$$\tan^2\theta = \tan^2\theta L + \tan^2\theta T$$

$$K_\theta = \frac{\eta_\theta(\theta)}{\eta_0}$$





$$K_\theta = K_{\theta b} + K_d$$

$$K_{\theta b} \approx K_{\theta L}\, K_{\theta T}$$

For collectors with an AR ≈1 and no 3-dimensional surface geometries

=> rotationally symmetric IAM

If not, a biaxial measurement has to be realised and further calculations need to be done in order to determine the complex 3-dimensional IAM.

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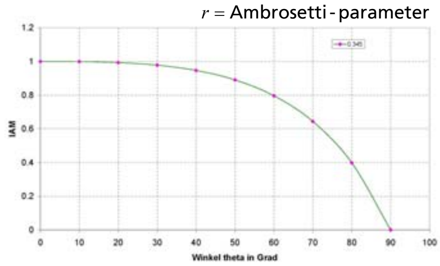
Incidence angle modifier (IAM)
Ambrosetti formula

$$K_{\theta b} = 1 - [\tan(\theta/2)]^{\frac{1}{r}} \quad \text{with}$$
r = Ambrosetti-parameter



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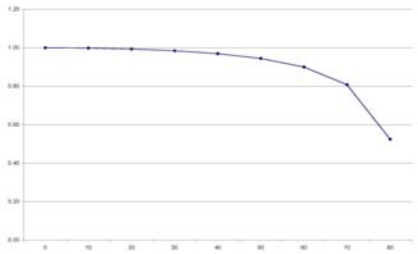
Incidence angle modifier (IAM)
b_0-formula

$$K_{\theta b}(\theta) = 1 - b_0\left(\left(\frac{1}{\cos\theta}\right) - 1\right)$$



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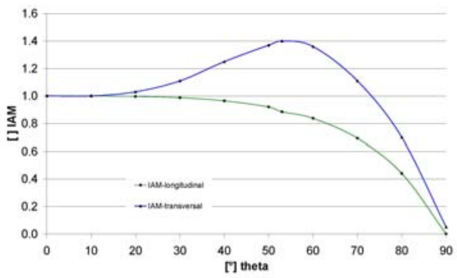
IAM
Bi-dimensional modelling



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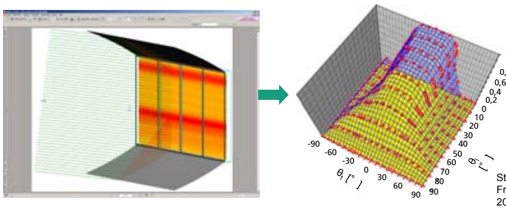
IAM
Multi-dimensional modelling

A simple **multiplication of longitudinal and transversal IAM** is a significant **simplification** and depending on the collector geometry.

=> may cause an considerable error

Possibility of spatial geometric consideration of IAM behaviour via ray-tracing.



Stefan Hess, Fraunhofer ISE, 2009

Reliability test procedures
Thermal capacity - calculation

Determination of the time constant of the collector

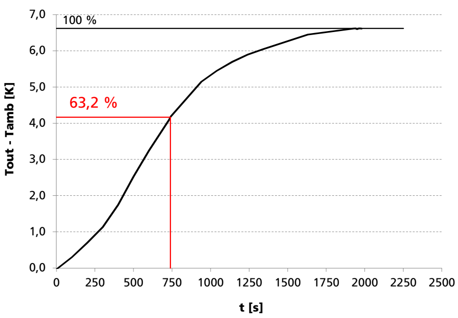
τ_c = time it takes the system`s step response to reach 63,2 % of the total temperature rise

Determination of the thermal capacity of a collector

- via calculation of the single capacities by taking into account the weighing factors: $C = \sum_i m_i c_i p_i$
- via the collector equation on the basis of the entrance temperature, as integral between two stationary states

$$C = \frac{A\eta_0 \int_{t_1}^{t_2} I dt - \dot{m} c_f \int_{t_1}^{t_2} \Delta T dt - AU\left[\int_{t_1}^{t_2} (t_{in} - t_a) dt + \frac{1}{2}\int_{t_1}^{t_2} \Delta T dt\right]}{t_{m2} - t_{m1}}$$

Reliability test procedures
Thermal response



Reliability test procedures
Capacity – an example

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Reliability test procedures
Internal pressure tests for fluid channels (1)

Resistance against pressure in any operating state

Inorganic absorbers

- 1.5 x max. pressure for 15min
- No heat input during the entire test
- For organic absorbers at a higher temperature level

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Reliability test procedures
Internal pressure tests for fluid channels (2)

Organic absorbers

2 different methods

- high temperature hydraulic pressure test
- high temperature pneumatic pressure test

Test pressure raised in 5 steps a 5 min

Test pressure maintained for 1h

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Reliability test procedures
Internal thermal shock test

Collector shall be exposed for 1h, before beeing cooled by the heat transfer medium

- Heat transfer fluid > 25 °C
- G > 800 W/m²
- ϑ_{amb} > 10 °C

Reliability test procedures
External thermal shock test

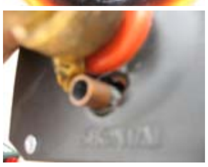
Simulates a summer rain

- Fast cooling of the transparent cover to cause thermal stress
- Exposure for 1h before rain
- 15 min rain on the collector
- 2 external thermal shocks

Reliability test procedures
High temperature resistance

All used materials must be able to withstand high temperatures

- Empty collector
- Air circulation prevented
- Exposed at about 1000 W/m²
- Ambient temperature above 10 °C



Reliability test procedures
Stagnation temperature

$$t_{stg} = t_{as} + \frac{I_s}{I_m}\left(t_{sm} - t_{amb}\right)$$

applies when:

$I_m = \pm 10\% I_S$

with:

t_{stg} = normed stagnation temperature

t_{as} = reference temperature

t_{sm} = measured absorber temperature

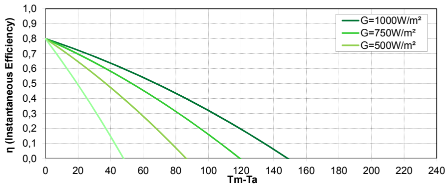
t_{amb} = measured ambient temperature

I_S = reference irradiance

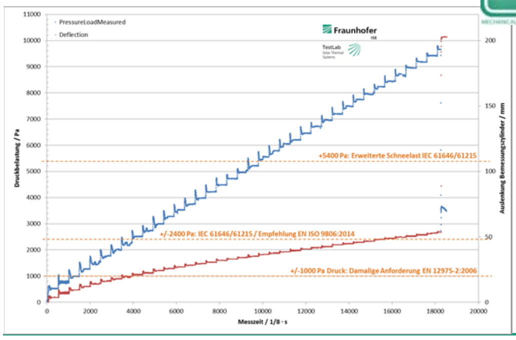
I_m = measured irradiance

Reliability test procedures
Stagnation temperature by ccalculation using the efficiency equation

$$\vartheta_{stg} = \vartheta_{as} + \frac{-a_1 + \left(a_1^2 + 4\,\eta_0\,a_2\,G_s\right)^{1/2}}{2\,a_2}$$



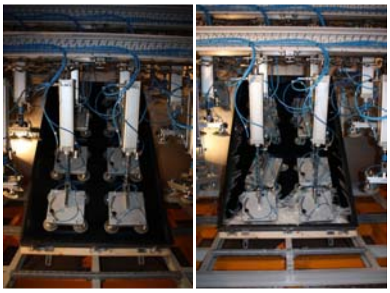
Reliability test procedures
Mechanical load (1)



Reliability test procedures
Mechanical load (2)

Simulates wind and snow loads

- Affect push and pull loads
- Large variety of different module shapes



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Reliability test procedures
Mechanical load (3)

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Reliability test procedures
Rain penetration test

- Spraying water on the collector at minimum installation angle (max. 30°)
- Absorber temperature min 50 °C (by flow or irradiance)
- 4 hours plus handling time before and after test
- Assesment if the collector can handle humidity, which is entering during the test without affecting it permanently

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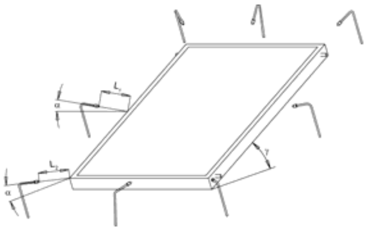
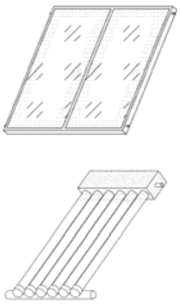
New set-up in ISO 9806
Rain penetration test

L$_1$: 250 – 400 mm
L$_2$: 250 mm
α: 30 ° angle of spray nozzle with respect to the collector surface
γ: smallest tilt angle to the horizontal recommended by the manufacturer. If this angle is not specified use 30°

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Reliability test procedures
Impact Resistance

Steel ball

Mass [g ± 10 g]	Hight [m]
150	0.4, 0.6, 0.8, …,2.0

Ice ball

Diameter [mm ± 5 %]	Mass [g ± 5 %]	Test velocity [m/s ± 5 %]
15	1.63	17.8
25	7.53	23.0
35	20.7	27.2
45	43.9	30.7

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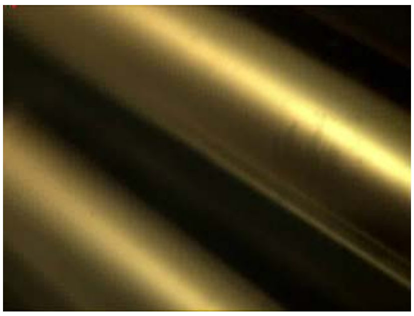
Reliability test procedures
Impact Resistance using an Ice ball



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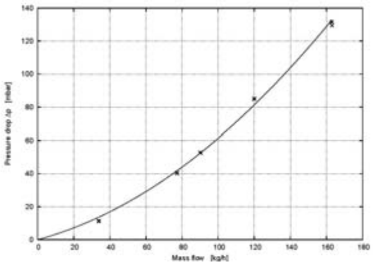
Performance test procedures
Pressure drop

Determination of the pressure drop at different volume flows

- At least 5 measurements equally spaced over volume flow range
- Zero level checked



Reliability test procedures
Exposition

Climate condition	Class C „moderate“	Class B „sunny“	Class A „very sunny“
G [W/m²] Hemispherical solar irradiance on collector plane during minimum 30 hours (or 15 hours in case of pre-exposure), min. ambient temperature, t_a [°C]	800 bei 10	900 bei 15	1000 bei 20
Irradiation on collector plane for exposure test during minimum 30 days, *H* [MJ/m²]	420	540	600
Irradiation on collector plane for pre-exposure sequence during minimum 15 days, *H* [MJ/m²]	210	270	300

Table 4 from ISO 9806:2013

Reliability test procedures
Final Inspection

Examination of

- defects
- absorber connection
- material changes
- tricks
- any other abnormalities

Reliability test procedures
Solar Air Heaters only

Air collectors need further investigations because of the gaseous heat transfer medium

- **Leakage Test (closed loop)**

The test is intended to quantify the leakage volumetric flow rate of air heating collectors. In some cases of collector designs the leakage test is not applicable, e.g. collectors open to ambient

- **Rupture or collapse test**

This test is intended to determine the ability of air heating solar collectors to withstand the pressure levels expected in the air duct systems with which they will be incorporated

Air collectors only
Leakage Test

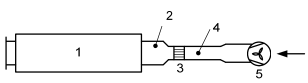
Quantify the leakage volumetric flow rate of air heating collectors

- 4 positive, 4 negative pressure values
- Max. pressure 1.5 x max. operating pressure
- 10 min per step

Air collectors only
Rupture or collapse test

Determine the ability of air heating solar collectors to withstand the pressure levels expected in the air duct systems with which they will be incorporated.

Fig.1 : Outdoor tracking device with solar air heater test stand at TestLab Solar Thermal Systems of Fraunhofer ISE



STANDARDS FOR SYSTEM TESTS

Scope

This European Standard specifies test methods for validating the requirements for Factory Made Thermal Solar Heating Systems as specified in prEN 12976-1.

The standard also includes two test methods for thermal performance characterization by means of whole system testing.

5 Testing

5.1 Freeze resistance
5.2 Over temperature protection
5.3 Pressure resistance
5.4 Water contamination
5.5 Lightning protection
5.6 Safety equipment
5.6.1 Safety valves
5.6.2 Safety lines and expansion lines
5.6.3 Blow-off lines
5.7 Labeling
5.8 Thermal performance characterization
5.9 Ability of solar-plus-supplementary systems to cover the load
5.10 Reverse flow protection
5.11 Electrical safety

Performance test procedure
Thermal performance characterization

EN 12976 contains **no specific performance test procedures**, but references to 2 established test methods in **ISO 9459**

- CSTG-method (Collector and System Testing Group)
- DST-method (Dynamic System Test)

Test method	Solar plus supplementary syst.	Solar-only and preheat systems
ISO 9459-2 (*CSTG*)	No	Yes
ISO 9459-5 (*DST*)	Yes	Yes

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Performance test procedure
CSTG-method (1)

Target: Long time performance prediction over a whole year for different climatic situations

Consists mainly of 3 test sequences

- Performance test - series of one-day outdoor tests on the complete system
- Degree of mixing in the storage tank during draw-off - short test
- Heat loss coefficient in the storage tank - overnight test

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Performance test procedure
CSTG-method (2)

Performance test

- Irradiation per day: 8 – 25 MJ/m²
- Range of $t_{a(day)} - t_{mean}$: -5 – 20 K

Description	Draw-off	$t_{a(day)} - t_{mean}$	Duration
1. one-day-test	Evening	≈ 0	Min. 4 days
2. one-day-test	Evening	± 9 K to 1.	Min. 2 days
3. one-day-test (optional)	Midday / Evening	= 1. or 2.	1 day

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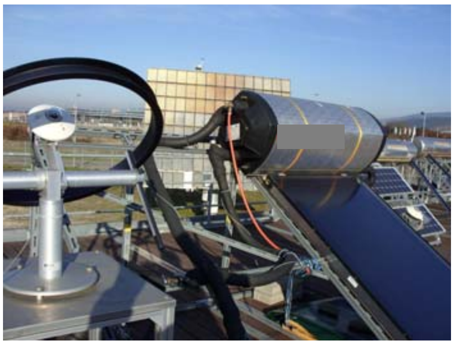
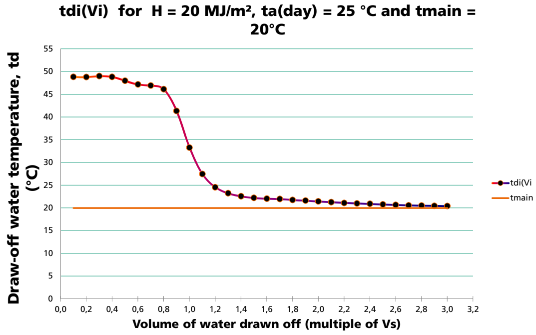
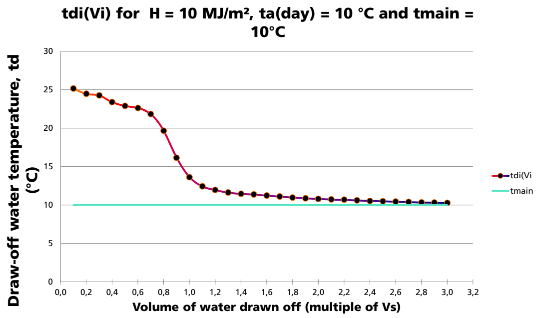
Example of a typical system



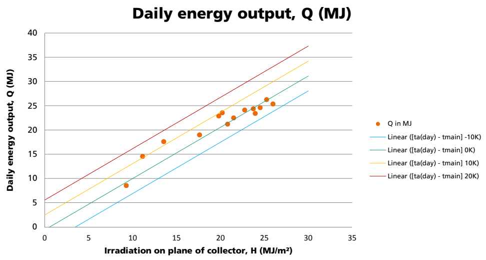
Typical Draw-off profile



Typical Draw-off profile



Daily energy output



Results - Round Robin 2011

Performance indicators of the system on annual base					DST demand volume l/day
Location	Q_d (MJ)	Q_L (MJ)	F_{sol}	Q_{par} (MJ)	140
Stockholm	7797	3532,032	0,453		
Wuerzburg	7493	3626,64	0,484		
Davos	8488	4982,688	0,587		
Athens	5824	4635,792	0,796		

Q_DST = (a+/- Sigma_a) Q_CSTG

CSTG – including „BtG“ calculation

140 l/d

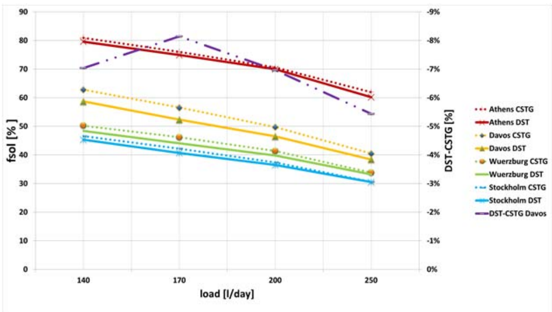
Yearly values for a demand volume of 140l/day

Localidade/Location	Q_d (MJ)	Q_L (MJ)	F_{sol}	Q_{par} (MJ)
Stockholm	8206	3621	47	---
Wuerzburg	7867	3744	50	---
Davos	8908	5300	63	---
Athens	6105	4679	81	---

Difference DST-CSTG [%]

Q_d	Q_L	F_{sol}
-5,2	-2,5	-2,8
-5,0	-3,2	-3,8
-4,9	-6,4	-7,0
-4,8	-0,9	-1,7

Comparison



Performance test procedure
DST-method (1)

Target: Long time performance prediction over a whole year for different climatic situations (like CTSG + supplementary systems)

- The system is described by parameters, which result from a prevoiusly implemented parameter identification. The performance of the solar system is therefore determined by means of these parameters.
- `Black-box`-procedure
  - No need for steady-state conditions
  - No need for measurements inside the store or inside the collector loop

Performance test procedure
DST-method (2)

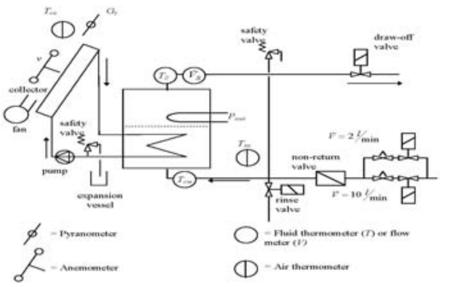
Can be applied to the following SDHW systems including:

- Systems with forced circulation of fluid in the collector loop
- Thermosiphon systems
- Integral collector storage (ICS) systems

Systems are limited to the following dimensions

- The collector aperture area of the SDHW system is between 1 and 10 m²
- The storage capacity of the SDHW system is between 50 and 1000 l
- The specific storage-tank volume is between 10 and 200 l / m² of collector aperture area

Performance test procedure
DST-method (3)



Performance test procedure
DST-method (4)

Procedure

- Conditioning
  - At the beginning and at the end of each test sequence, the store is brought to uniform temp. by applying a draw-off rate of 10 ± 1 l / min
  - At the beginning of each sequence, at least 3 store volumes shall be withdrawn
  - At the end as well or $\Delta\vartheta < 1$ K
  - Integrated auxiliary heating shall be disabled during conditioning

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Performance test procedure
DST-method (5)

Procedure

The test itself consists of 3 test sequences, called

- S-sol
  - number of consecutive days of measurement with significant solar input. Two specific daily operation conditions named **Test A** and **Test B**
- S-store
  - Store-loss test sequence
- S-aux
  - Test of the operation of the system with an integrated auxiliary heater under low solar irradiation conditions

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Performance test procedure
DST-method (6)

Test A

- The aim of Test A days is to acquire information about collector array performance at high efficiencies
- t_0 shall be between 6:30 and 8:00 solar time
- Integrated auxiliary heater (if present) shall be disabled

Draw-off No.	Draw-off start time
1	t_0
2	$t_0 + 2\mathrm{h} \pm 5\,min$
3	$t_0 + 4\mathrm{h} \pm 5\,min$
4	$t_0 + 5\mathrm{h} \pm 5\,min$
5	$t_0 + 6\mathrm{h} \pm 5\,min$
6	$t_0 + 8\mathrm{h} \pm 5\,min$
7	$t_0 + 11\mathrm{h} \pm 5\,min$

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Performance test procedure
DST-method (7)

Test A

- Volume of any draw-off ≥ 20 l
- Daily irradiance ≥ 12 MJ/m²

System dimensions	Draw-off volume
100 l/m² ≤ Vs/Ac ≤ 200 l/m²	0,2 Vs +/- 10%
60 l/m² ≤ Vs/Ac ≤ 100 l/m²	0,25 Vs +/- 10%
40 l/m² ≤ Vs/Ac ≤ 60 l/m²	0,33 Vs +/- 10%
20 l/m² ≤ Vs/Ac ≤ 40 l/m²	0,5 Vs +/- 10%

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Performance test procedure
DST-method (8)

Test B

- The aim of this test is to acquire information about store heat losses and collector array performance at low efficiencies
- Integrated auxiliary heater (if present) shall be enabled before and after draw-off

Draw-off No.	Draw-off start time
1	t_0
2	$t_0 + 2\text{h} \pm 5\,min$
3	$t_0 + 4\text{h} \pm 5\,min$
4	$t_0 + 6\text{h} \pm 5\,min$
5	$t_0 + 8\text{h} \pm 5\,min$

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Performance test procedure
DST-method (9)

Test B

- Draw-off > 5 l **and** outlet temp. < threshold temperature
- Daily irradiance > 12 MJ/m²

System dimensions	Temperature
100 l/m² ≤ Vs/Ac ≤ 200 l/m²	70 °C
60 l/m² ≤ Vs/Ac ≤ 100 l/m²	60 °C
40 l/m² ≤ Vs/Ac ≤ 60 l/m²	50 °C
20 l/m² ≤ Vs/Ac ≤ 40 l/m²	40 °C

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Performance test procedure
DST-method (10)

- S-sol sequence
  - ≥ 3 Test A days
  - 3 Test B days, 2 of them consecutive
- S-store sequence
  - Conditioning
  - Heating up the store, two consecutive valid Test B days (without aux)
  - Cooling period
  - Conditioning
- S-aux sequence
  - 4 Test B days with solar radiation < 200 W/m²
  - Aux enabled from $t_0 + 9\,h$ to $t_0 + 23\,h$

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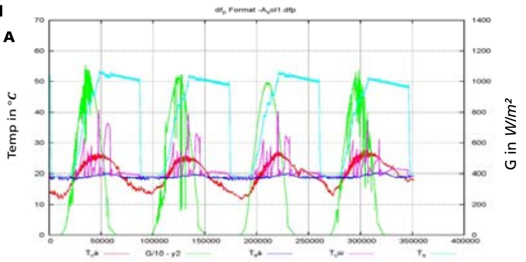
Performance test procedure
DST-method (11)

S-sol
Test A



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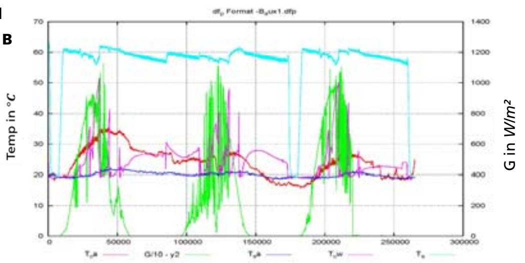
Performance test procedure
DST-method (12)

S-sol
Test B



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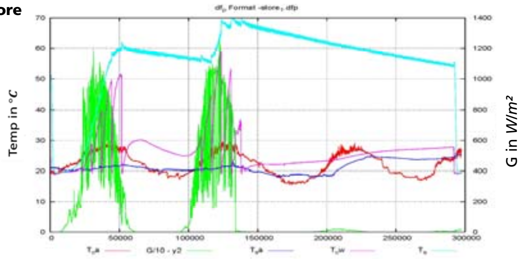
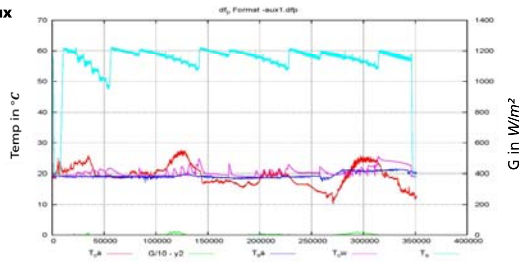
Performance test procedure
DST-method (13)

S-store

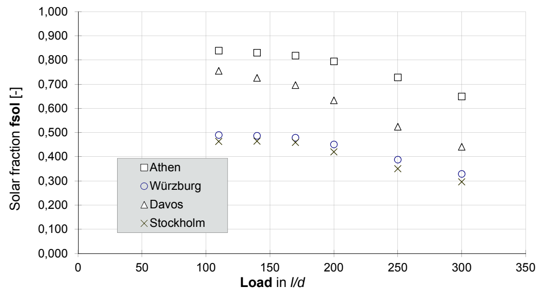


Performance test procedure
DST-method (14)

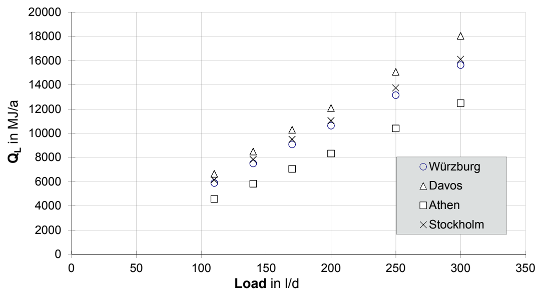
S-aux



Performance test procedure
DST-method (15)



Performance test procedure
DST-method (16)



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Performance test procedure
DST-method (17)

Q_{par}

EN 12976-1:2006 4.6.3. Documents for the user"	prEN 12976-1:2012 4.6.3 "Documents for the user"
the annual electricity consumption for pumps, control systems and electrical valves of the system for the same conditions as specified for the thermal performance, assuming a yearly pump operating time of the collector pump of 2000 h	the annual electricity consumption Qpar for pumps, control systems and electrical valves of the system as determined according to 5.8.3 of EN 12976-2

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Performance test procedure
DST-method (18)

EN 12976-2:2006 5.8.3.4 "Calculation of the parasitic energy"	prEN 12976-2:2012 5.8.3.4 "Calculation of the parasitic energy"
Calculate the yearly parasitic energy needed by pumps, controllers etc, in conformity with 4.6.3 h) 3) of EN 12976-1:2005	The parasitic energy Q_{par} shall be calculated as follows: $Q_{par} = \sum_i yot_i * P_{par,mean\_i}$ $P_{par,mean\_i}$ shall be determined as mean values during the operating time of each measured device

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Performance test procedure
Relation between CSTG and DST

In October 1999, the EU-SMT project team "Bridging the Gap" reported on the comparability between CSTG (ISO 9459-2) and DST (ISO/DIS 9459-5) and conversion factors were successfully established.

$$Q_{DST} = (a \pm \sigma_a) Q_{CSTG}$$

Type of system	Condition	A	σ_a
Forced circulation	$V_{load} \geq V_{store}$	1.004	0.004
Thermosyphon system	All V_{load}	1.056	0.004
ICS system	All V_{load}	1.037	0.003

Short comings:

- Scaling procedure for ETC based compact systems
- Auxiliary more then 70%

Reliability test procedures
Freeze resistance

- Ensure that the protective antifreezing provisions are operating properly
  - testing authority shall identify which method has to be employed
- Distinction of different system types
  - Systems using anti freeze fluid
  - Drain-back systems
  - Drain-down systems
  - Freeze protection and control functions combined
  - Other systems

Reliability test procedures
Over temperature protection

Determine whether the solar water heating system is protected against damage and the user is protected from scalding hot water delivery after a period of no hot water draw and failure of electrical power

- Empty collector
- Solar irradiance > 1000 W/m²
- Ambient air temp. 20-40 °C
- Wind velocity < 1m/s
- Duration: 1h under steady-state conditions

Reliability test procedures
Pressure resistance

Evaluate hydraulic pressure rating of all components and interconnections of a solar water heating system when installed according to the manufacturer's instructions

- Collector temperature = amb. air temperature
- Safety valve has to be disabled
- hydraulic pressure equal to 1.5 times the manufacturer's stated maximum individual working pressures
- Hold pressure for 15 min

Reliability test procedures
Water contamination

Check of the documentation

- Instructions for the installation of precautions to prevent back flow to drinking main supply

Reliability test procedures
Lightning Protection

- requirements given in **IEC 61024-1**

Reliability test procedures
Safety equipment

- Safety valve
  - Each collector circuit or group of collector circuits is fitted with at least one safety valve
  - Material withstands temperature and heat transfer medium
- Safety lines and expansion lines
  - Verify that safety and expansion lines can't be shut-off
  - Check the dimension of the safety line
- Blow-off lines
  - Verify that the blow-off lines can't freeze up and that no water can accumulate within these lines
  - Verify that steam or heat transfer do not threaten the immediate environment

Labelling (1)

Check if all items from the labelling list are completed

- Name of the manufacturer
- Designation of system type
- Serial number
- Year of production
- Absorber- and aperture area in m²
- Nominal storage contents in l
- Rated pressure of the drinking water pipeline in kPa
- Heat transfer medium
- Rated pressure of the heat transfer medium

Labelling (2)

- Overtemperature protection
  - Dependant on electrical supply
  - Dependant on chilled water distribution net
- Electrical power of any electrical devices

Ability of solar-plus-suppl. systems to cover the load

- Ensure that the solar-plus-supplementary system is able to cover the maximum daily load without solar contribution

Draw-off start time	Draw-off volume
$t_0 + 12\,h$	40 % daily load
$t_0 + 17\,h$	20 % daily load
$t_0 + 22\,h$	40 % daily load

Reverse flow protection

- Visual inspection
- For systems without check valve the system shall be tested according to 7.8.2 of **ISO 9459-2**. The difference between the heat loss coefficient of the storage tank with the collector loop connected and the heat loss coefficient of the storage tank with the collector loop disconnected should be less than 10%

Electrical safety

- Requirements given in **EN 60335-1** and **EN 60335-2-21**

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INNOVATIVE PRODUCTS – INNOVATIVE METHODS

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Definitionen – on-going discussions

What is a PVT? A CPVT? What is the aperture area of a PVT?

A PVT collector/module is a device which converts solar radiation into both heat and electricity (from a PV effect) and from which both are simultaneously usefully/ utilizable removed.

A CPVT is a PVT using a optical device to concentrate insolation from a bigger aperture to a smaller absorber area.

For PVT collectors a precession of area definition is necessary:

The absorber area of a PVT is the area absorbing insolation. (regardless if converting partly more into heat or electricity.)

The aperture area of a PVT collector is the projected area of the product of optical acceptance width and height.

If you think it is necessary we could add to this another sentence, (I actually do not think this is necessary):
In case the two functions (heat and electricity conversion) are separated into two layers of the device, the bigger area shall be taken as reference area.

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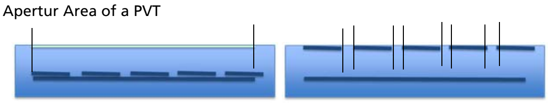
Example of Complications with Area Definitions in regards to PVT

Apertur Area of a PVT



Case A)
Complete aperture area throu which radiation is enterning the collector

okay

Case B)
Sum of the gaps between teh PV cells on the cover

Leads to non realistic over estimation

-> better show „power output per collector" or „power output per 1m² A_G" (P_{el} und P_{th})
-> QDM including some extension [1]

[1] **Helmers, H. und Kramer, K.** (2013). "Multi-linear performance model for hybrid (C)PVT solar collectors." Solar Energy **92**: 313-322.

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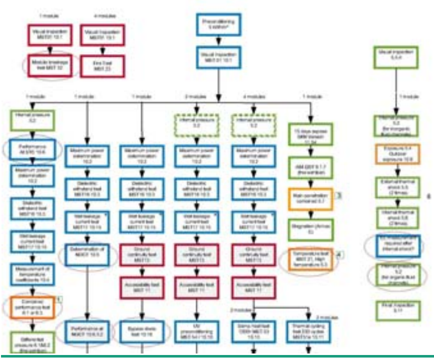
Method



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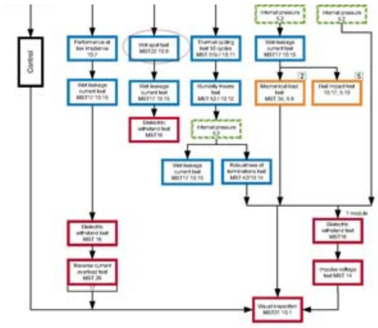

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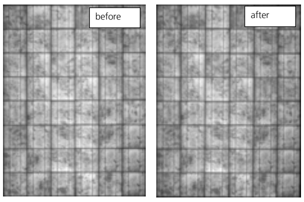
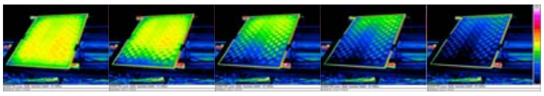
Specific Test on Function



Electro-luminescence photography, before and after a thermal shock



Thermograhic Picture of a interal thermal schock test

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Quasi-dynamic method with H-K extension

Including wind speed dependency and long wave radiative losses if relevant, MPP- tracked, measurement recording for thermal and electrical parameters simultaniously

Model (electric):

$$\dot{q} = \underbrace{b_0}_{p_{1el}} \cdot \underbrace{G_{gl}}_{y_1} - \underbrace{b_1}_{p_{2el}} \cdot \underbrace{G_{gl} \cdot T_m}_{y_2} - \underbrace{b_2}_{p_{3el}} \cdot \underbrace{G_{gl} \cdot T_a}_{y_3} - \underbrace{b_3}_{p_{4el}} \underbrace{G_{gl}{}^2}_{y_4}$$

Model (thermal):

$$\dot{q} = \underbrace{F'(\tau\alpha)_{en}}_{p_{1th}} \cdot \underbrace{G_b}_{x_1} - \underbrace{F'(\tau\alpha)_{en} \cdot b_0}_{-p_{2th}} \cdot \underbrace{(\frac{1}{\cos(\theta)} - 1)) \cdot G_b}_{x_2} + \underbrace{F'(\tau\alpha)_{en} \cdot K_{\theta d}}_{p_{3th}} \cdot \underbrace{G_d}_{x_3} - \underbrace{c_6}_{-p_{4th}} \underbrace{uG^*}_{x_4}$$

$$- \underbrace{c_1}_{-p_{5th}} \cdot \underbrace{(\vartheta_m - \vartheta_a)}_{x_5} - \underbrace{c_2}_{-p_{6th}} \cdot \underbrace{(\vartheta_m - \vartheta_a)^2}_{x_6} - \underbrace{c_3}_{-p_{7th}} \underbrace{u(\vartheta_m - \vartheta_a)}_{x_7} - \underbrace{c_5}_{-p_{9th}} \cdot \underbrace{(\frac{d\vartheta_m}{dt})}_{x_9}$$

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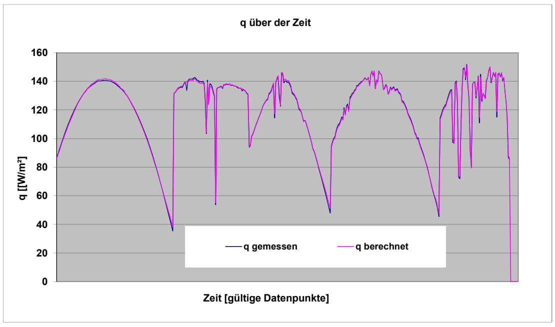
Quasi-dynamic method with H-K extension
Parameter identification (electric)



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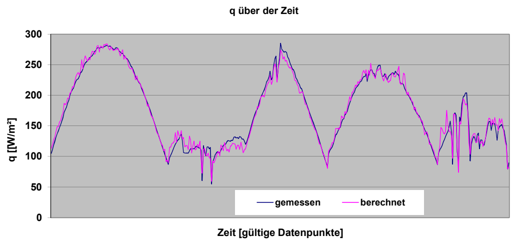
Quasi-dynamic method with H-K extension
Parameter identification (thermal)



- Second order heat loss coefficient set to zero, because T-value was to low
- No long wave radiation measured in this very case, parameter set to zero

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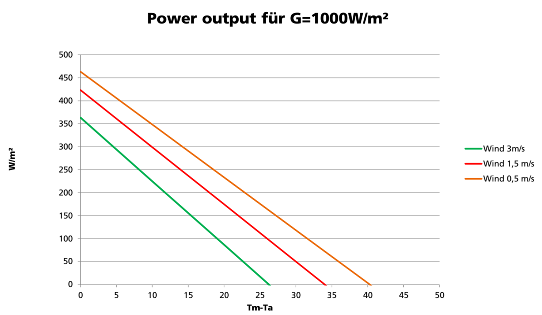
Power Output thermisch



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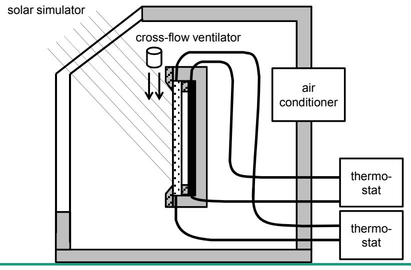
BIST G-value



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Visual Comfort

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Thank you for your attention!

Fraunhofer-Institute for Solar Energy Systems ISE

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