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In-situ measurement of LFC and other process heat collectors

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AGENDA

- Motivation and background
- Testing concentrating collectors according to ISO 9806
- Dynamic Testing Procedure
- Comparison QDT vs. DT
- Remaining issues for in-situ measurements
- Certification of concentrating collectors
- Summary and Outlook

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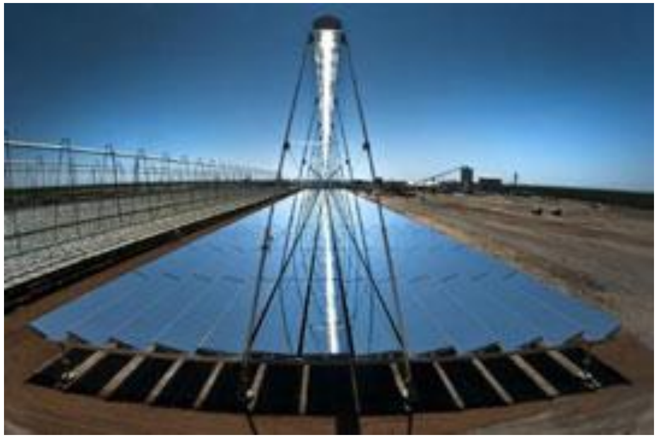
Motivation and Background
Reasons for in-situ measurement

- Size limitations in lab-testing
- Often disadvantageous weather and irradiation conditions at Testlab sites
- vast investment needs for high temperature test loops
- Reducing testing costs for manufacturers



Motivation and Background
Testing standard and deficits

- EN ISO 9806:2013 includes concentrating collectors in its scope
- provides two methods: steady-state test (SST) and quasi-dynamic test (QDT)

BUT

- In-situ measurements not mentioned
- No adaption / extension of methodologies in standard

→ no ready-made solutions for large-scale and technically challenging collectors

Testing concentrating collectors according to ISO 9806
Methods and challenges

- SST not well suited for concentrating collectors, especially LFC, and in-situ measurement
- QDT needs to be modified for LFC

$$\frac{\dot{Q}_{out\_col}}{A_{ap}} = \eta_{0,b} \cdot K_b(\theta_t, \theta_l) \cdot G_b + \eta_{0,b} \cdot K_d \cdot G_d - c_1 \cdot (T_m - T_{amb}) - c_2 \cdot (T_m - T_{amb})^2 - c_5 \frac{dT_m}{dt}$$

Reduced model applicable for most concentrating collectors

(yellow) → Challenge in measurement technology, test-loop design

(grey) → Challenge in parametrization

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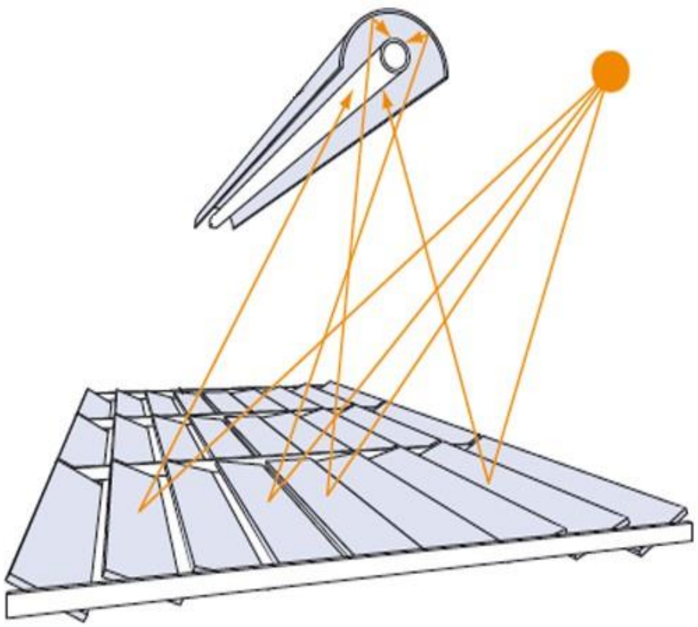
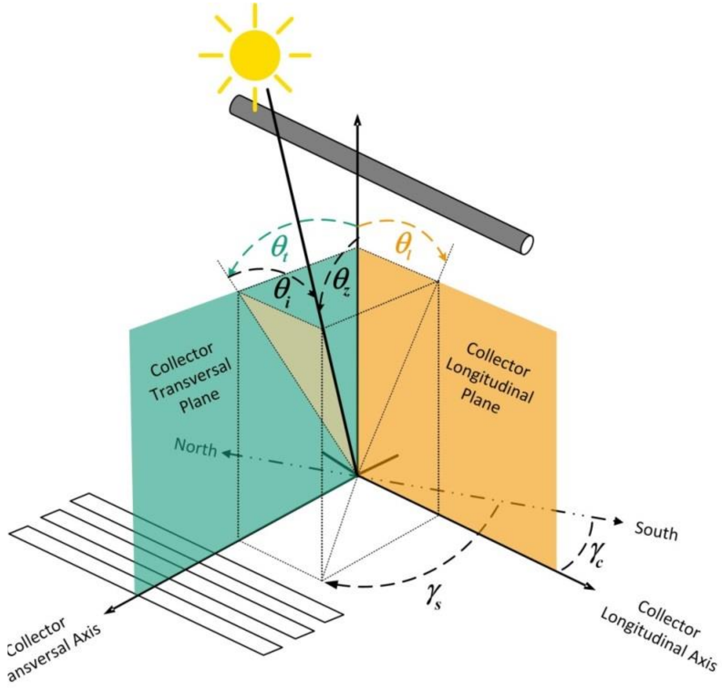
Testing concentrating collectors according to ISO 9806

LFC: η_{opt} and Incidence Angle Modifier

- LFC has two-dimensional IAM





➔ Factorization of IAM_{LFC} in transversal and longitudinal part

Testing concentrating collectors according to ISO 9806

LFC: η_{opt} and Incidence Angle Modifier

$$\frac{\dot{Q}_{out\_col}}{A_{ap}} = \eta_{0,b} \cdot K_b(\theta_t, \theta_l) \cdot G_b + \ldots$$

→

$$\frac{\dot{Q}_{out\_col}}{A_{ap}} = \eta_{opt,0} \cdot IAM_t(\theta_t) \cdot IAM_l(\theta_i) \cdot G_b + \ldots$$

Introduction of iteration method

- Modell I

$$\frac{\dot{Q}_{out\_col}}{A_{ap}} = \eta_{opt,0} \cdot \sum_{j=1}^{n_j} K_{t,w_j-w_{j+1}}(\theta_t) \cdot K_l \cdot (\theta_i) \cdot G_b + \eta_{opt,0} \cdot K_d \cdot G_d - c_1(T_m - T_a) - c_2(T_m - T_a)^2 - c_5 \frac{dT_m}{dt}$$

↕ Iteration

- Model II

$$\frac{\dot{Q}_{out\_col}}{A_{ap}} = \eta_{opt,0} \cdot \sum_{k=1}^{n_k} K_{l,w_k-w_{k+1}}(\theta_i) \cdot K_t \cdot (\theta_t) \cdot G_b + \eta_{opt,0} \cdot K_d \cdot G_d - c_1(T_m - T_a) - c_2(T_m - T_a)^2 - c_5 \frac{dT_m}{dt}$$

to identify | fixed

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Testing concentrating collectors according to ISO 9806

LFC: η_{opt} and Incidence Angle Modifier

fixed | measured | to identify

1st iteration (fixed starting values from ray tracing):

$\theta_{i/t}$	IAM_t	IAM_l
0	…	…
5	…	…
10	…	…
⋮	⋮	…

$$\dot{Q}_{col\_out}/A_p = \eta_{opt,0}\cdot IAM_t \cdot IAM_l \cdot G_b + \eta_{opt,0}\cdot K_d \cdot G_d - c_1\cdot \Delta T - c_2 \cdot \Delta T^2 - c_5 \frac{dT_m}{dt}$$

2nd iteration:

$\theta_{i/t}$	IAM_t	IAM_l
0	…	…
5	…	…
10	…	…
⋮	⋮	…

$$\dot{Q}_{col\_out}/A_p = \eta_{opt,0}\cdot IAM_t \cdot IAM_l \cdot G_b + \eta_{opt,0}\cdot K_d \cdot G_d - c_1\cdot \Delta T - c_2 \cdot \Delta T^2 - c_5 \frac{dT_m}{dt}$$

3rd iteration:

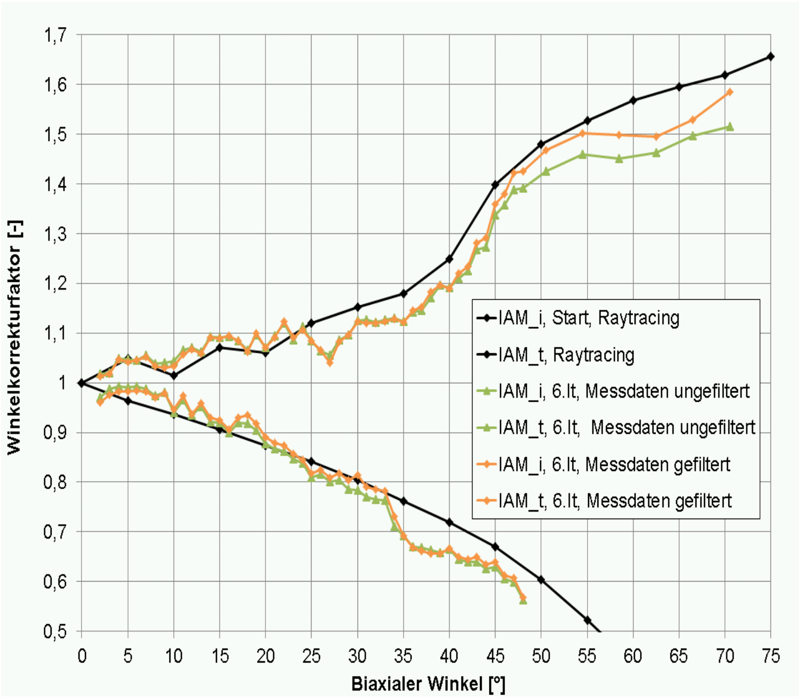
$\theta_{i/t}$	IAM_t	IAM_l
0	…	…
5	…	…
10	…	…
⋮	⋮	…

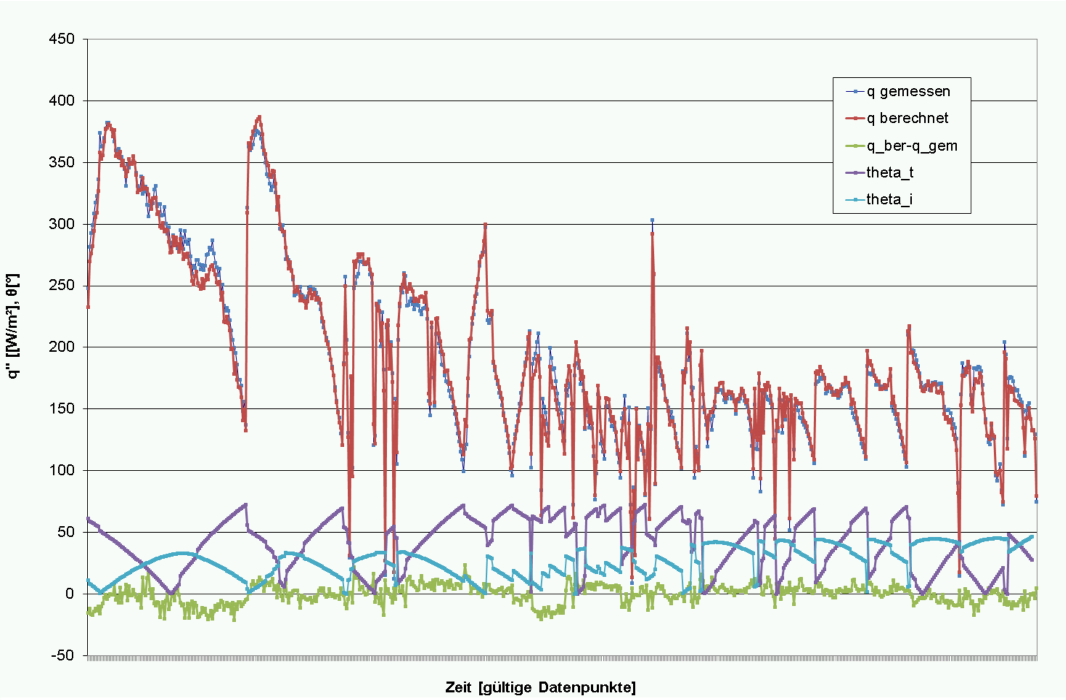
$$\dot{Q}_{col\_out}/A_p = \eta_{opt,0}\cdot IAM_t \cdot IAM_l \cdot G_b + \eta_{opt,0}\cdot K_d \cdot G_d - c_1\cdot \Delta T - c_2 \cdot \Delta T^2 - c_5 \frac{dT_m}{dt}$$

⋮

Testing concentrating collectors according to ISO 9806
QDT in-situ measurement of LFC

- Results from in-situ measurement on LFC done by ISE





- Good results for optical parameters
- On-going investigations on identification of heat loss parameters

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Testing concentrating collectors according to ISO 9806
Limits to the QDT for in-situ measurement

- Installation set-ups may not be suitable
  - Variations inlet temperature and mass flow strictly limited
  - $\boldsymbol{\eta}_{opt}$-conditions can often not be realized

- Dependency on system operator
  - Warm-up / cool-down sequences cannot be used

→ Fully dynamic test procedure (DT) has potential to solve these problems

→ DT-Method has been developed at ISE and successfully compared to QDT

→ ***A. Hofer*** *et al.: Comparison of Two Different (Quasi-) Dynamic Testing Methods for the Performance Evaluation of a Linear Fresnel Process Heat Collector, SolarPACES 2014, Beijing*

→ *www.sciencedirect.com*

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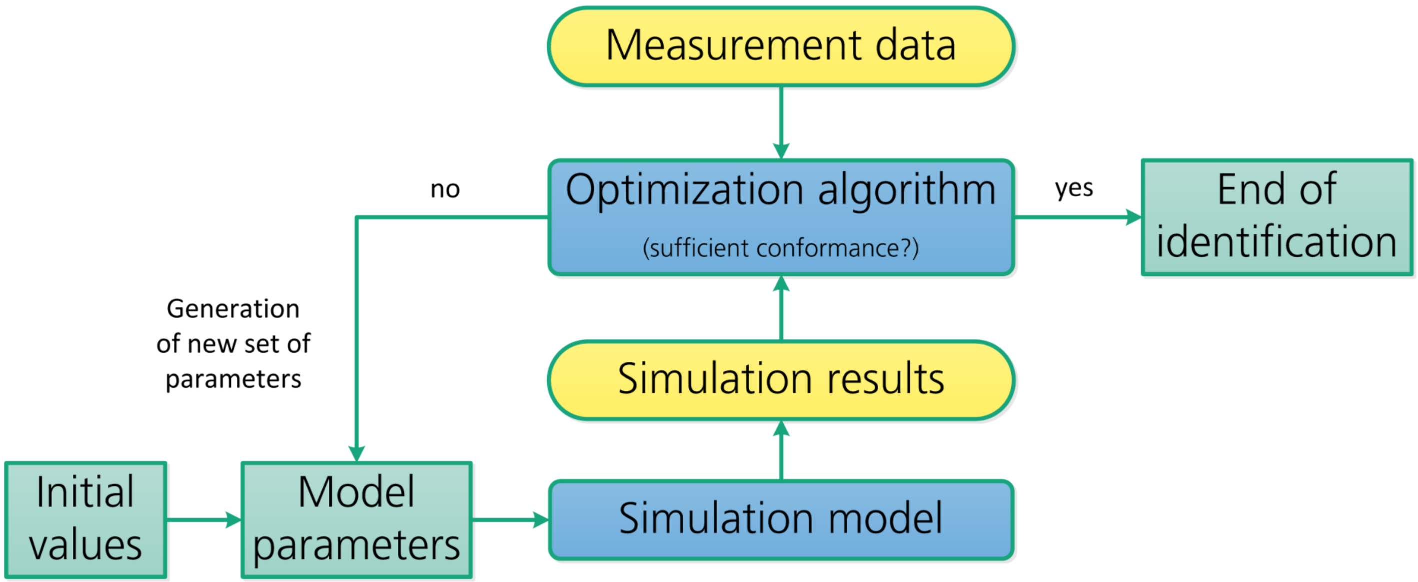
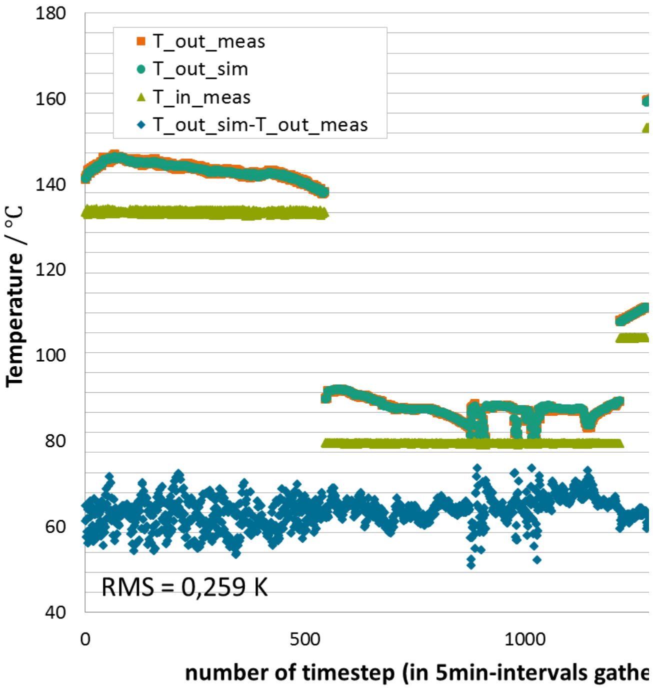
Dynamic Testing Procedure
Alternative Performance Evaluation for in-situ



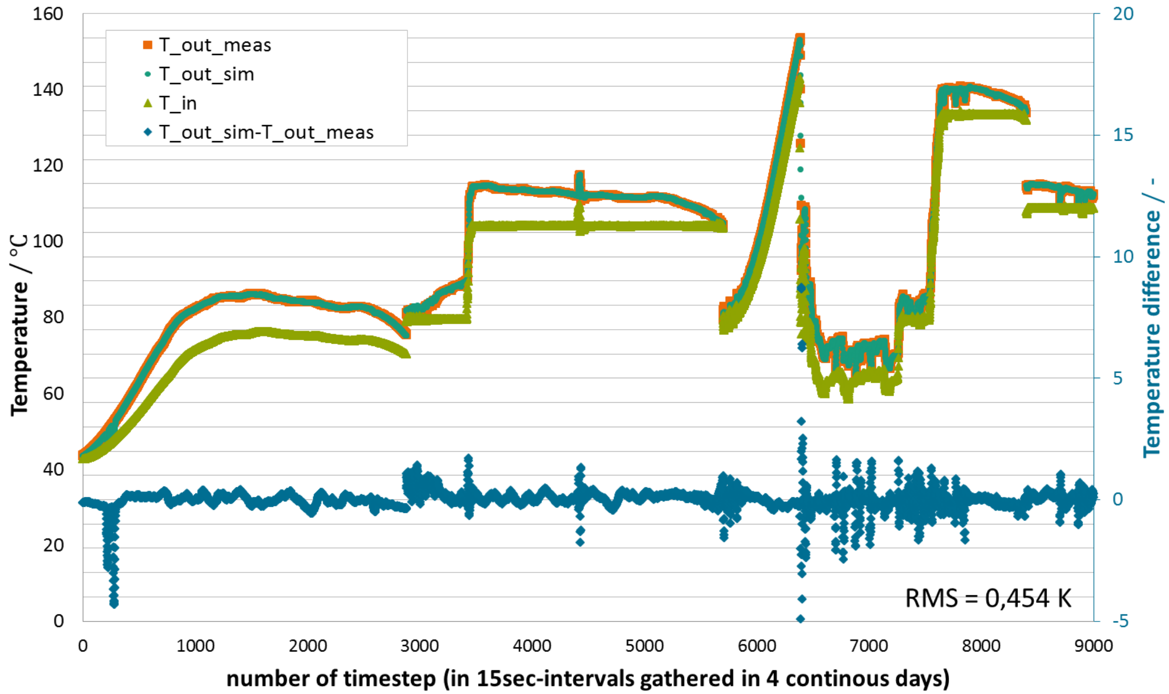
- Plug-flow/multi-node model
- Complexity of the model requires higher computational effort
- Temperatures, mass flow and DNI may vary without restraint
- Possibility of evaluating warm-up and cool-down measurement periods

Comparison QDT vs. DT
Measurement Data Base

a) measured and simulated data base for QDT-metho



b) measured and simulated data base for DT-method



① QDT Accredited testing procedure

② DT Higher degrees of freedom

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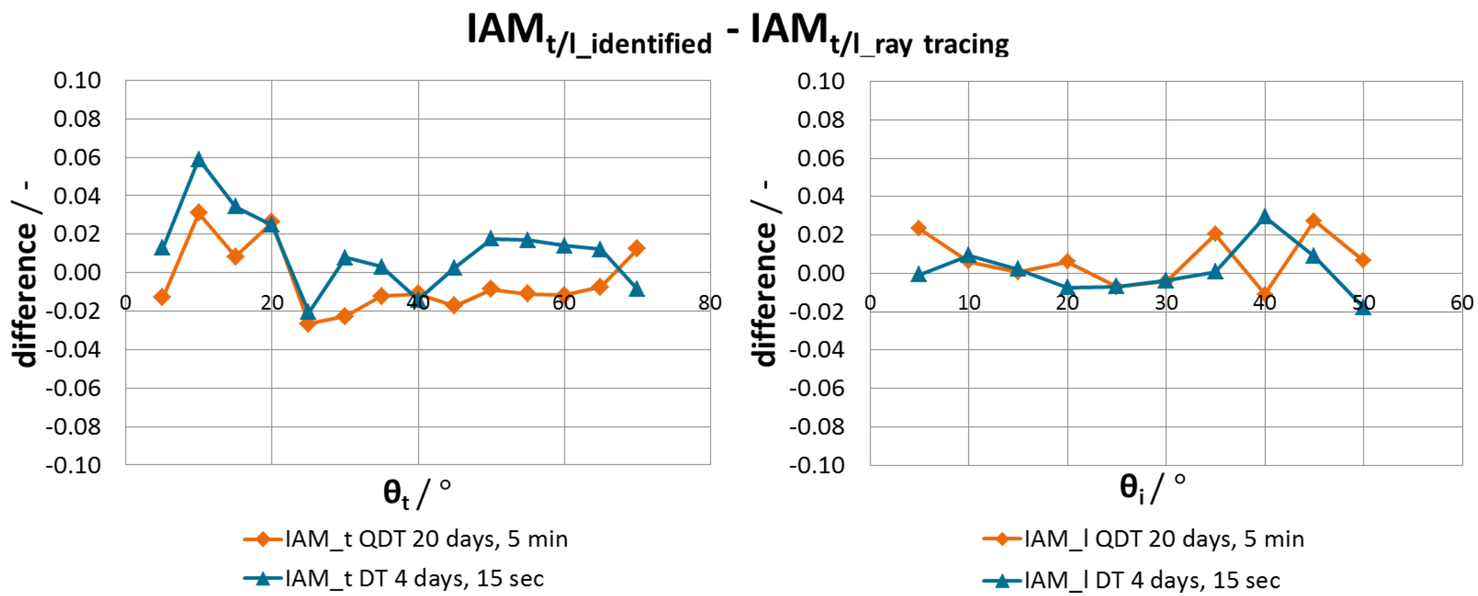
Comparison QDT vs. DT
Identified Optical Parameters

- Identified RMS of $\eta_{opt,0}$-values = ±0,009 < ±0,02 = results reached in Round Robin Test[2)]



- Absolute mean deviation over entire angle space for optical efficiency η_{opt} ensues differences of only < 0.0098

2) Weißmüller et al. Final Report - Proficiency Test; QAiST testing of solar collectors and systems. By: DAkkS, Marl, 2012.

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Remaining issues for in-situ testing

- Installation of sensors → inline vs. Clamp-on
  - Mass flow clamp-on possible but expensive
  - Temperature clamp-on difficult
- Calibration of sensors
- Heat transfer fluid
- Surveillance of measurement
  - cleaning of mirrors and sensors
  - Reflectance measurement
  - Monitoring of tracking devices
- Data transfer from remote areas

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Certification of concentrating collectors
Functional testing and safety features

Test	Safety feature / substitute
Dry Exposure	No-flow / high temperature protection / UPS
Internal pressure	Certificate by other approved institution
Internal thermal shock	No-flow / high temperature protection / UPS
External thermal shock	No cutback for concentrating collectors
High temperature resistance	No-flow / high temperature protection / UPS
Rain penetration	Procedure to be designed by TestLab
Mechanical load	Wind / snow load protection, Procedure designed by TestLab

- Manufacturer to submit detailed info on all active and passive controls (sensors, motors, actuators etc.) including control set points and parameters
- TestLab establishes test cycle to verify their suitable operation

Certification of concentrating collectors
Accredited TestLab / Test report

- All tests to be performed by accredited Testlab
- Testlab files report including results from efficiency testing and functional tests in accordance with ISO 9806
- Manufacturer applies for Certification

→ Presentation on certification issues by Korbinian Kramer

Summary and Outlook

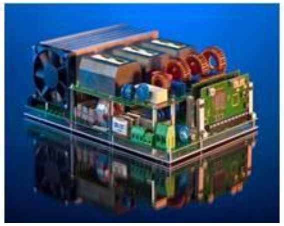
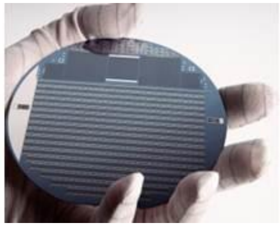
- Characterization of LFC in strict accordance with ISO 9806 not possible
- Enhanced QDT-method based on ISO 9806 has shown good results for optical parameters of LFC
- Comparison with Dynamic Test Procedure has shown good compliance
- Further investigations on determination of heat loss parameters on-going

- Possibility of in-situ measurement strongly depending on installation set-up
- Large potential for DT in in-situ measurement

- Remaining issues with sensor selection and measurement surveillance

Thank you for your attention!

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